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GROSSMAN'S ENDODONTIC PRACTICE

14TH EDITION



Editor

V. Gopikrishna

Wolters Kluwer

With Videos

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Cover page image: Micro CT image showing complex root canal anatomy of a mandibular first molar. (*Courtesy:* Prof. Marco A. Versiani, DDS, MSc, PhD)

This labor of love is dedicated to

Late Prof Dr. B. Suresh Chandra

for having the faith in me to carry forward the legacy of
this monumental textbook...

My Parents

Sulochana & Ambuja ... for all the love you bestow upon us...
M Velayutham ... for teaching me integrity and humility in life...
Late *VG Sivasubramanian* ... for showing me the path of caring and giving...

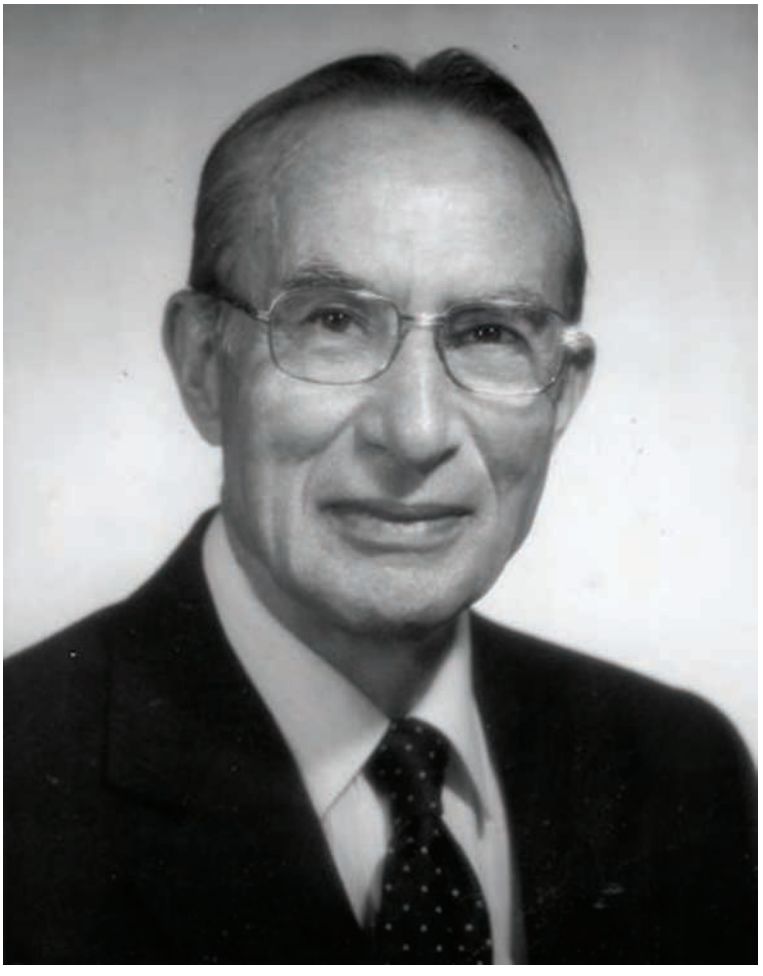
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Dr. Lakshmi S ... for being my ever-supportive and caring wife...
Sanjana & Sidharth ... for being our perennial source of happiness !!

—V. Gopikrishna



Dr. Louis I. Grossman (*Reproduced with permission from AAE Archives, American Association of Endodontists, Chicago, IL*)

Louis I. Grossman: The Visionary Father of Modern Endodontics

Dr. Louis I. Grossman was born in a Ukranian village near Odessa on December 16, 1901, and was brought to the United States by his family as a boy. He grew up in Philadelphia and completed his high school education at South Philadelphia High School in 1919. He earned a doctorate in dental surgery at the University of Pennsylvania in 1923 and a doctorate in medical dentistry (Dr. Med. Dent.) at the University of Rostock in Germany in 1928.

On December 21, 1928, he married Emma May MacIntyre, and they had two children, a daughter Clara Ruth Grossman in 1939 and a son Richard Alan Grossman in 1943.

Dr. Grossman began his teaching career as an Instructor in Operative Dentistry at the University of Pennsylvania in 1927, in addition to being appointed as a Fellow in Research at the American Dental Association. In 1941, he was an Associate in Oral Medicine; he became Assistant Professor of Oral Medicine in 1947, Associate Professor of Oral Medicine in 1950, and Professor in 1954.

His achievements and honors were extensive in many sectors of dentistry with a prime focus in endodontics. He was an honorary member of the Association of Licentiates in Dental Surgery and University of Dentists of Belgium; Montreal Endodontia Society; Vancouver Endodontic Study Club, Brazilian Dental Association; Dental Association of Medellin (Colombia); and the Japanese Endodontic Association. He received an honorary Doctor of Science (ScD) from the University of Pennsylvania.

His major publication and crowning achievement was his textbook *Root Canal Therapy* published in 1940 (now known as *Endodontic Practice*) with multiple editions appearing worldwide. Subsequently translated into eight languages, the book has served as a benchmark for the development of modern endodontic philosophy and practice. Dr. Grossman also authored *Dental Formulas and Aids to Dental Practice,* first published in 1952, and *Handbook of Dental Practice*, published in 1948.

He was the chairman of the American Board of Endodontics, was a charter member of the American Association of Endodontists (AAE), and served as its President from 1948 to 1949. He was a Fellow of the American Association for the Advancement of Science.

Dr. Grossman passed away at the age of 86 in 1988. The University of Pennsylvania has honored Dr. Grossman with an endowed Professorship, usually given to the department chairperson. The AAE has honored him with the Louis I. Grossman Award that recognizes an author for cumulative publication of significant research studies that have made an extraordinary contribution to endodontology. This award is given at the AAE meeting when warranted.

A study club was formed in Philadelphia in the honor of Dr. Louis I. Grossman for his unyielding dedication and commitment towards facilitating the recognition of endodontics as a specialty in the field of dentistry. The purpose of the Louis I. Grossman Study Club was to provide an opportunity to endodontists as well as other interested dentists to meet, share ideas, and expand and update their knowledge in the field of endodontics and dental medicine.

Dr. Louis I. Grossman was the founder of the first Root Canal Study Club. It was established in 1939 in Philadelphia, Pennsylvania, at a time when the Focal Infection Theory threatened the future of endodontics. The purpose of the Root Canal Study Club as stated in the original letter compiled by Dr. Grossman was "to study problems connected with root canal therapy and to present clinics so as to help others in practicing this important phase of dentistry more adequately." Endodontists from as far away as Massachusetts chose Philadelphia as the hub for scientific and educational learning in the field of endodontics.

James L. Gutmann

Preface to the Fourteenth Edition

It is much simpler to buy books than to read them
and easier to read them than to absorb their contents.

—Sir William Osler

It has been a great learning experience to have the opportunity to edit three editions of *Grossman's Endodontic Practice* over the past twelve years. I would be forever indebted to my teacher Dr. B Suresh Chandra who gave me the opportunity to be his co-editor for the previous two editions. The twelfth edition (2010) and thirteenth edition (2014) re-established this textbook as the premier teaching and clinical textbook for students across South Asia. Dr. Suresh Chandra's untimely demise leaves a great void in life and I have humbly tried my best to carry forward his and Grossman's legacy with this current fourteenth edition of *Grossman's Endodontic Practice*.

The ultimate goal of a textbook is in bringing clarity of thought and ease of understanding. As exemplified by the above given quote by Sir Osler, this textbook strives to bring complex concepts and techniques in a reader friendly manner for the student and clinician in you. I have added two new chapters in this edition—"Magnification in Endodontics" and "Nonsurgical Endodontic Retreatment" while comprehensively revising the remaining chapters to make the learning experience enjoyable to the student and clinician in you. This edition has more than 1,200 clinical images, x-rays, flowcharts, tables and boxes to make this a precise yet concise textbook cum reference guide for an astute practitioner of endodontics.

—V. Gopikrishna

Preface to the Thirteenth Edition

He who studies Medicine without books sails an uncharted sea,
but he who studies Medicine without patients does not go to sea at all.

—Sir William Osler

It has personally been an intellectual evolution in bringing out this thirteenth edition of the evergreen classic *Grossman's Endodontic Practice*. The process necessitates oneself to be a student in assimilating the sweeping changes that are happening in the specialty of endodontics. It was as much a learning and enriching process as it was enlightening.

The twelfth edition brought out by us in 2010 re-established this textbook as the premier teaching and clinical textbook for students across South Asia. The current edition builds up on this platform by updating and revising concepts, materials, and techniques. The increased awareness and research in biological concepts of treating the pulp tissue has made us revisit the chapter on vital pulp therapy, thereby updating it according to the current clinical guidelines. We have incorporated two new chapters into this edition: Chapter 7, *Endodontic Emergencies*, and Chapter 11, *Regenerative Endodontics*. We have also included *"Clinical Notes"* in each chapter that highlight the pertinent important clinical aspects of the topic being discussed. This book contains over 1100 figures, radiographs, and illustrations, many of which are contributions from clinicians and academicians from across the world. The format and style of presentation has also been changed to make it reader friendly. Accompanying the text is a *"Visual Masterclass" DVD* presenting videos of important clinical procedures.

We have strived to live up to the legacy of Louis I. Grossman by ensuring that this edition of *Grossman's Endodontic Practice* continues to be an evidence-based resource for students and practitioners in the field of endodontics.

B. Suresh Chandra • V. Gopikrishna

Preface to the First Edition

The last several years have witnessed a gradual return to the practice of root canal therapy. The dental profession has slowly come to realize that extraction is not the solution to the root canal problem. The physician, too, has learned that extraction is not the solution he had hoped it might be to those baffling cases in which oral focal infection was suspected. And the public has awakened to the realization that dental substitutes do not always function as well as natural teeth.

We have not yet arrived at that stage in dental education of the public when preventive dentistry is an accomplished fact. Despite our sincerest efforts to practice preventive dentistry, exposure or death of the pulp will nevertheless occur from decay under a filling, from trauma, from accidental exposure during cavity preparation, etc. The need for intelligent practice of root canal therapy is therefore evident if one is to do the right thing, rather than the most expedient.

Recent studies have given support to clinical observation that non-vital teeth, in selected cases and with careful treatment, may be retained with safety to the patient. The reader will find a brief account of these studies in the chapter on Pulpless Teeth and Focal Infection.

It is the hope of the author that root canal work will be practiced with greater care and thoroughness that in the past, and that this book, by acting as a guide, may have a share in pointing the way to more successful root canal therapy. In preparing its text the author has kept in mind the necessity for a practical treatise, but basic principles have also been discussed in order to establish fundamentals of practice. Methods of conserving the pulp after exposure and of treating non-vital teeth are presented. Careful selection of root canal cases has been stressed, and aseptic technic has been emphasized, and bacteriologic control has been urged. The importance of treating pulpless teeth as an integral part of the body, not as a separate entity, has also been e4mphasized. For the aim of root canal therapy should be to retain the tooth not only with comfort, but also with safety to the patient. And, if we are to avoid the criticism of the past, root canal work must be done more adequately than in the past.

It is hoped the dentist who is already practicing root canal work will find in this book sufficient aids and "pointers" to make it worth his perusal; the dentist who is returning to root canal work, or who practices it only occasionally, will find in it much food for thought as well as a guide for everyday practice; the student will find the text sufficiently adequate to give him a good understanding of the root canal problem, yet practical enough to apply in the college clinic, or later in his office.

The author wishes to acknowledge his indebtedness to Dr. J. L. T. Appleton for the privilege of pursuing research studies in his laboratory, for constant help and advise, and for reviewing three of the chapters; to Dr. Hermann Prinz for early training and guidance; to Dr. H. R. Churchill for reviewing two of the chapters and for the use of several photomicrographs; to Dr. Elsie Gerlach for contributing the chapter on Root Canal Therapy in Deciduous Teeth; to his wife, without whose help, both material and spiritual, this book would probably not have been written; and to that large number of dentists who, by their laboratory research or clinical studies have enriched our knowledge of the science and practice of the art of root canal therapy. He desires also to thank Mr. Leon E. Lewis for correcting the manuscript and reading proof, and Mr. W. D. Wilcox of Lea & Febiger for his coöperation in seeing the book through press.

Louis I. Grossman
Philadelphia, PA

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"Thank you" are two little words which would probably never completely convey the sense of gratitude and regards which I have for each one of the following wonderful people who have made *Grossman's Endodontic Practice*, fourteenth edition, a reality.

I would take this opportunity to thank each one of my teachers who have helped in my growth as an endodontist. My *pranams* to my *Gurus* Dr. A. Parameswaran, Dr. B. Suresh Chandra, and Dr. E. Munirathnam Naidu.

I would like to specially thank two people who have been instrumental in my growth as an academician and a clinician: *James "Jim" Gutmann*, for being a perennial source of inspiration, motivation, and support in my academic endeavors; and *Dr. Vijailakshmi Acharya*, for motivating me to give the very best to our patients and inspiring me to be a quality-conscious clinician.

The true soul of this edition has been the numerous images and clinical contributions by eminent researchers and clinicians from across the world. I thank each one of you for accepting my invitation to contribute and for your kindness and generosity in sharing your knowledge and expertise.

I would like to compliment the wonderful team at Wolters Kluwer India for showing genuine passion and professionalism in giving life and body to this edition. Thank you Dr. Binny Mathur and team, Dr. Richa Sharma and Mr. Amit Rai, and Ms P. Sangeetha for your support.

Last but not the least, my indebtedness to my parents and family for being understanding and supportive during this journey.

V. Gopikrishna

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1 The Dental Pulp and Periradicular Tissues

The beginning of all things is small....

PART 1: EMBRYOLOGY

The pulp and dentin are different components of a tooth that remain closely integrated, both functionally and anatomically, throughout the life of the tooth. The two tissues are referred to as the *pulp–dentin organ* or the *pulp–dentin complex*.

DEVELOPMENT OF THE DENTAL LAMINA AND DENTAL PAPILLA

The dental pulp has its genesis at about the sixth week of the intrauterine life, during the initiation of tooth development (**Fig. 1.1**). The oral stratified squamous epithelium covers the primordia of the future maxillary and mandibular processes in a horseshoe-shaped pattern.

FORMATION OF DENTAL LAMINA

Tooth development starts when stratified squamous epithelium begins to thicken and forms the *dental lamina*. The cuboidal basal layer of the dental lamina begins to multiply and thicken in five specific areas in each quadrant of the jaw to mark the position of the future primary teeth.

FORMATION OF ECTOMESENCHYME

The stratified squamous oral epithelium covers an embryonic connective tissue that is called the ectomesenchyme because of its derivation from the neural crest cells. By a complex interaction with the epithelium, this ectomesenchyme initiates and controls the development of the dental structures. The ectomesenchyme below the thickened epithelial areas proliferates and begins to form a capillary network to support further nutrient activity of the ectomesenchyme–epithelium complex. This condensed area of ectomesenchyme forms the future *dental papilla* and subsequently the pulp (**Figs 1.2** and **1.3**).

BUD STAGE (FORMATION OF ENAMEL ORGAN)

The thickened epithelial areas continue to proliferate and to migrate into the ectomesenchyme and in the process form a bud enlargement called the *enamel organ*. This point is considered the bud stage of tooth development (**Fig. 1.4**).

CAP STAGE (OUTER AND INNER ENAMEL EPITHELIUM)

The enamel organ continues to proliferate into the ectomesenchyme with an uneven rhythmic cell division producing a convex and a concave surface characteristic of the cap stage of tooth development (**Fig. 1.5**).

The convex surface consists of the cuboidal epithelial cells and is called the *outer enamel epithelium*. The concave surface, called the *inner enamel epithelium*, consists of elongated epithelial cells with polarized nuclei that later differentiate into ameloblasts. A distinct basement membrane separates the outer and the inner enamel epithelium from the ectomesenchyme. In the region of the inner enamel epithelium, a cell-free or acellular zone also separates the enamel organ from the ectomesenchyme. This acellular zone contains the extracellular matrix, where the future predentin will be deposited. Between the inner and the outer enamel epithelium, the cells begin to separate due to the deposition of intercellular mucoid fluid rich in glycogen that forms a branch reticular arrangement called the *stellate reticulum*.

FORMATION OF DENTAL PAPILLA

The ectomesenchyme, which is partially enclosed by the inner enamel epithelium, continues to increase its cellular density. The cells are large and round or polyhedral with a pale cytoplasm and large nuclei. This structure is the *dental papilla* (**Fig. 1.6**) which differentiates into the dental pulp.

FORMATION OF DENTAL FOLLICLE (OR DENTAL SAC)

When the ectomesenchyme surrounding the dental papilla and the enamel organ condenses and becomes more fibrous, it is called the *dental follicle* or the *dental sac*—the precursor of the cementum, the periodontal ligament (PDL), and the alveolar bone (**Fig. 1.6**). The dental lamina continues to proliferate at the point where it joins the deciduous enamel organ and thereby produces the permanent bud lingual to the primary tooth germ.

BELL STAGE (CERVICAL LOOP)

The cells of the inner enamel epithelium continue to divide and thus increase the size of the tooth germ. During this

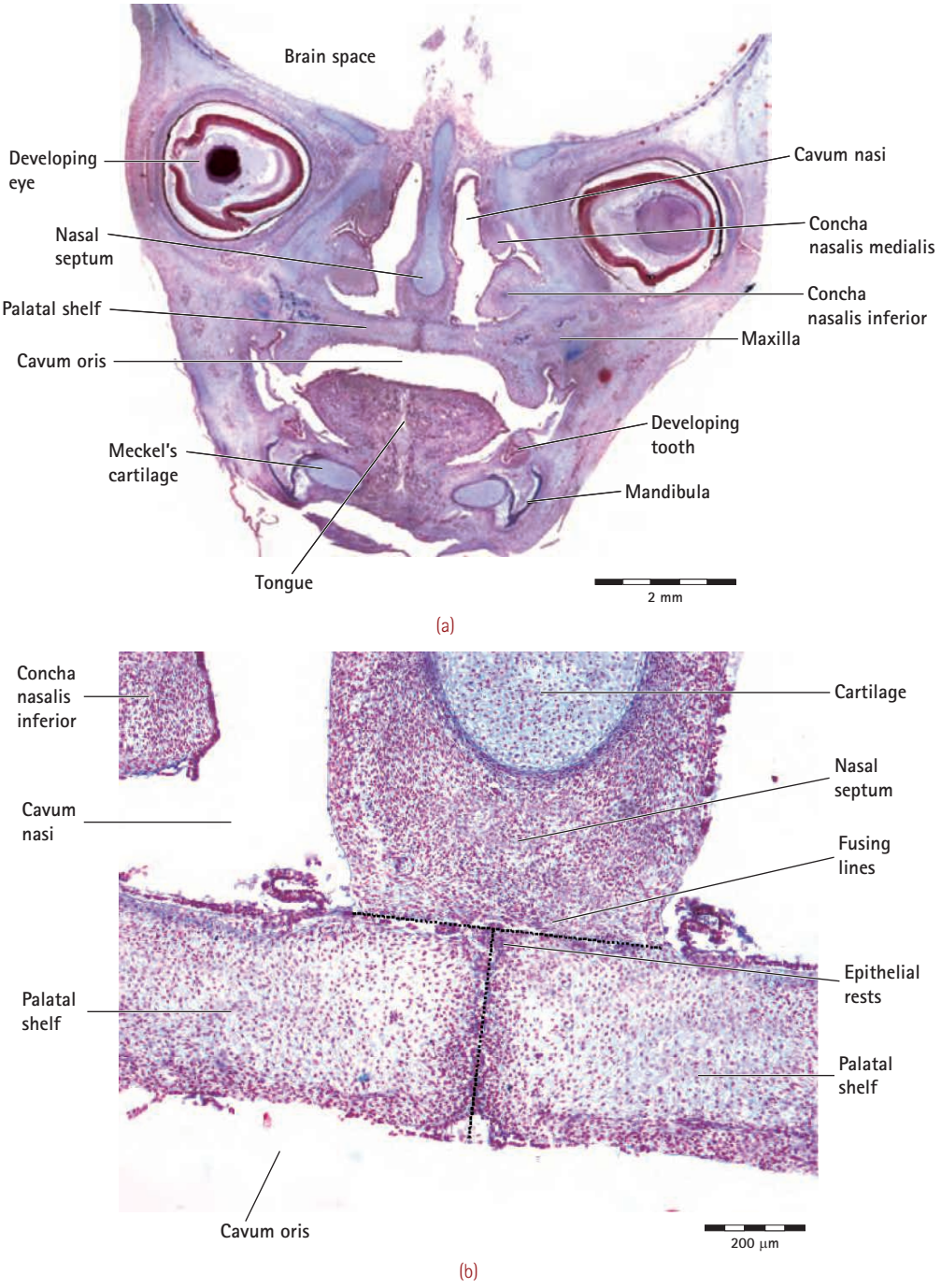


Figure 1.1 (a) Human fetus, head. This is a frontal section of the head of a human fetus. You can see the maxilla and the mandible taking shape. You can also see Meckel's cartilage in the mandible. The mandible also contains two dental buds in this section (stain: Azan). (b) At higher magnification, you can see the fusing lines between the nasal septum and the palatal shelf. If something goes wrong during this process, the fetus may develop a cleft palate (stain: Azan). (*Courtesy: Mathias Nordvi, University of Oslo, Norway.*)

growth, the inner enamel epithelium invaginates deeper into the enamel organ, and the junction of the outer and the inner enamel epithelium at the rim of the enamel organ becomes a distinct zone called the *cervical loop*. The deep invagination of the inner enamel epithelium and the growth of the cervical loop partially enclosing the dental papilla begins to give the crown its form. This point is called the bell stage of development (**Fig. 1.7**).

During this stage, the dental lamina that migrated into the ectomesenchyme degenerates, the primary and permanent buds are thus separated from the oral epithelium, and the distal portion of the dental lamina proliferates to form

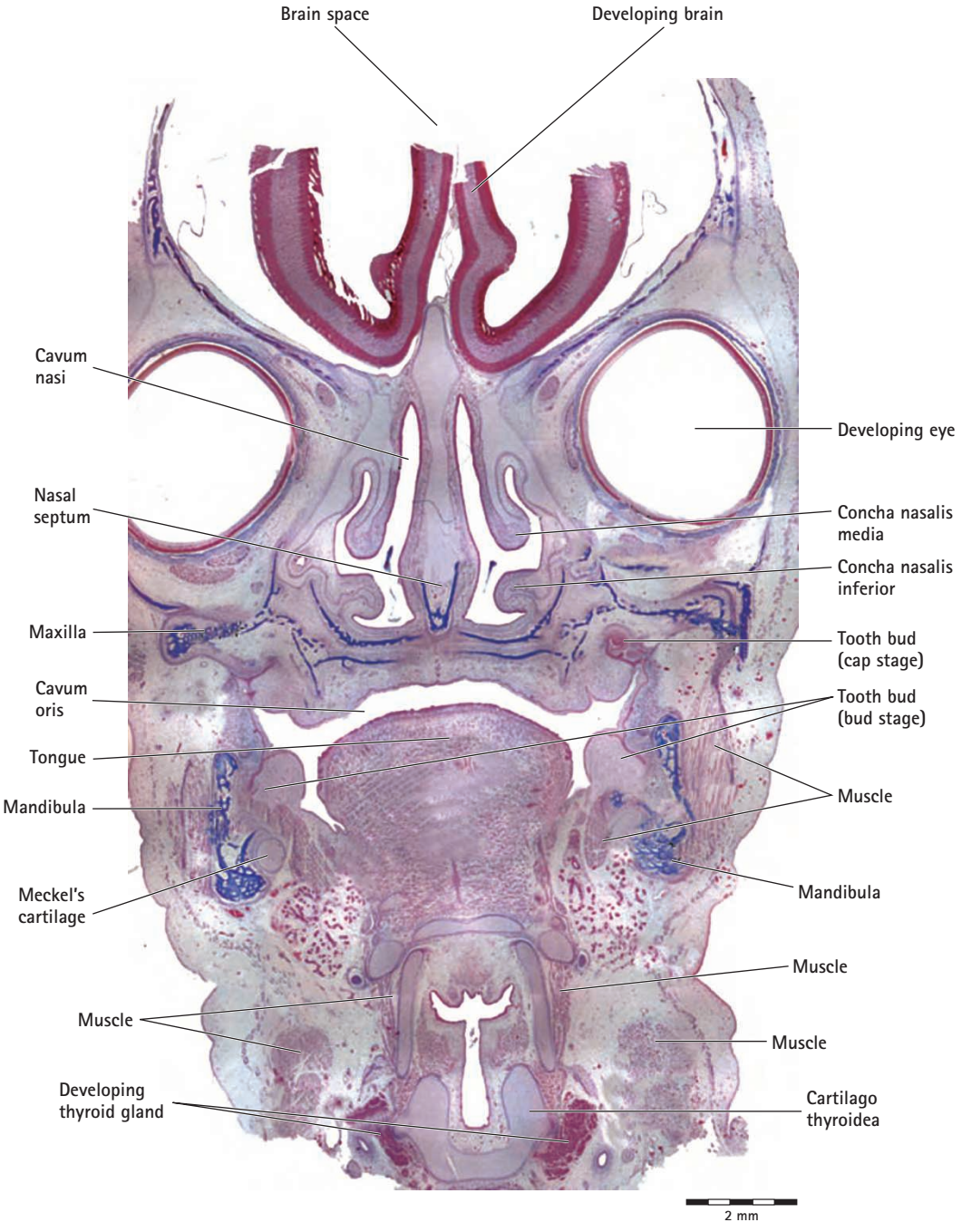


Figure 1.2 Human fetus, head. This is a frontal section of the head of a human fetus. The nasal cavity (Latin *cavum nasi*) is divided into two by the nasal cartilage within the nasal septum. At both sides of the septum, you can see the nasal conchae (Latin *concha nasalis media et inferior*). They are made up of cartilage at this stage of development. The palate and the maxilla also contain a few spicules of bone. (*Courtesy: Mathias Nordvi, University of Oslo, Norway.*)

the buds of the permanent molars, which have no primary predecessors.

As the development progresses, several layers of the squamous cells between the stellate reticulum and the inner enamel epithelium form the *stratum intermedium*. This layer of cells is limited to the area of the inner enamel epithelium and seems to be involved with enamel formation.

Clinical Note

- *Stratum intermedium* → Enamel
- *Ectomesenchyme* → Dentin
- *Dental papilla* → Pulp
- *Dental follicle* or *dental sac* → Cementum, the periodontal ligament (PDL), and the alveolar bone

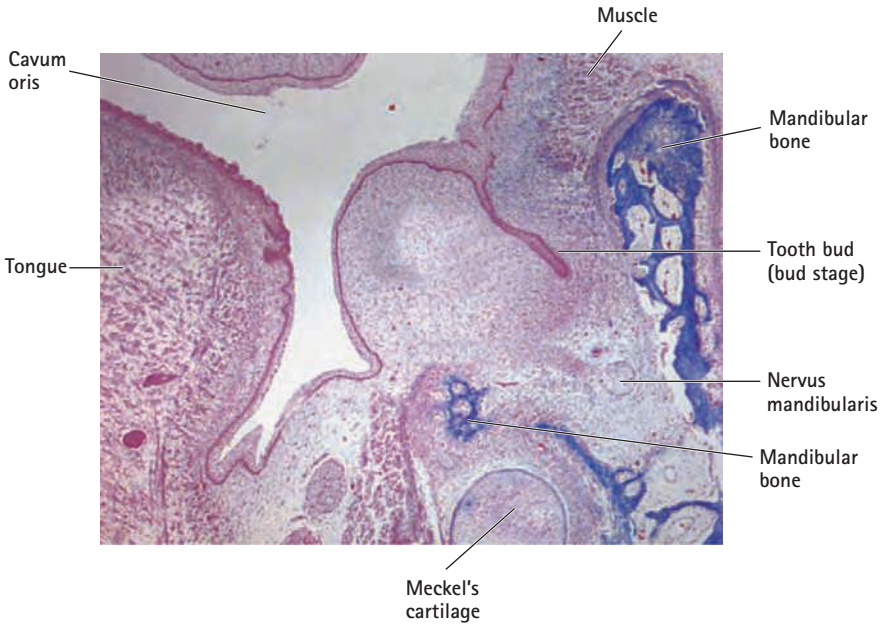


Figure 1.3 Dental lamina with its tooth bud. Around the bud, the mesenchyme is condensated. Just below the tooth bud in the mandible, you can see the alveolar nerve (Latin *n. alveolaris*). Meckel's cartilage can also easily be spotted. The tongue is also developing. It consists of muscular fibers oriented in different directions. At both sides of the tongue, you can see salivary glands. Cartilage comprising parts of the larynx can be seen below the tongue. (*Courtesy: Mathias Nordvi, University of Oslo, Norway.*)

Clinical Note

Primary dentin is formed in increments of *4–8 µm per day* and is continually deposited until the end of tooth development.

DENTINOGENESIS

In a complex series of events, the inner enamel epithelium exerts an inductive influence on the ectomesenchyme to begin dentinogenesis, and consequently, dentinogenesis has an inductive influence on the inner enamel epithelium to start amelogenesis. This series of events begins in the area of the future cusp tips and continues to the cervical loop, the future cementoenamel junction.

PREODONTOBLASTS

The periphery of the adjacent dental papilla consists of the polymorphic mesenchymal cells that develop into the cuboidal cells and, align themselves parallel to the basement membrane of the inner enamel epithelium and the acellular zone. These cuboidal cells stop dividing and develop into the columnar cells with polarized nuclei away from the basement membrane of the inner enamel epithelium. At this stage, these cells are called *preodontoblasts*.

MANTLE DENTIN FORMATION

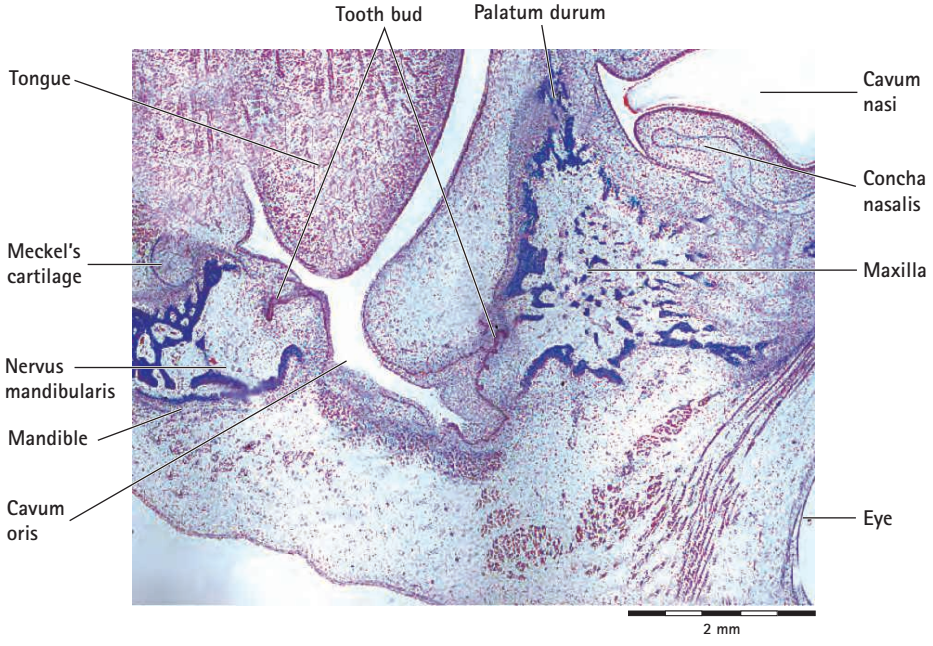
The preodontoblasts mature into odontoblasts by elongating themselves, by contacting adjacent odontoblasts through an increase in size, and by sending the cytoplasmic processes into the acellular zone. These odontoblastic processes continue to elongate and move the odontoblast cell body toward the center of the dental papilla. During this movement, large-diameter collagen fibers known as von Korff fibers are deposited at right angles to the basement membrane in the extracellular matrix of the acellular zone. This process creates the organic matrix of the first-formed dentin or *mantle dentin*. As more collagen fibrils are deposited, the inner enamel epithelium basement membrane starts to disintegrate. The vesicles carrying apatite crystals bud off from the odontoblastic processes and the crystals are deposited in the organic matrix for the initiation of mineralization. The dental papilla becomes the pulp at the moment of the mantle dentin formation.

PRIMARY DENTIN

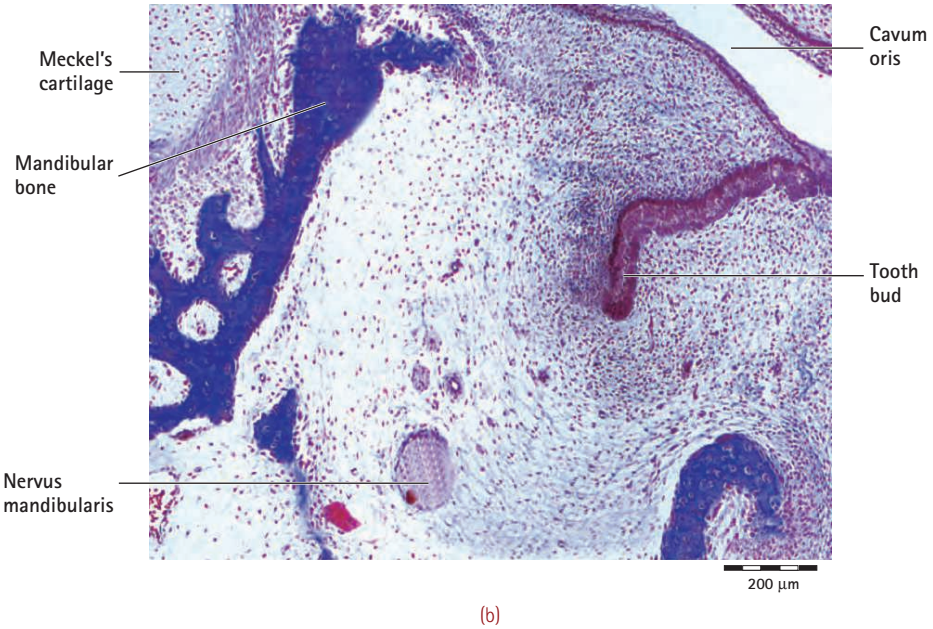
After the deposition of mantle dentin, the odontoblasts continue to move toward the center of the pulp and to leave the odontoblastic processes behind. The organic matrix or *predentin* (**Fig. 1.8a** and **1.8b**) is deposited around the odontoblastic processes. The predentin later calcifies and thereby forms the dentinal tubules. Primary dentin differs from the mantle dentin in which the matrix originates solely in the odontoblasts. The collagen fibers are smaller, are more closely packed, are at right angles to the tubules, and are interwoven. The mineralization of primary dentin originates from the previous mineralized dentin.

PERITUBULAR DENTIN

As the incremental deposition of dentin continues toward the center of the pulp, the diameter of the odontoblastic processes is reduced peripherally. Along with this, there is a reduction in size due to the circumferential deposition of dentin in the walls of the dentinal tubules. This dentin, which is more mineralized and is harder than primary dentin, is called *peritubular dentin*.

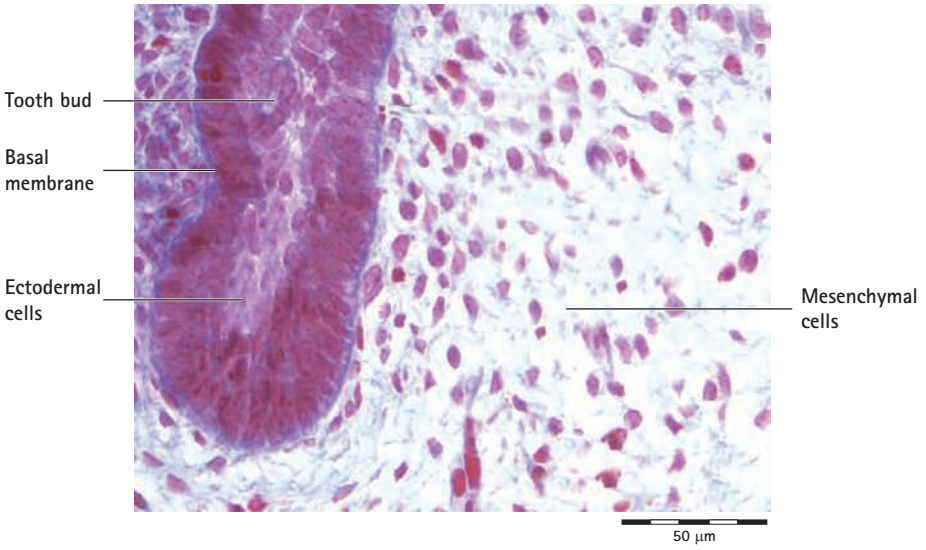


(a)

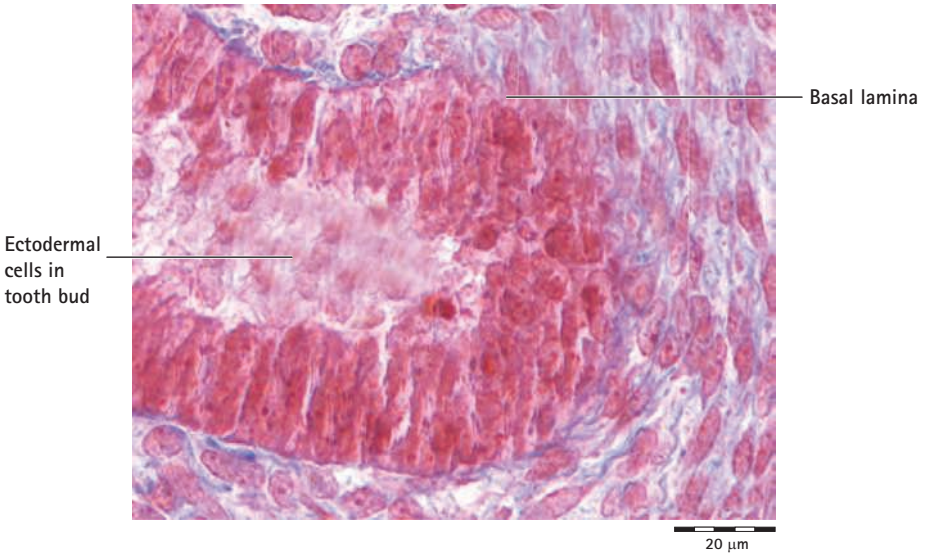


(b)

Figure 1.4 Tooth development, bud stage: (a and b) This is a frontal section of the head of a human fetus (tilted 90° to the right). The bone has started to develop in the maxilla as well as in the mandible. Because of the stain used to color this tissue sample, the bone has a blue color. Within the two quadrants seen here, there are dental laminae, and encircling these laminae, a condensation of the mesenchyme takes place. In between the spicules of bone in the mandible, you can see a cross-section of the alveolar nerve (Latin *n. alveolaris inferior*). Meckel's cartilage is situated medially to the mandibular bone. If you look closely, you can see the downgrowth of the parenchyma of the salivary glands and the developing muscular fibers of the tongue. (*Courtesy: Mathias Nordvi, University of Oslo, Norway.*) *(continued)*



(c)



(d)

Figure 1.4 *(continued)* (c and d) At higher magnifications, you can see the ectodermal cells within the developing tooth bud (stain: Azan). (*Courtesy: Mathias Nordvi, University of Oslo, Norway.*)

Clinical Note

- Dentin consists of:
  - Approximately 70% inorganic material
  - Twenty percent organic matrix, of which 91% is collagen
  - Ten percent water
- Dentinal tubule density varies from 40,000 to 70,000 tubules/mm^2.

AMELOGENESIS

Concomitant with dentinogenesis, the cells of the inner enamel epithelium cease to divide. These cells are the elongated epithelial cells called *preameloblasts*.

AMELOBLASTS

The preameloblasts differentiate into tall columnar epithelial cells with their nuclei polarized toward the stratum intermedium and the ameloblasts. While the ameloblasts are differentiating, the basement membrane of the inner enamel epithelium is being resorbed and dentin is being deposited to follow the contour established by the basement membrane. This process forms the future *dentinoenamel junction*. The ameloblasts begin to secrete enamel matrix to follow the contour of the already deposited dentin (**Fig. 1.9**).

DEPOSITION OF ENAMEL MATRIX

The deposition of enamel matrix causes the ameloblasts to migrate peripherally and form conic projections called

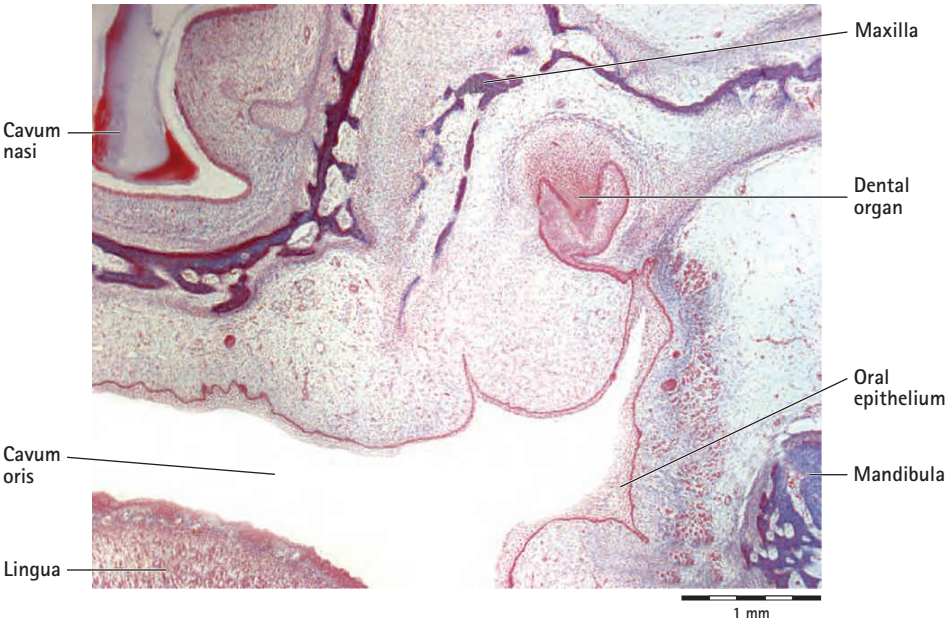


Figure 1.5 Tooth development, cap stage. This is a frontal section of the head of a human fetus. In the maxilla, you can see a developing tooth at the cap stage. The dental papilla is proliferating with cells. (*Courtesy: Mathias Nordvi, University of Oslo, Norway.*)



Figure 1.6 At higher magnification, you can appreciate the dental organ, dental papilla, and dental follicle. (*Courtesy: Mathias Nordvi, University of Oslo, Norway.*)

Tomes' processes on their secretory surfaces. The migration of ameloblasts peripherally (as they secrete enamel) outlines the crown of the tooth, but blocks the source of nutrition from the dental pulp. To gain a new source of nutrition, the outer enamel epithelium becomes a flattened layer of cells that folds because of the loss of the intracellular material of the stellate reticulum. This change brings the capillary network of the dental follicle, the new source of nutrition, closer to the ameloblasts.

MATURATION OF ENAMEL

The orderly deposition of enamel continues until the form of the crown is fully developed. At this time, the ameloblasts

lose their Tomes' processes, and the outer enamel epithelium, the stellate reticulum, and the stratum intermedium form a protective layer of stratified epithelium around the newly formed crown. This marks the beginning of enamel maturation or the higher mineralization of the existing enamel. This maturation process begins in the dentinoenamel junction and progresses peripherally to the enamel surface. During the final phase of the maturation process, the ameloblasts join the stratified epithelium to form the *reduced enamel epithelium* and to cover and protect the enamel until eruption of the tooth.

DEVELOPMENT OF THE ROOT

On completion of the crown, the cervical loop, formed by the union of inner and outer enamel epithelia, proliferates to form the *Hertwig's epithelial root sheath*, which determines the size and shape of the root of the tooth (**Fig. 1.10**).

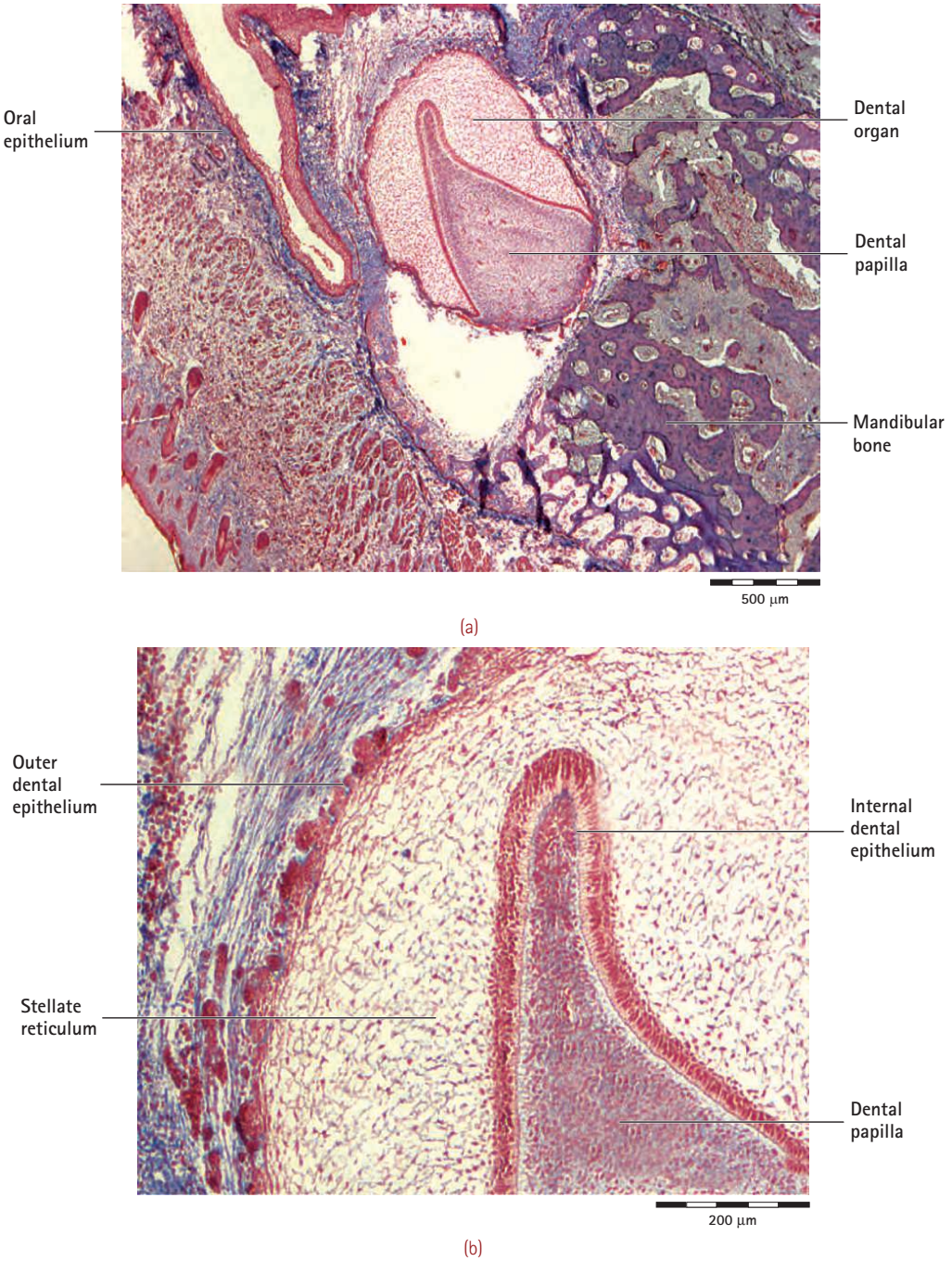
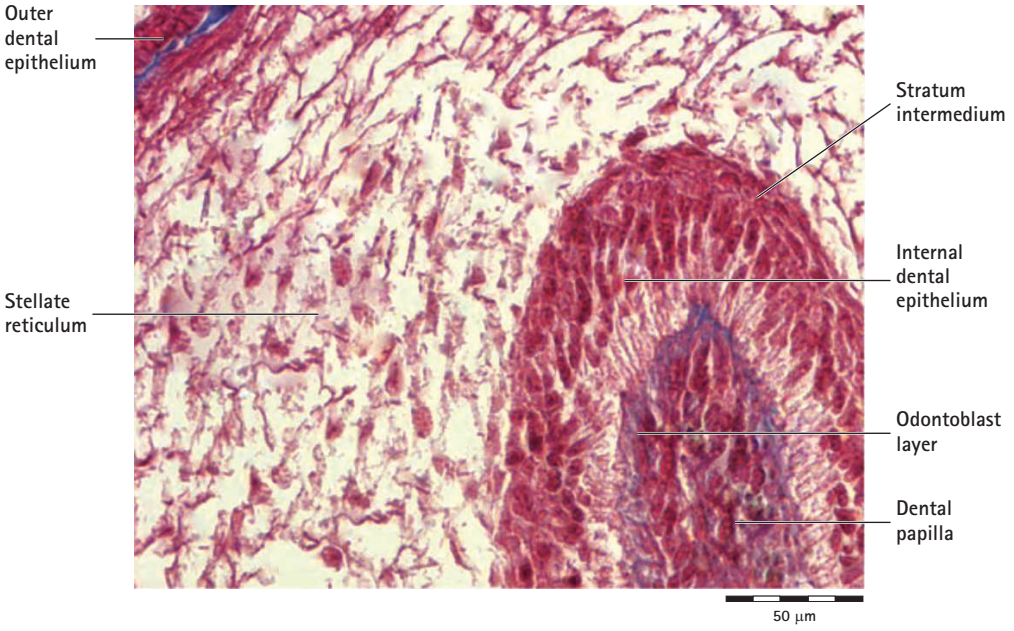


Figure 1.7 (a and b) Tooth development, bell stage. This section displays a developing tooth that has reached the bell stage. At the border between ectoderm and mesoderm (internal dental epithelium and dental papilla), at the incisal part of the tooth bud, you can see a narrow blue zone. This is the beginning of the dentin production. (*Courtesy: Mathias Nordvi, University of Oslo, Norway.*) *(continued)*



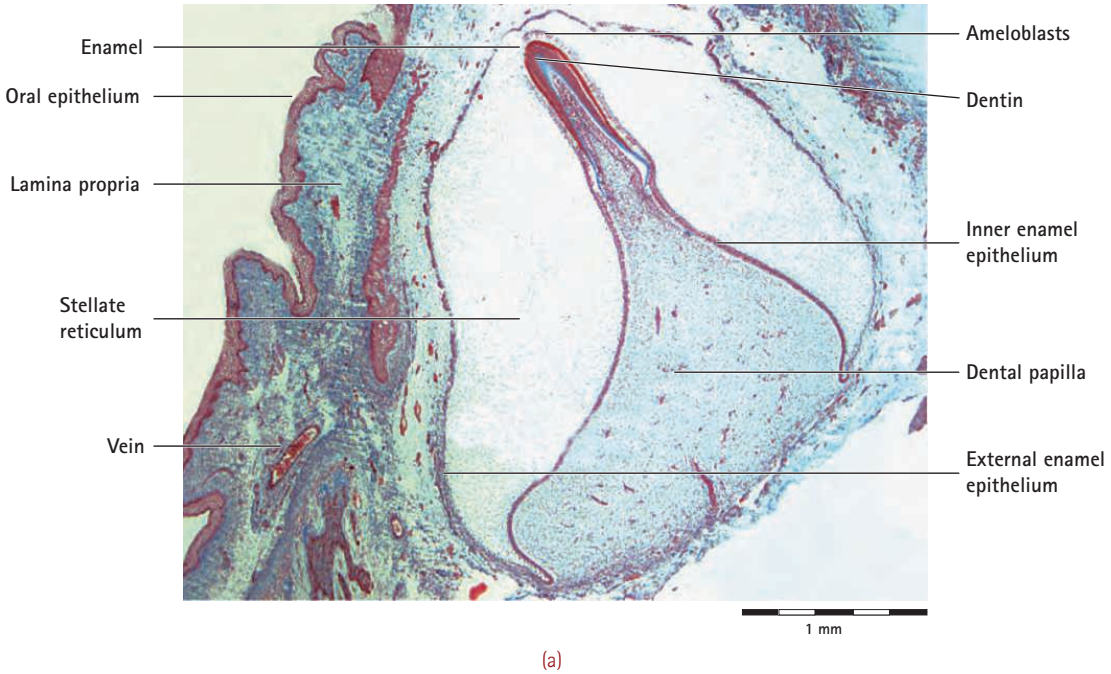
(c)

Figure 1.7 *(continued)* (c) This section also displays the different layers of the tooth bud (stain: Azan). (*Courtesy: Mathias Nordvi, University of Oslo, Norway.*)

HERTWIG'S EPITHELIAL ROOT SHEATH

The tip of the Hertwig's epithelial root sheath proliferates horizontally between the dentinal papilla and the dental follicle; this process partially encloses the dental papilla and delineates the apical foramen or foramina. This proliferation is called the *epithelial diaphragm*.

In single-rooted teeth, the epithelial diaphragm has a single opening which guides the formation of the root, root canal, and apical foramen. In double-rooted teeth, the



(a)

Figure 1.8 (a) This is a section of the developing tooth at the bell stage. The mineralization has just started. This can be seen at the incisal part of the bud. *(continued)*



(b)

Figure 1.8 *(continued)* (b) At higher magnification, you can see the odontoblasts. They are surrounded by a blue layer which is the predentin (stain: Azan). (*Courtesy: Mathias Nordvi, University of Oslo, Norway.*)

diaphragm evaginates in two predetermined places that come together and form two openings. In three-rooted teeth, the evagination occurs in three predetermined places to form three openings.

Clinical Note

In multirooted teeth, the epithelial diaphragm guides the formation of the *furca, roots, root canals,* and *apical foramina.*

The vertical section of the epithelial root sheath continues to grow in an apical direction and forces the fully formed crown toward the oral cavity while maintaining the epithelial diaphragm in a stable position in the jaw. This process marks the beginning of the tooth eruption.

The inner enamel epithelium below the future cementoenamel junction induces the peripheral mesenchymal cells of the dental papilla to differentiate into odontoblasts. Matrix formation and mineralization of the dentin occur as previously described.

CEMENTOBLASTS

As dentin is formed, the basement membrane of the inner enamel epithelium disintegrates and the epithelial cells lose their continuity. The disintegration of the basement membrane and the loss of continuity of the epithelial cells allow the mesenchymal cells from the dental follicle to penetrate the newly deposited dentin. These mesenchymal cells differentiate into *cementoblasts*, which are round, plump cells that have basophilic cytoplasm with an open nucleus in the active phase of cementogenesis and a closed nucleus with reduced cytoplasm during the resting phase.

The collagen fibers followed by the ground substance elaborated by the cementoblasts are deposited between the epithelial cells. The cluster of cells left behind from the epithelial root sheath migrates toward the dental follicle and the future PDL. This cluster of epithelial cells comprises the *cell rests of Malassez*. When some matrix production has taken place, mineralization of the cementum starts by the spread and deposition of the hydroxyapatite crystals from the dentin into the collagen fibers and the matrix. As dentinogenesis progresses in incremental phases, the apical foramen or foramina are formed by an apposition of dentin and cementum that reduces the size of the opening of the epithelial diaphragm.

Clinical Note

The *cell rests of Malassez* remain dormant in the mature PDL and have the potential of proliferating into periradicular cysts if stimulated by chronic inflammation.

ACCESSORY CANAL FORMATION

The accessory canals, which are an inefficient source of collateral circulation for the pulp, are formed during the development of the root. A defect in the epithelial root sheath, a failure in the induction of dentinogenesis, or the presence of a small blood vessel produces a gap that results in the formation of an accessory canal.

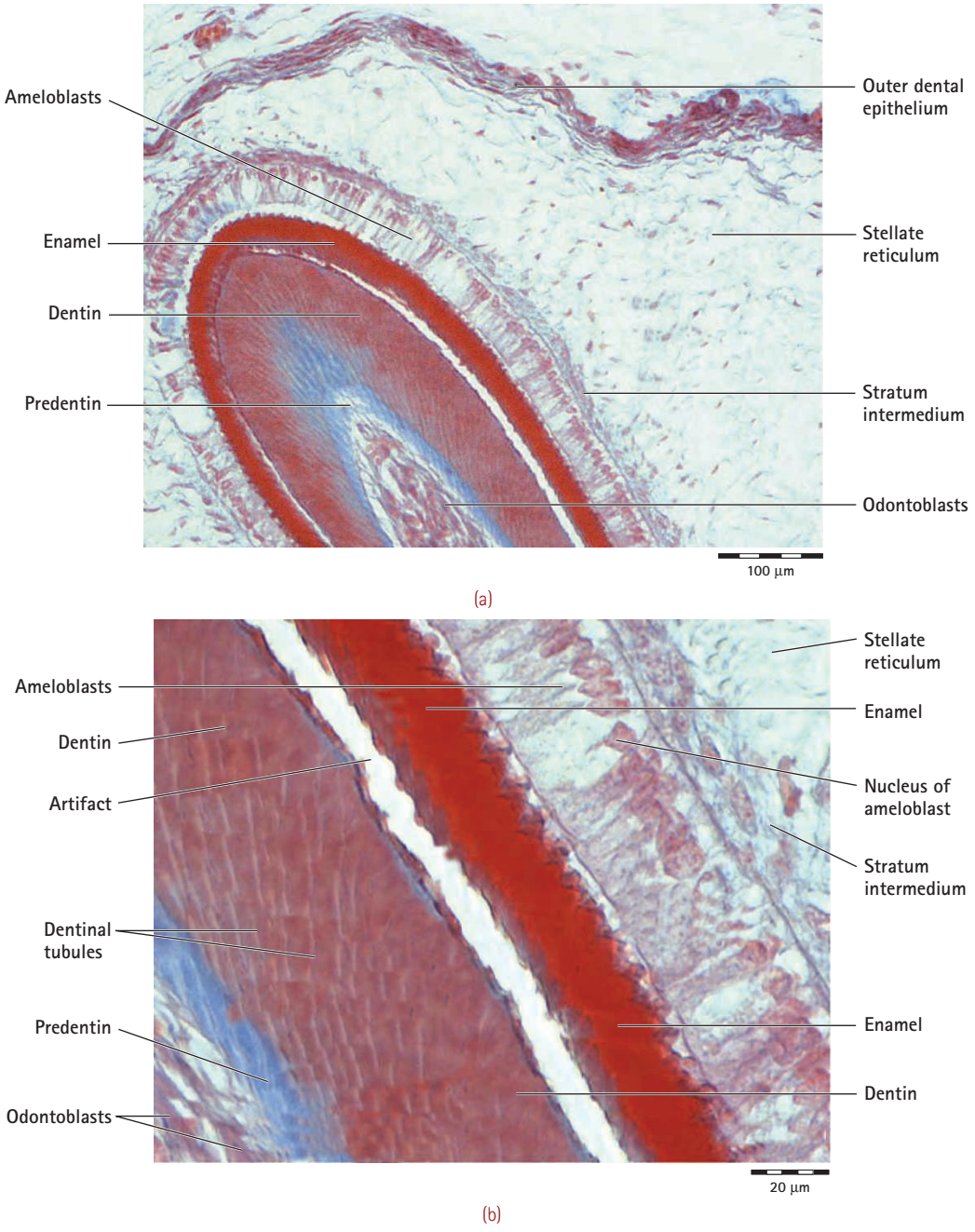


Figure 1.9 (a and b) Developing enamel: the dentin stains pale red in this section. The dentin is easily identified by its dentinal tubules. Surrounding the dentin, there is a thin layer of enamel. This layer is again surrounded by a layer of ameloblasts. The white zone between the dentin and the enamel is just an artifact. The distance between the outer dental epithelium and the incisal part of the bud is quite small. If this was not so, the ameloblasts would not get the nutrients they need from the blood because the stellate reticulum is not vascularized. The highest magnification shows all layers beautifully. (*Courtesy: Mathias Nordvi, University of Oslo, Norway.*)

Clinical Note

Accessory canals are more prevalent in the apical third of the root.

FORMATION OF CEMENTUM

Two kinds of cementum are laid down on the root. If the cementoblasts retract as the cementum is laid, it will be *acellular cementum*; on the other hand, if the cementoblasts do not retract and are surrounded by the new cementum, the tissue formed will be *cellular cementum* and the trapped cementoblasts are called *cementocytes* (**Fig. 1.11**). The acellular cementum is found adjacent to the dentin. The cellular cementum is found usually in the apical third of the root overlying the acellular cementum and in alternating layers with it. The cementocytes receive their nutrients from the PDL;

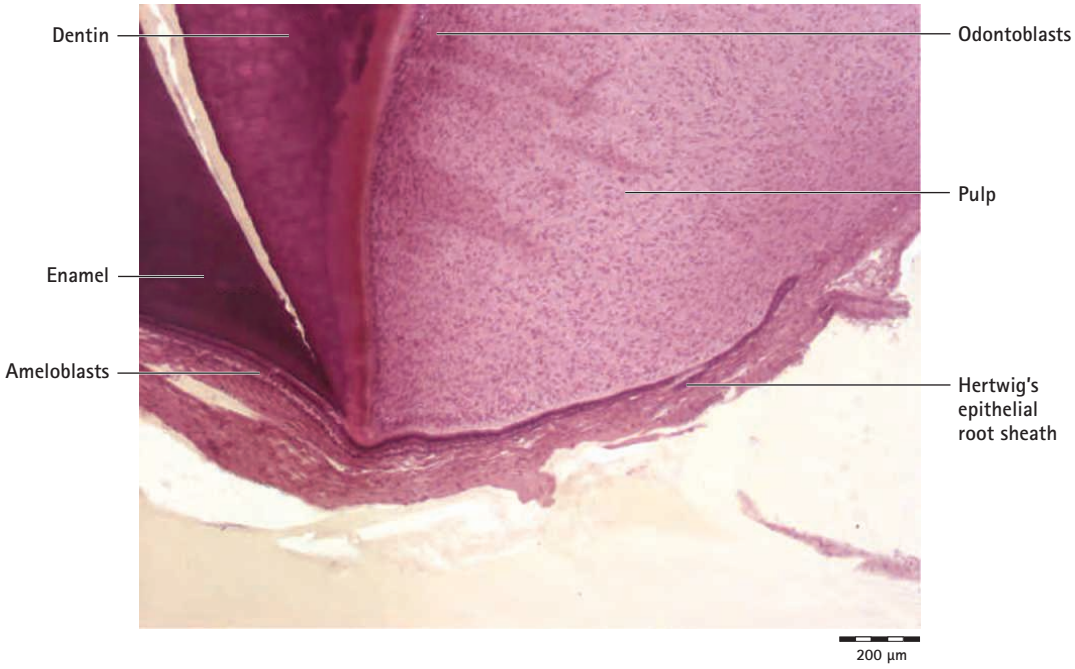


Figure 1.10 Development of the Hertwig's epithelial root sheath. (*Courtesy: Mathias Nordvi, University of Oslo, Norway.*)

the cementum is completely avascular. Because cementum is deposited in layers throughout the life of the tooth, the cementocytes are separated from the PDL, their source of nutrition, and die, leaving empty lacunae in the cementum.

The incremental deposition of cementum continues throughout the life of the tooth and leaves rest lines on the tooth's surface, and makes the layer of cementum thicker on the apical third of the root than on the cervical third.

Clinical Note

- Cementum is deposited in a thin layer at the cementoenamel junction to form one of the following three configurations:
  - A butt joint (30%)
  - An overlap joint (60%)
  - A gap between cementum and enamel (10%) (this gap may produce cervical sensitivity or may predispose the tooth to cervical caries)
- The continued incremental deposition of cementum in the apical third maintains the length of the tooth, constricts the apical foramen, and deviates the apical foramen from the center of the apex.

DEVELOPMENT OF THE PERIODONTAL LIGAMENT AND ALVEOLAR BONE

The PDL and alveolar bone develop at the same time as the root of the tooth. As the mesenchymal cells of the dental follicle adjacent to the tooth differentiate into cementoblasts, the cells in the periphery of the follicle differentiate into osteoblasts to form the bony crypt or alveolus of the tooth, and the mesenchymal cells of the center of the follicle differentiate into fibroblasts. These fibroblasts deposit obliquely oriented collagen fibrils that develop into fiber bundles. These obliquely oriented fiber bundles become entrapped in bone and cementum as they are deposited and thereby give rise to the PDL fibers. The deposition of bone to form the alveolus and the deposition of cementum to cover the dentin of the root give form to the attachment apparatus, the *periodontium*.

Clinical Note

The surface of the bony crypt becomes known as the *lamina dura* radiographically.

CIRCULATION AND INNERVATION OF DEVELOPING TOOTH

The blood vessels of the pulp originate from an oval or circular reticulated plexus. When fully developed, this plexus encircles the enamel organ and the dental papilla in the region of the dental follicle. A series of vessels arise from this plexus and grow into the dental papilla. At the beginning of dentinogenesis, the vessels that have penetrated the dental papilla give rise to a vascular subodontoblastic plexus, which follows the shape of the newly formed dentin. This subodontoblastic plexus atrophies as soon as the mature thickness of dentin is established and leaves the vessels that connect with the circular reticulated plexus to form the pulpal vessels. As the tooth matures, the circular reticulated plexus develops into the periodontal plexus. The formation of the root elongates the pulpal vessels, causes the reappearance of the

subodontoblastic plexus, and constricts the pulpal vessels into a small apical foramen. In the multirooted teeth, the epithelial diaphragm divides the pulpal vessels randomly into the different foramina.

In the early stages of tooth development, the nerve fibers can be seen in the dental follicle. At the beginning of dentinogenesis, some of the nerve fibers from the dental follicle migrate into the dental papilla. Not until the beginning of the root formation does the nerve proliferation of the pulp begin. The sensory nerve fibers traverse the dental papilla and, on reaching the coronal pulp, they branch toward the periphery to form a plexus of nerves called the *plexus of Raschkow*. This plexus of Raschkow is located in the subodontoblastic zone of the coronal pulp. These sensory nerve fibers are myelinated; therefore, they are enclosed in a sheath made of Schwann's cells. A number of nerves leave the plexus and extend into the odontoblastic layer. Some contact the odontoblasts, whereas others lose their myelin sheath and enter the predentin and the dentinal tubules. The unmyelinated nerve fibers that enter the dentinal tubules lie in the proximity of the odontoblastic processes.

Nair addressed the structural and quantitative aspects of human tooth innervations and formulation and clinical relevance of tooth axons. Human premolars receive almost 2300 axons at the root apex, of which about 13% are myelinated and 87% are nonmyelinated fibers. Most apical myelinated axons are fast-conducting *Aδ fibers* with their receptive fields located at the pulpal periphery and inner dentin. These fibers

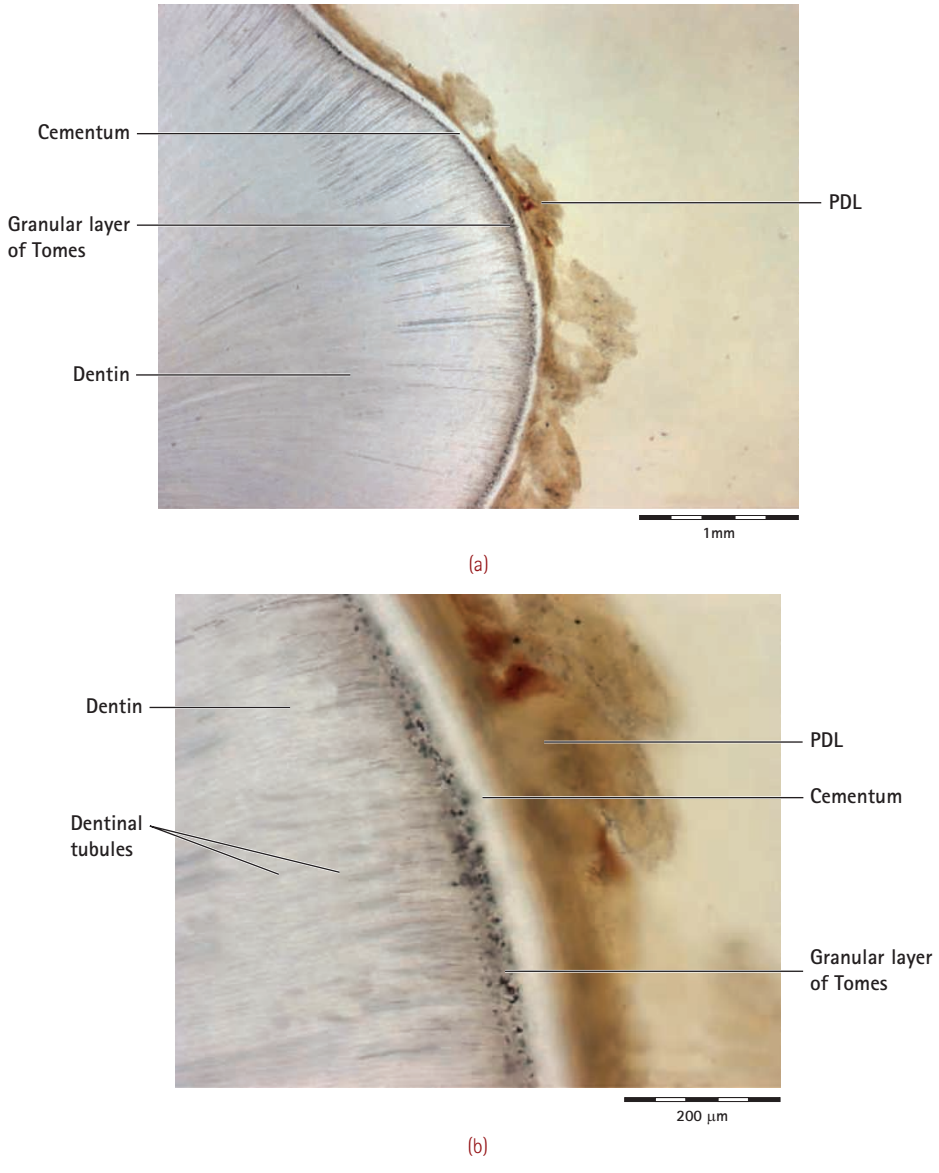
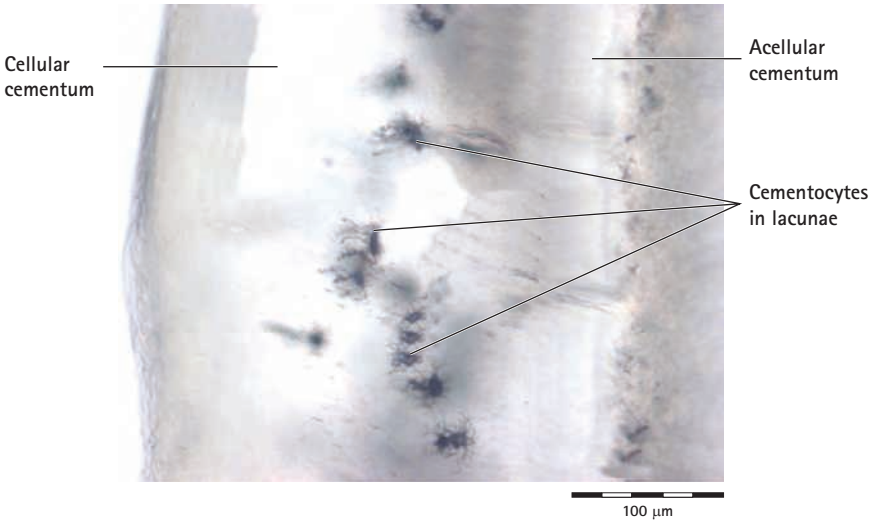


Figure 1.11 Premolar, cross-section: (a) This is a ground section of a premolar, showing dentin, cementum, and periodontal ligament (PDL). (b) At higher magnification, the dentinal tubules are easily distinguished as well as the granular layer of Tomes. *(continued)*



(c)

Figure 1.11 *(continued)* (c) Cellular and acellular cementum evident along with cementocytes in the lacunae (stain: ground section). (*Courtesy: Mathias Nordvi, University of Oslo, Norway.*)

are probably activated by a hydrodynamic mechanism and conduct impulses that are perceived as a short, well-localized, sharp pain. Most *C fibers* are slow conducting and fine sensory afferents. Their receptive fields are located in the pulp and these transmit impulses that are experienced as a dull, poorly localized, and lingering pain. In addition to nociceptive alarm signaling, the intradental sensory axons may play a regulatory role in the maintenance and repair of the pulpodentinal complex.

The blood vessels entering the dental papilla during the development bring with them the sympathetic nerve fibers which are unmyelinated. These sympathetic nerve fibers play a role in the vasoconstriction of the blood vessels. As the apical foramen matures and reduces the size of its opening, the myelinated nerve fibers form bundles located in the center of the pulp in conjunction with the blood vessels.

PART 2: NORMAL PULP

Pulp is a connective tissue consisting of nerves, blood vessels, ground substance, interstitial fluid, odontoblasts, fibroblasts, and other cellular components. The dental pulp consists of vascular connective tissue contained within rigid dentinal walls. Although similar to other connective tissues in the human body, it is specialized, owing to its functions and environment.

FUNCTIONS OF THE PULP

- *Formative:* Elaboration of dentin to form the tooth
- *Protective:* Protection against and repairing of the effects of noxious stimuli
- *Nutritive:* Preserving the vitality of all the cellular elements
- *Sensory:* Perception of stimuli

The elaboration of dentin creates a special environment for the pulp. The pulp space becomes limited by dentin formation in permanent adult human teeth. This volume is continuously reduced by the deposition of secondary dentin throughout the life of the pulp as well as by the deposition of reparative dentin in response to noxious stimuli. The encasement of the pulp in dentin creates an environment that allows only small amounts of intercellular accommodation of exudate during inflammatory reactions.

The anatomic limitation of encasement of dentin on the pulp makes the pulp an organ of terminal circulation, with limited portals of entry and exit: the apical and accessory foramina. This feature limits the vascular supply and drainage of the pulp and thereby limits its collateral circulation.

Clinical Note

The inability of the pulp to swell creates abnormally high pressure in an area of inflammation, with interruption of blood flow due to the collapse of the pulpal veins, possibly resulting in anoxia and localized necrosis.

ZONES OF PULP

Starting at the periphery, the pulp is divided into four zones:

I. Odontoblastic zone, which surrounds the periphery of the pulp
II. Cell-free zone
III. Cell-rich zone
IV. Central zone

I. ODONTOBLASTIC ZONE

The odontoblasts are specialized cells that generally last the entire life of the tooth. They consist of cell bodies and their

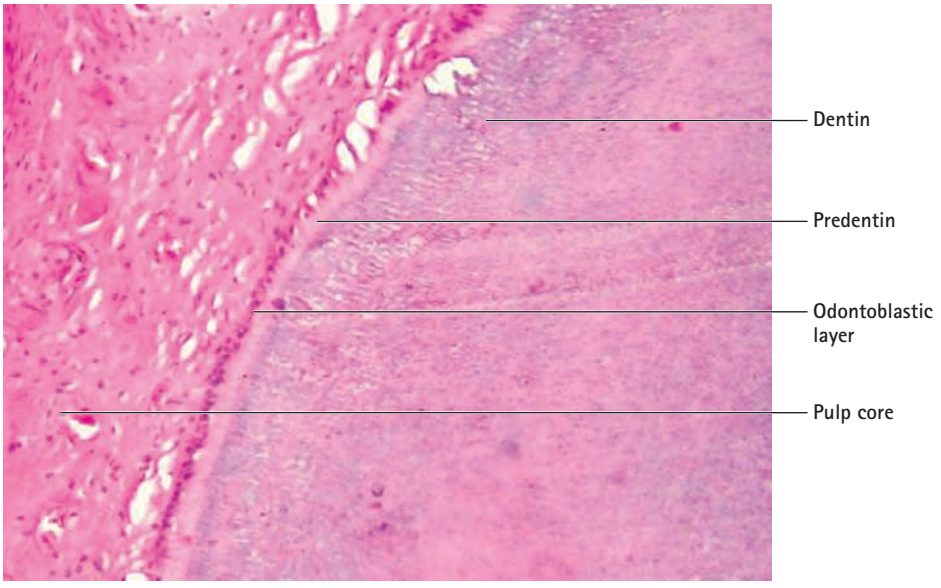


Figure 1.12 H+E-stained decalcified section of tooth showing dentin, predentin, odontoblastic layer, and pulp (10×). (*Courtesy: B. Sivapathasundharam and K. Manjunath, India.*)

cytoplasmic processes. The odontoblastic cell bodies form the *odontoblastic zone*, whereas the odontoblastic processes are located within the predentin matrix and the dentinal tubules, extending into the dentin. In this odontoblastic zone, capillaries and unmyelinated sensory nerves are found around the odontoblastic cell bodies (**Fig. 1.12**).

The odontoblasts lining the predentin represent the link between the dentin and the pulp. They are the *matrix-producing cells* and show characteristic features associated with protein synthesis.

Clinical Note

The primary function of the odontoblasts throughout the life of the pulp is the production and deposition of dentin.

Histology

In histologic sections, the odontoblasts appear to be lined up in a palisading arrangement at the periphery of the pulp. The cell bodies of the odontoblasts have junctional complexes, such as gap junctions, which unite the cells and allow an interchange of metabolites. These cytoplasmic bridges among odontoblasts may explain the palisading formation and the action in unison of these cells. These cell bodies vary in size, shape, and arrangement from the coronal pulp to the apical pulp. In the coronal pulp, the odontoblasts are tall, columnar cells with a nucleus polarized toward the center of the pulp. They change shape gradually to flattened cells in the apical third, and their arrangement changes from a six- to eight-cell layer in the pulp horns to a one-cell layer in the apical pulp.

Clinical Note

- The crowded arrangement of the coronal odontoblasts is due to the rapid reduction of the pulp chamber by the deposition of dentin, which compresses the existing cells to a stratified layer.
- This crowding of odontoblasts produces more cells per unit area and, therefore, more dentinal tubules (45,000/mm^2) in the pulpal side than in the enamel side (20,000/mm^2).

As a result of this phenomenon, the configuration of the dentinal tubules in these areas is "S" shaped. Reduction of odontoblasts per unit area produces fewer tubules and results in a straighter course, as seen in the cervical third of the root or beneath the incisal edges or cusps (**Fig. 1.13**). Further reduction in the number of cells and, consequently, in the number of dentinal tubules produces dentin typically found in the apical third. The presence of "S"-shaped tubules is a consideration in clinical endodontic practice. Operative procedures in areas with such tubules produce inflammatory changes in the odontoblastic layer further apically than expected.

Predentin Layer

Dentinogenesis includes the production, deposition, and calcification of the matrix. This matrix is the predentin layer deposited around the odontoblastic processes and is found between the calcified dentin and the odontoblastic zone (**Fig. 1.14**). This *predentin layer*, elaborated by the odontoblasts, is a protein–carbohydrate complex consisting of proteoglycans, phosphoproteins, plasma proteins, glycoproteins, and collagen fibrils. Calcium and phosphorus salts are deposited into this matrix to produce the mineralized

structure known as *dentin*. The pattern of calcification around the odontoblastic processes forms the *dentinal tubules*, and the dentin between these tubules is called *intertubular dentin*.

Odontoblastic Processes

The odontoblastic processes, also referred to as *Tomes' processes*, are housed within the dentinal tubules. The extent of the odontoblastic processes in dentin has not been determined. During the early stages of tooth development, the processes extend into the entire thickness of the dentin. Studies in adult teeth have given conflicting information on the extent of the processes. Some studies claim that these processes extend into one-third of the thickness of the dentin (0.7 mm), whereas others claim that the processes extend through the thickness of the dentin and reach the dentinoenamel junction.

The space around the odontoblastic processes, the *perodontoblastic space*, and the space peripheral to the end of the odontoblastic processes are filled with *extracellular fluid*. This fluid originates from the capillary transudate and plays an important role in sensory transmission.

Clinical Note

The unmyelinated nerves for sensory perception are also found in the pulpal end of the periodontoblastic space of the dentinal tubules.

Incremental Lines

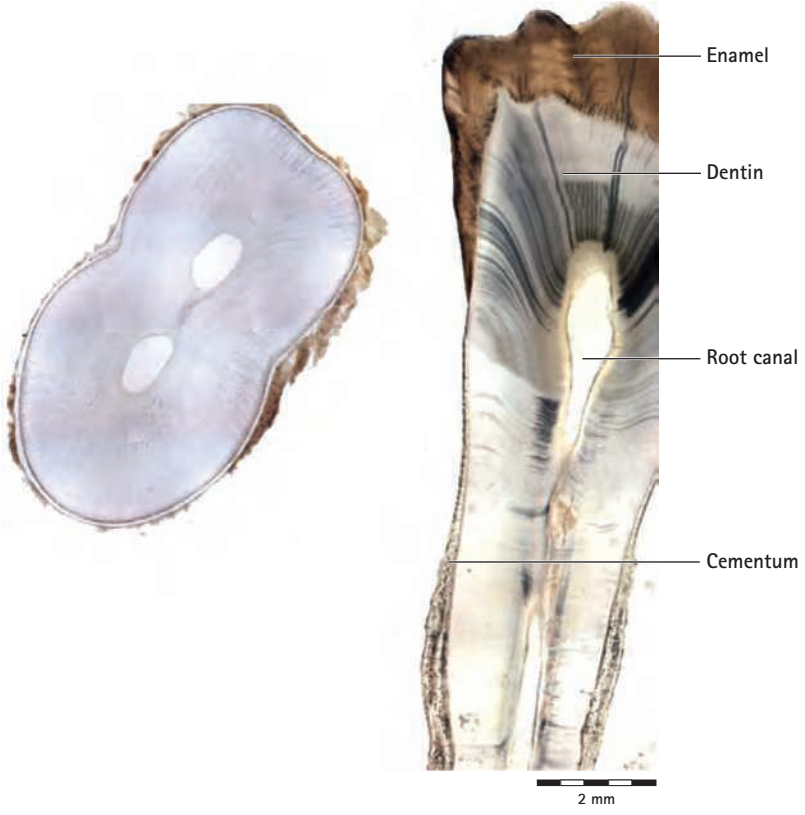
During dentinogenesis, there are periods of activity and periods of rest. These periods are demarcated by the presence of lines, called *incremental lines*. These lines are accentuated during periods of illness, by deficiencies in nutrition, and at birth. The accentuated incremental line that occurs at birth is called the *neonatal line*. In some areas in the mature dentin, the matrix has not calcified or is hypocalcified. These areas are called *interglobular dentin* (**Fig. 1.15a** and **1.15b**). One also sees spaces in the root dentin near the cementodentinal junction called the *granular layer of Tomes*.

Clinical Note

The incremental lines represent rest periods in dentinogenesis, whereas the interglobular dentin and the granular layer of Tomes probably represent a defect in matrix formation.

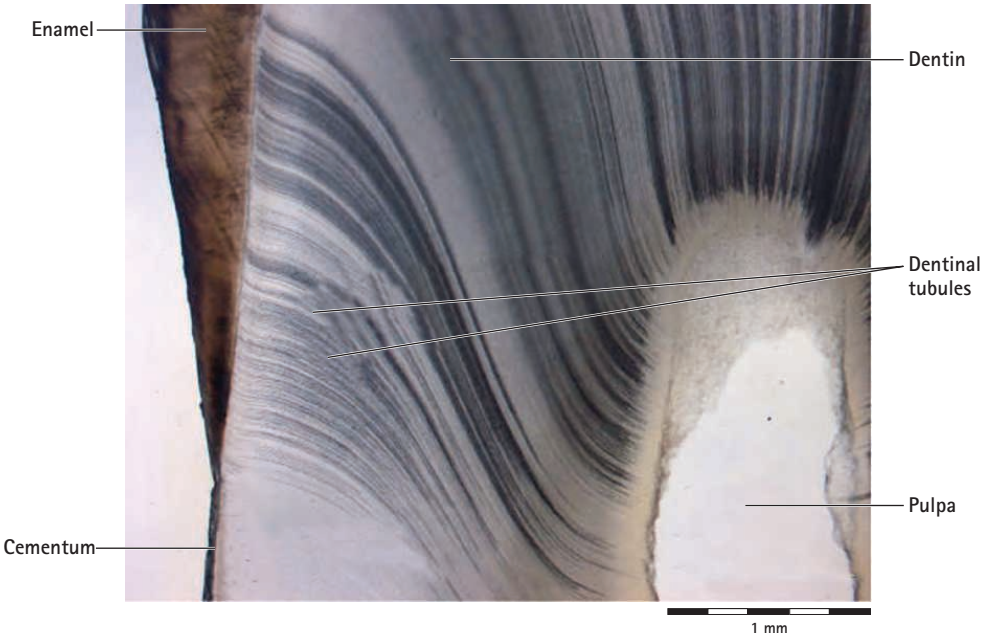
Dentinal Tubules

The dentinal tubules extend from the predentin border to the dentinoenamel and the dentinocemental junctions (**Fig. 1.16**). They are conical in shape, with a 2.5 µm mean diameter in the pulpal wall and a 0.9 µm mean diameter in the dentinoenamel or dentinocemental junctions because of the deposition of the *peritubular dentin* (**Fig. 1.17**).

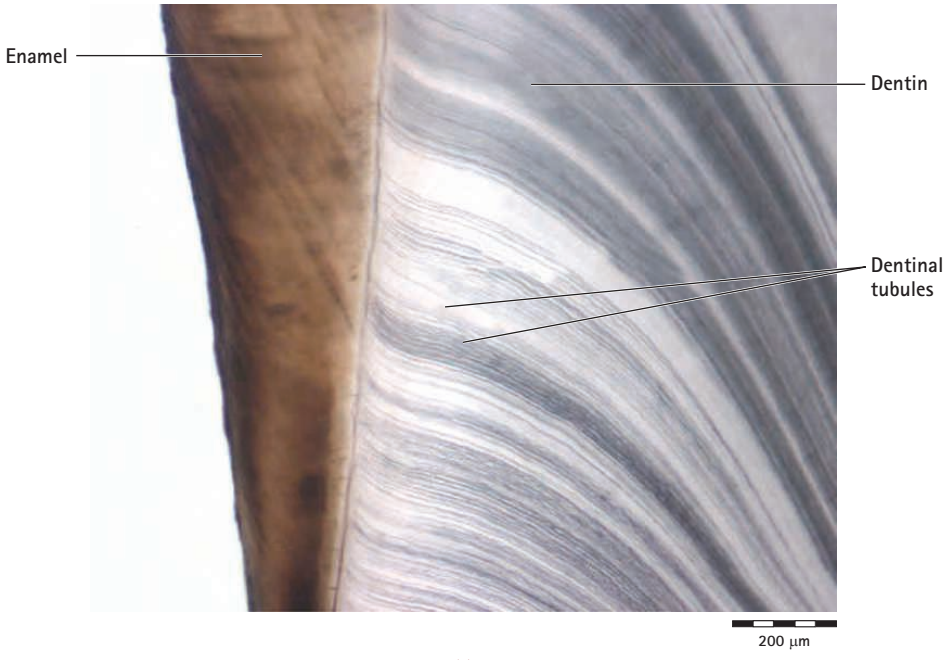


(a)

Figure 1.13 (a) Premolar: cross and longitudinal sections. *(continued)*



(b)



(c)

Figure 1.13 *(continued)* (b and c) Longitudinal section: the enamel is brown in this section. In some areas of the enamel, you can even see the direction of the enamel prisms. The dentinal tubules can easily be tracked through the dentin (stain: ground section). (*Courtesy: Mathias Nordvi, University of Oslo, Norway.*)

As the dentinal tubules approach the dentinoenamel junction, they branch and increase the ratio per unit area over that of the middle third of the dentin. The branching of the dentinal tubules occurs during the beginning of dentinogenesis. Each preodontoblast sends various cytoplasmic processes into the acellular zone and thereby produces several future dentinal tubules. As the fully mature odontoblast migrates pulpally, the processes unite to form a single dentinal tubule with terminal branches at the dentinoenamel junction. This branching may explain the extreme sensitivity of the dentinoenamel junction (**Fig. 1.18**).

Because the peritubular dentin has an organic matrix with fewer collagen fibers than the intertubular dentin, it is more mineralized and harder. As the pulp ages, the continuous deposition of peritubular dentin may obliterate the dentinal tubules peripherally. This obliteration of tubules results in the

formation of the *sclerotic dentin*, which has a glassy appearance under transmitted light.

Clinical Note

Sclerosis reduces the permeability of the dentin and may serve as a pulp-protective mechanism. A mild stimulus of short duration may accelerate the production of the peritubular dentin, may produce sclerosis peripherally, and may thus reduce the permeability of dentin and enhance pulp protection.

By dentinogenesis, the odontoblasts are involved in the formation of the teeth and the protection of the pulp from noxious stimuli. To fulfill the formative and protective functions of the pulp, the odontoblasts deposit primary, secondary, and tertiary dentin.

Primary Dentin

Primary dentin is elaborated before the teeth erupt and is divided into *mantle* and *circumpulpal* dentin. Mantle dentin,

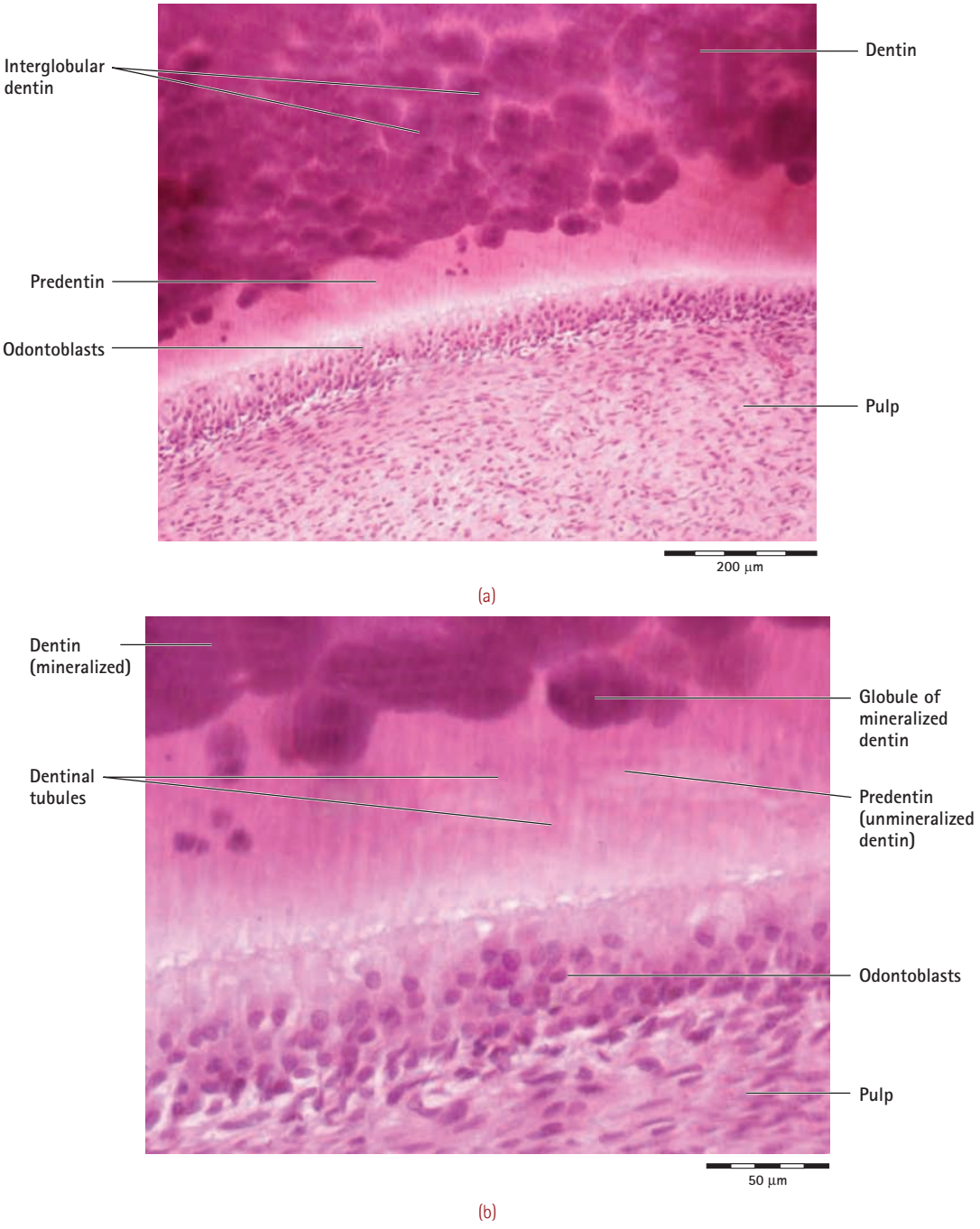
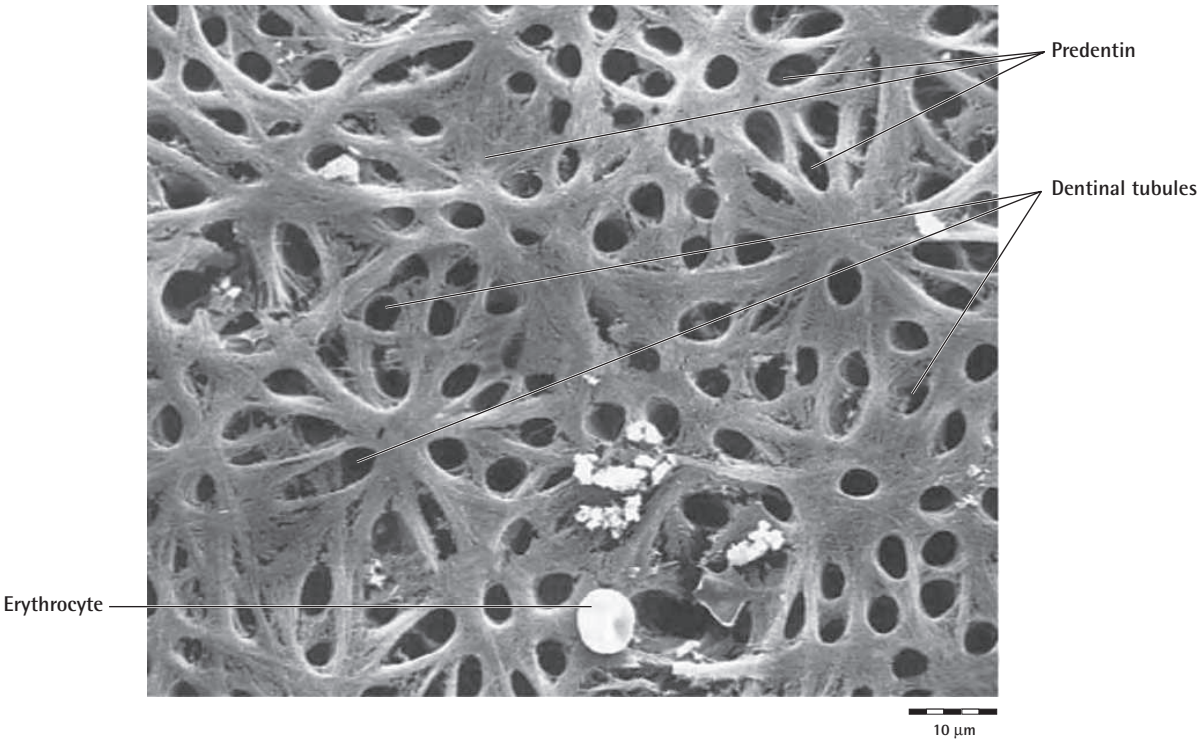


Figure 1.14 (a) Predentin layer and odontoblastic zone surrounding the periphery of the pulp. (b) Predentin layer and odontoblastic zone surrounding the periphery of the pulp at a higher magnification. (*Courtesy: Mathias Nordvi, University of Oslo, Norway.*) *(continued)*



(c)

Figure 1.14 *(continued)* (c) Dentinal tubules, pulpal view. This image shows predentin with dentinal tubules. This is the pulpal side of the dentin. The odontoblasts have been removed (scanning electron microscopy [SEM]). (*Courtesy: Randi F. Klinge, University of Oslo, Norway.*)

the first calcified layer of the dentin deposited against the enamel, forms the dentinal side of the dentinoenamel junction. Circumpulpal dentin is the dentin formed after the layer of mantle dentin. Primary dentin fulfills the initial formative function of the pulp.

Secondary Dentin

Secondary dentin is elaborated after eruption of the teeth. It can be differentiated from primary dentin by the sharp bending of the tubules producing a line of demarcation. It is deposited unevenly on primary dentin at a low rate and has incremental patterns and tubular structures less regular than those of primary dentin. For example, secondary dentin is deposited in greater quantities in the floor and roof of the pulp chamber than on the walls. This uneven deposition explains the pattern of reduction of the pulp chamber and pulp horns as teeth age. This deposition of secondary dentin protects the pulp.

Tertiary Dentin

Two types of tertiary dentin are recognized:

1. Tertiary dentin formed by primary odontoblasts following a mild stimulus is called *reactionary dentin.*
2. Tertiary dentin formed by newly differentiated or secondary odontoblasts is termed *reparative dentin.*

Clinical Note

- Reparative dentin, also known as irregular or tertiary dentin, is elaborated by the pulp as a protective response to noxious stimuli.
- These stimuli can result from caries, operative procedures, restorative materials, abrasion, erosion, or trauma.
- The reparative dentin is deposited in the affected area at an increased rate that averages **1.5 µm per day**.
- The rate, quality, and quantity of reparative dentin deposited depend on the severity and duration of the injury to the odontoblasts and are usually produced by "replacement" odontoblasts.

When a mild stimulus is applied to the odontoblasts for a prolonged period of time, such as abrasion, reparative dentin may be deposited at a slower rate. This tissue is characterized by slightly irregular tubules. On the other hand, an aggressive carious lesion or other abrupt stimulus stimulates the production of reparative dentin with fewer and more irregular tubules. If the odontoblast is injured beyond repair, the degenerated odontoblasts will leave empty tubules, called *dead tracts*, which allow bacteria and noxious products to enter the pulp (**Fig. 1.19**). Reparative dentin is deposited on the pulpal wall of a dead tract unless the pulp is too atrophic. Because reparative dentin has fewer tubules, although it is less mineralized, it blocks the ingress of noxious products into

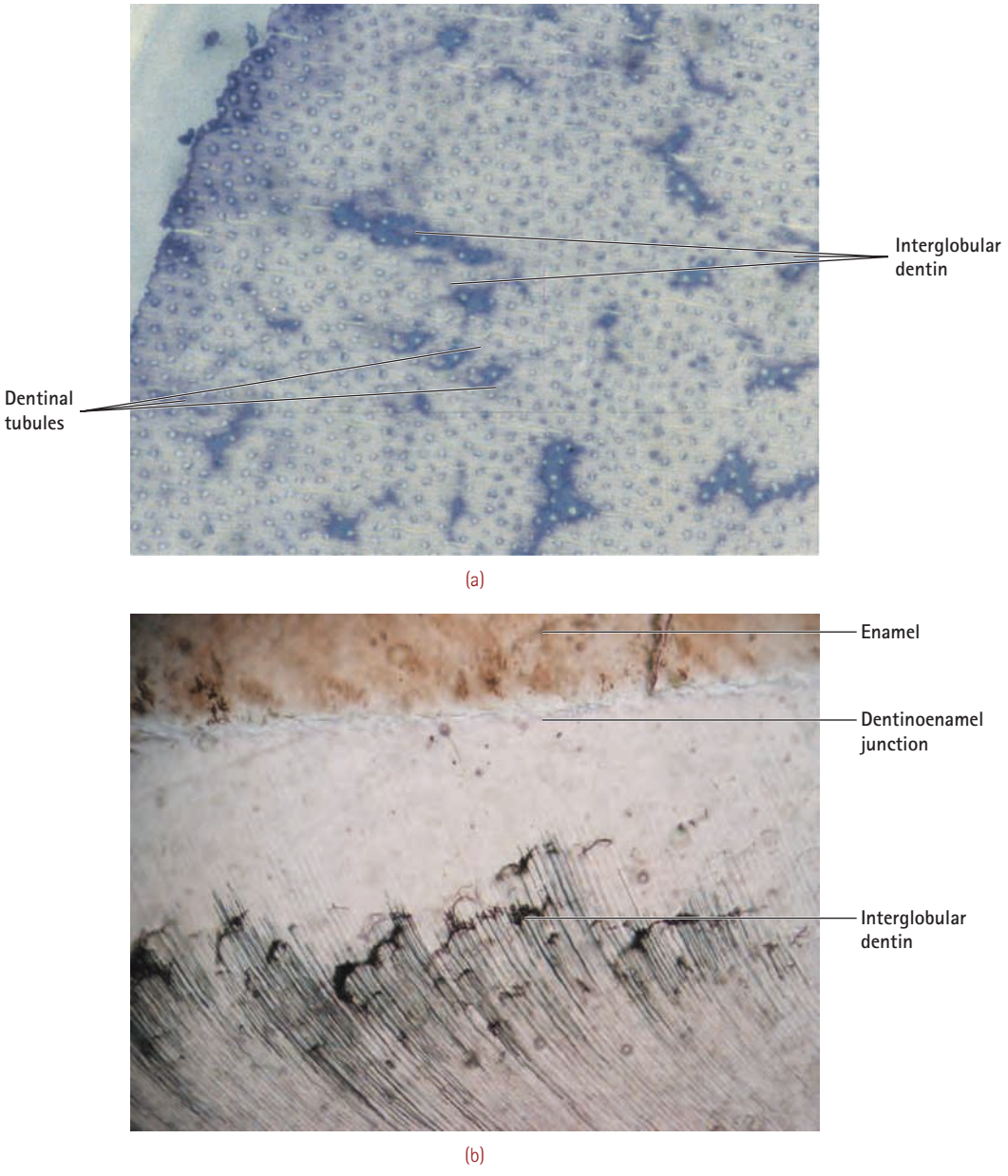
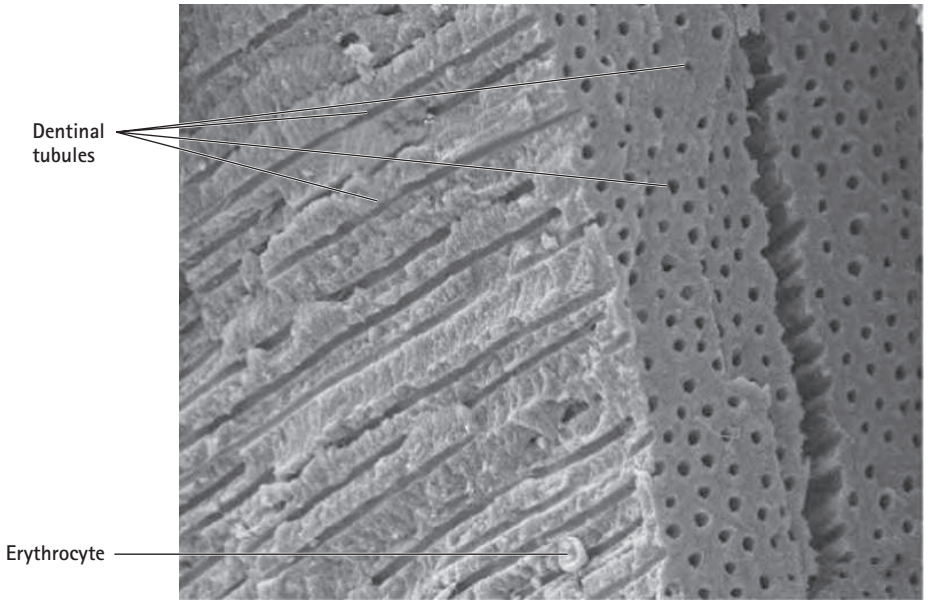


Figure 1.15 (a) Dentinal tubules, cross-section. This section is not decalcified. It is colored by toluidine blue. The interglobular dentin can be seen (stain: toluidine blue). (*Courtesy: Randi F. Klinge, University of Oslo, Norway.*) (b) Longitudinal section of tooth showing enamel, dentinoenamel junction, and areas of interglobular dentin (ground section, 10×). (*Courtesy: B. Sivapathasundharam and K. Manjunath, India.*)

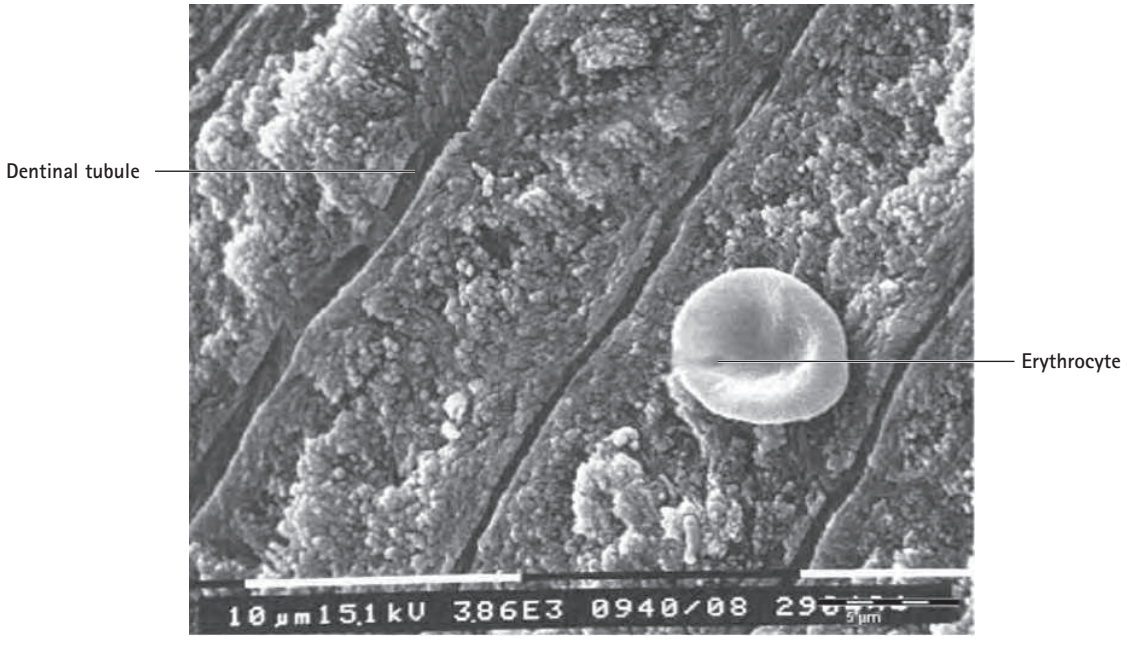
the pulp. As the caries progress and as more odontoblasts are injured beyond repair, the layers of reparative dentin become more atubular and may have cell inclusions, i.e., trapped odontoblasts. The cellular inclusions are uncommon in human teeth. On removal of the caries, the mesenchymal cells of the cell-rich zone differentiate into odontoblasts to replace those that have necrosed. These newly formed odontoblasts can produce well-organized dentin or an amorphous, poorly calcified, permeable dentin. The demarcation zone between secondary and reparative dentin is called the calcifotraumatic line.

II. CELL-FREE ZONE

The cell-free zone, or *zone of Weil*, is a relatively acellular zone of the pulp, located centrally to the odontoblast zone (**Fig. 1.20**). This zone, although called cell-free, contains some fibroblasts, mesenchymal cells, and macrophages. Fibroblasts are involved in the production and maintenance of the reticular fibers found in this zone. When odontoblasts are destroyed by noxious stimuli, mesenchymal cells and fibroblasts differentiate into new odontoblasts. Macrophages are present for the phagocytosis of debris.



(a)



(b)

Figure 1.16 (a and b) Dentinal tubule. This is an image of a piece of dentin acquired using a scanning electron microscope. It illustrates the number of dentinal tubules and their size. (Size may vary as to what part of the dentin you look at and the age of the individual.) An erythrocyte can be seen at the bottom of the image telling us about the scale involved. (Diameter of an erythrocyte is approximately 7.5 µm; scanning electron microscopy [SEM].) (*Courtesy: Randi F. Klinge, University of Oslo, Norway.*)

The main constituents of this zone are a plexus of capillaries, the nerve plexus of Raschkow, and the ground substance. The capillary plexus is involved in the nutrition of the odontoblasts and the cells of the zone and is conspicuous only during periods of dentinogenesis and inflammation. The ground substance is involved in the metabolic exchanges of the cells and limits the spread of infection because of its consistency. The zone of Weil is more prominent in the coronal pulp, but it may be completely absent during periods of dentinogenesis.

Clinical Note

The unmyelinated nerve plexus of Raschkow is involved in the neural sensation of the pulp.

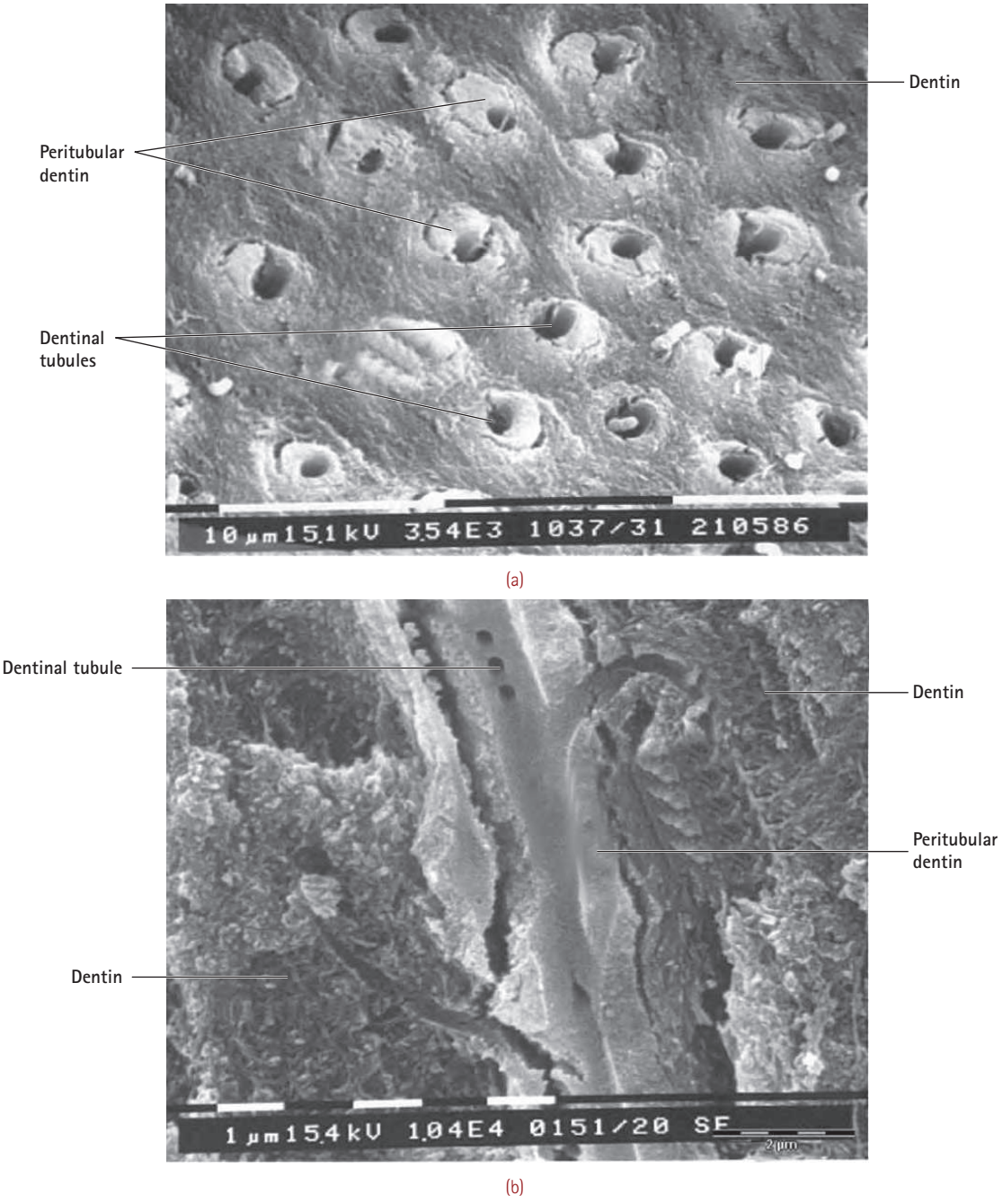


Figure 1.17 (a and b) Peritubular dentin, dentinal tubules, highly mineralized dentin: dentinal tubules containing highly mineralized dentin. The section is made halfway through the dentin (scanning electron microscopy [SEM]). (*Courtesy: Randi F. Klinge, University of Oslo, Norway.*)

III. CELL-RICH ZONE

The cell-rich zone is located central to the cell-free zone (**Fig. 1.20**). Its main components are ground substance, fibroblasts with their product, i.e., the collagen fibers, undifferentiated mesenchymal cells, and macrophages.

Ground Substance

Ground substance, the main constituent of the pulp, is the part of the matrix that surrounds and supports the cellular and vascular elements of the pulp. It is a gelatinous substance composed of proteoglycans, glycoproteins, and water. Ground substance serves as a transport medium for metabolites and waste products of cells and as a barrier against the spread of bacteria. Age and disease may change the composition and function of the ground substance.

Fibroblasts

The fibroblasts are the predominant cells of the pulp (**Fig. 1.20**). They may originate from undifferentiated

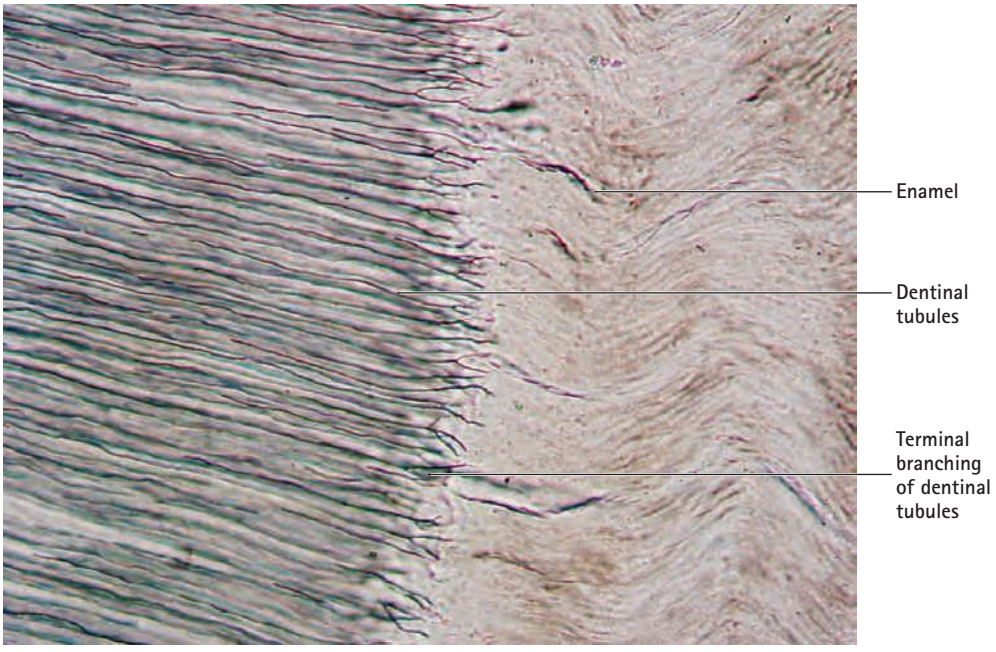


Figure 1.18 Longitudinal section of tooth showing wavy enamel rods and dentinal tubules along with their terminal branching (ground section, 10×). (*Courtesy: B. Sivapathasundharam and K. Manjunath, India.*)

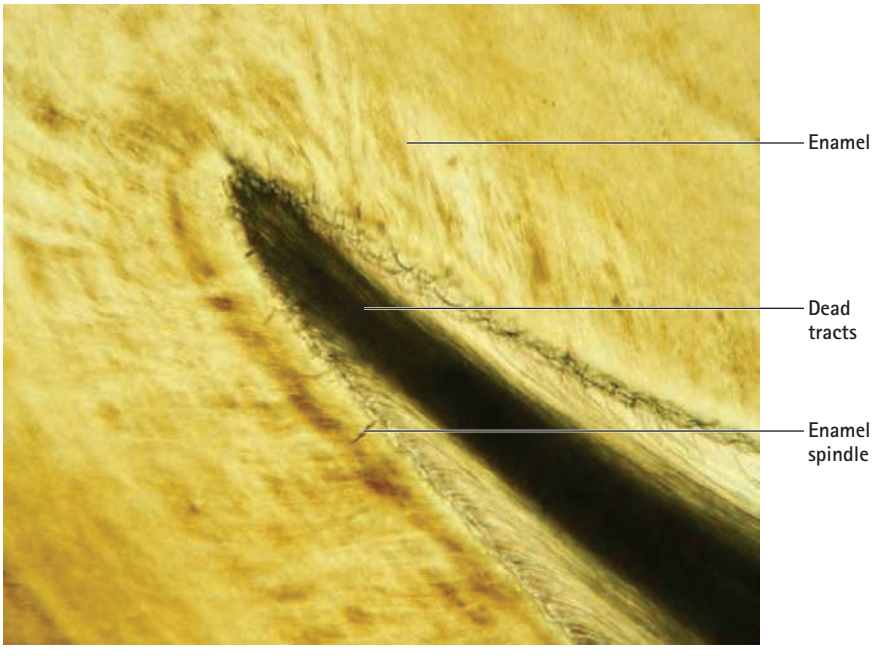
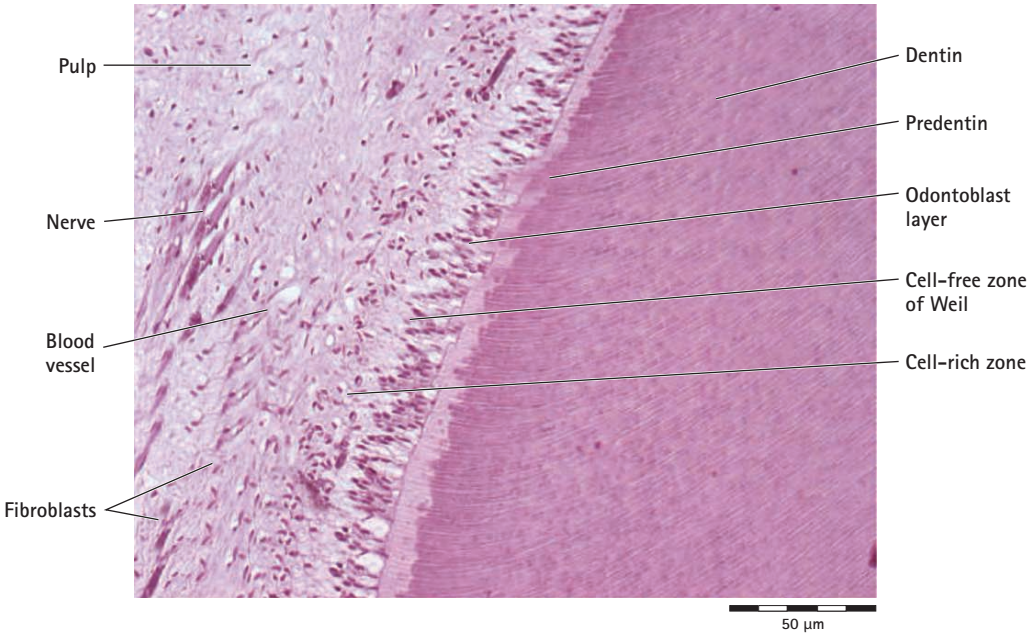


Figure 1.19 Longitudinal section of crown showing dead tracts and enamel with enamel spindle emerging from dentinoenamel junction (ground section, 10×). (*Courtesy: B. Sivapathasundharam and K. Manjunath, Department of Oral and Maxillofacial Pathology, Meenakshi Ammal Dental College, India.*)

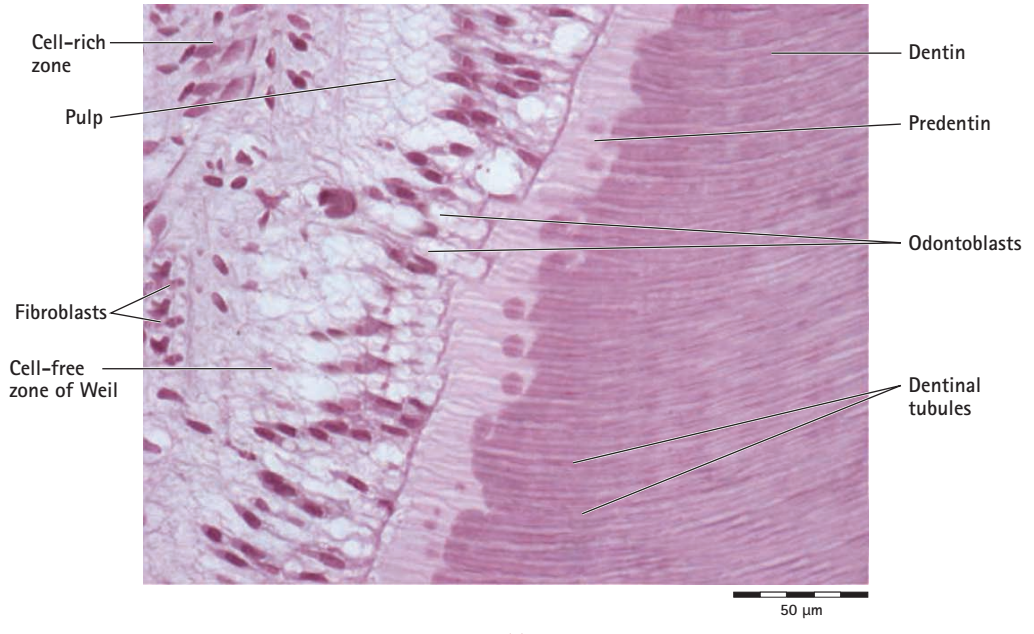
mesenchymal cells of the pulp or from the division of existing fibroblasts. The fibroblasts are stellate in shape, with ovoid nuclei and cytoplasmic processes. As they age, they become rounder, with round nuclei and short cytoplasmic processes. Although fibroblasts are present in the cell-free and central zones of the pulp, they are concentrated in the cell-rich zone, especially in the coronal portion.

The function of the fibroblasts is elaboration of ground substance and collagen fibers, which constitute the matrix of the pulp. The fibroblasts are also involved in the degradation of collagen and the deposition of calcified tissue. They can elaborate denticles and can differentiate to replace dead odontoblasts, with the potential for reparative dentin formation.

As compared to the coronal third, the apical third of the mature pulp contains more collagen fibers and is therefore more fibrous and has a whitish coloration. This fibrous characteristic of the apical third protects the neurovascular bundle from injury and is of clinical significance because it facilitates the removal of the pulp during pulpectomy. Because of the reduction of the pulp space through the continuous deposition of secondary dentin and because of the increased deposition of collagen, the pulp becomes more fibrous with age. Concomitantly, one sees a decrease in cellular elements and a reduction in the reparative potential of the pulp.

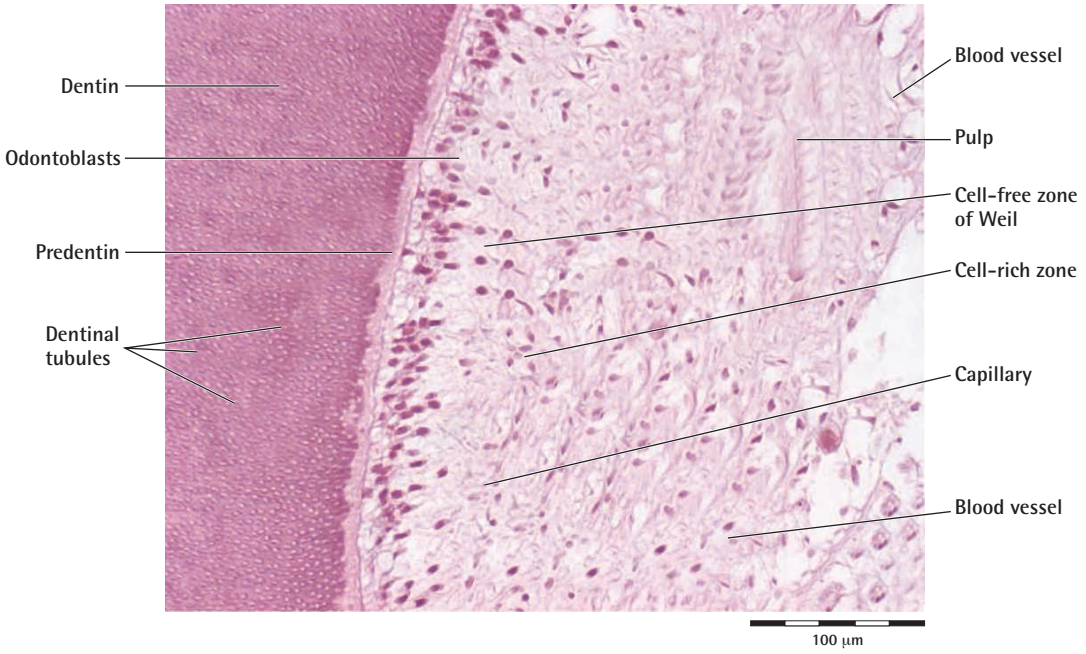


(a)



(b)

Figure 1.20 (a and b) Zones of pulp in a demineralized tooth, longitudinal section. The pulp (Latin *pulpa*) comprises loose connective tissue, blood vessels, and nerves. At higher magnification, you see that the concentration of cells close to the dentin is much higher than in the pulp in general. This "concentration of cells" is divided into three zones: the cell-rich zone, the cell-free zone of Weil, and the odontoblast layer. The predentin stains light pink/red, while the dentin stains pink/red. Within the predentins, you can see globules of mineralizing dentin. Dentinal tubules are seen throughout the dentin (stain: H + E). (*Courtesy: Mathias Nordvi, University of Oslo, Norway.*) *(continued)*



(c)

Figure 1.20 *(continued)* (c) Zones of pulp in a demineralized tooth, cross-section. If you take a look at the pulp, you can see the same structures as in "b." Try to compare the two images and bear in mind that this is a cross-section and "b" is a longitudinal section (stain: H + E). (*Courtesy: Mathias Nordvi, University of Oslo, Norway.*)

Undifferentiated Mesenchymal Cells

The undifferentiated mesenchymal cells are derived from the mesenchymal cells of the dental papilla. Because of their function in repair and regeneration, they retain pluripotential characteristics and can differentiate into fibroblasts, odontoblasts, macrophages, or osteoclasts. They resemble fibroblasts as they are stellate in shape, with a large nucleus and little cytoplasm. These cells, if present, are usually located around blood vessels in the cell-rich zone and are difficult to recognize.

Macrophages, Lymphocytes, and Plasma Cells

Macrophages are found in the cell-rich zone, especially near the blood vessels. These cells are blood monocytes that have migrated into the pulp tissue. Their function is to phagocytize necrotic debris and foreign materials. Lymphocytes and plasma cells, if present in the normal pulp, are found in the coronal subodontoblastic region. The function of these cells in the normal pulp may be immune surveillance.

IV. CENTRAL ZONE

The central zone or pulp proper contains blood vessels and nerves that are embedded in the pulp matrix together with fibroblasts. From their central location, the blood vessels (**Fig. 1.21**) and the nerves send branches to the periphery of the pulp.

BLOOD VESSELS OF PULP AND CIRCULATION

The neurovascular bundle enters the pulp through the apical foramina. It consists of one or two arterioles with their sympathetic nerve fibers and myelinated and unmyelinated sensory nerves entering the pulp, and two or three venules and lymphatic vessels exiting the pulp. In some teeth, accessory foramina may serve as portals of entry and exit for blood vessels only.

The pulpal blood flow mainly determines the speed of diffusion between the blood and the interstitial fluid; the higher the blood flow, the faster the diffusion. Regulation of an adequate blood flow is a crucial point for survival and normal function in any tissue.

i. *Afferent circulation* of the pulp consists of the arterioles entering the apical foramen. As these vessels traverse the center of the pulp, they branch into terminal arterioles, metarterioles, precapillaries, and finally capillaries. The capillaries end in the cell-poor zone and form a rich subodontoblastic plexus.

ii. *Efferent circulation* consists of postcapillary venules and collecting venules, which empty into two or three venules that exit through the apical foramina and empty into the vessels in the PDL. Lymphatic vessels follow this same pattern.

The function of blood vessels is to transport nutrients, fluids, and oxygen to the tissues and to remove metabolic waste from the tissues by maintaining an adequate flow of

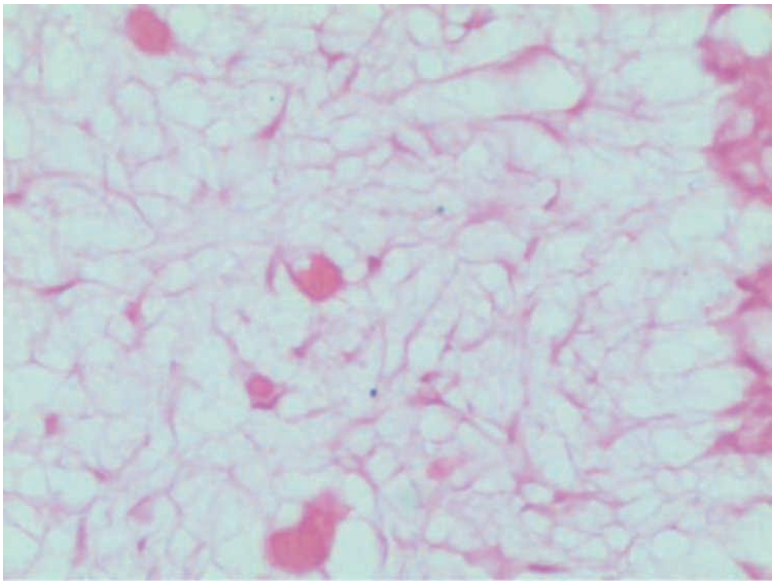


Figure 1.21 Centrally located blood vessels of the pulp.

blood through the capillaries. This metabolic exchange occurs in the capillary bed.

The transfer of nutrients and metabolic waste through the capillary walls is controlled by the laws of hydrostatics and osmosis. The walls of the capillaries are an average of 0.5 μm thickness and serve as a permeable membrane that permits the exchange of fluids. The absorption of metabolic wastes and fluids prevents their accumulation in the pulpal tissues and also precludes increases in the pulpal tissue pressure.

Clinical Note

In areas of pulpal injury, the permeability of the capillary walls permits the seepage of blood proteins into the pulpal tissues and increases the osmotic pressure of tissues of the area. This increase in osmotic pressure attracts more fluid to the area; the result is the stagnation of fluid known as *edema*.

Lymphatic Drainage of Pulp

Lymphatic vessels are present in the pulp. The function of these vessels is the removal of interstitial fluid and metabolic waste products to maintain the intrapulpal tissue pressure at a normal level. These lymphatic vessels follow the course of the venules toward the apical foramen.

Interstitial Fluid

Interstitial fluid bathes all the pulpal tissues and fills the dentinal tubules in their distal extension and around the odontoblastic processes. The interstitial fluid that fills the dentinal tubules is called the *dentinal fluid*. As previously discussed, the encasement of the pulp in dentin produces a limited environment permitting only a small amount of interstitial fluid.

Tissue Fluid Pressure

The hydrostatic pressure in the interstitial fluid surrounding the pulpal cells is called the pulpal tissue fluid pressure.

Clinical Note

- The presence of fluid in the pulpal cavity produces an average intrapulpal tissue pressure of approximately **10 mm Hg**.
- A small increase in intrapulpal pressure to **13 mm Hg** during inflammatory changes causes reversible changes in the pulp, but if intrapulpal pressure increases to **35 mm Hg**, it produces irreversible changes.
- Owing to the structural makeup of the matrix, in which the ground substance is reinforced by collagen fibers, the pulp seems to be *able to limit the area* of increased intrapulpal pressure during periods of inflammation.

Innervation of Pulp

The sensory mechanism of the pulp is composed of *sensory afferent* and *autonomic efferent* systems.

- The afferent system conducts impulses perceived by the pulp from a variety of stimuli to the cortex of the brain, where they are interpreted as pain, regardless of the stimulus (**Box 1.1**).
- The efferent motor pathway in the dental pulp consists of sympathetic fibers from the cervical ganglion that enter through the apical foramina in the outer layer of the arterioles, the tunica adventitia. The sympathetic nerves provide vasomotor control to circulation and therefore regulate the blood flow and intrapulpal blood pressure in response to stimuli.

Approximately 80% of the nerves of the pulp are **C fibers** and the rest are **Aδ fibers** (**Table 1.1**).

Box 1.1

Afferent Pain Pathway

Stimulated impulse travels from
C or Aδ fiber nerve endings
↓
The plexus of raschkow
↓
Nerve trunk in the central zone of the pulp that exits the tooth through the apical foramen
↓
Maxillary or the mandibular division of the trigeminal nerve
↓
Pons
↓
Thalamus
↓
Cortex
↓
Interpreted as pain

Clinical Note

The *hydrodynamic theory* explains the painful reaction of the pulp to heat, cold, cutting of the dentin, and probing of the dentin.

- Heat expands the dentinal fluid
- Cold contracts the dentinal fluid
- Cutting the dentinal tubules allows the dentinal fluid to escape
- Probing the cut or exposed dentinal surface may deform the tubules and produce fluid movement.

MINERALIZATIONS

The other histologic structures found in the dental pulp are mineralizations. Although their presence has been related to age and disease, they are also found in young normal dental pulps. They are present as:

- *Nodules called denticles* or *pulp stones*: The denticles are either true or false denticles, according to their histologic structure.
  - True denticles are uncommon, are usually found near the apex, and are composed of dentin or dentinal-type calcifications with tubules, surrounded by odontoblast-like cells.
  - False denticles (**Fig. 1.22**) are of two types histologically:
    - Round or ovoid with concentric calcified layers and smooth surfaces
    - Amorphous without lamination and rough surfaces

Pulp stones form under a number of different conditions. True pulp stones with the dentin structure probably form from fragmented portions of Hertwig's epithelium on the pulpal side. Odontoblasts may also be differentiated from the immature cells in the dental pulp and initiate histogenesis of denticles. Dentin fragments introduced into the pulp following pulpal exposures may act as foci for pulp stone formation.

- *Diffuse calcifications*: They usually follow the trajectory of the blood vessels, the nerves, and the collagen fiber bundles. They are most often found in the walls of blood

Table 1.1 Nerve Fibers of the Pulp: C and Aδ

C Nerve Fibers	Aδ Nerve Fibers
• C fibers are *unmyelinated* and fine sensory afferents. • C fibers have a diameter of 0.3–1.2 μm and a conduction velocity of 0.4–2 m/s. • The conduction of these fibers, which are of smaller diameter than Aδ fibers, is *slow*. • These fibers are probably distributed throughout the pulp tissue. With their receptive fields located in the pulp, C fibers transmit impulses that are experienced as *a dull, poorly localized*, and *lingering pain*; they conduct throbbing and aching pain associated with pulp tissue damage. • In addition to the nociceptive alarm signaling, the intradental sensory axons play a regulatory role in the maintenance and repair of the pulpodentinal complex. • ***Mechanism of stimulation:*** Inflammation that accompanies tissue injury leads to increase in tissue pressure and release of chemical mediators. This in turn stimulates the C fibers that result in pain.	• Most apical *myelinated* axons are fast-conducting Aδ fibers with their receptive fields located at the pulpal periphery and inner dentin. • The Aδ fibers have a diameter of 2–5 μm and a conduction velocity of 6–30 m/s. • The Aδ fibers, with a larger diameter than that of the C fibers, conduct impulses at a higher velocity. • They conduct impulses that are interpreted as a *short, well-localized, sharp*, and *pricking pain*. • The Aδ fibers are distributed in the odontoblastic and subodontoblastic zones and are associated with dentinal pain. • ***Mechanism of stimulation:*** Three theories have been proposed to explain the sensitivity of dentin. – *Direct stimulation theory:* The first is the direct stimulation of the nerve endings of the pulp; the lack of nerve endings at the periphery of the dentin negates this theory. – *Odontoblastic theory:* The second theory proposes that the odontoblasts function as nerve endings. This theory cannot be accepted, however, because no one knows for certain how far the odontoblastic processes extend in the dentinal tubules, and no evidence indicates that the odontoblasts are able to function as nerve endings. – *Hydrodynamic theory:* The third theory, the hydrodynamic theory, states that any fluid movement in the dentinal tubules and around the odontoblasts as the result of a stimulus excites the nerve endings and produces an impulse. This theory is the ***most acceptable*** of the three.

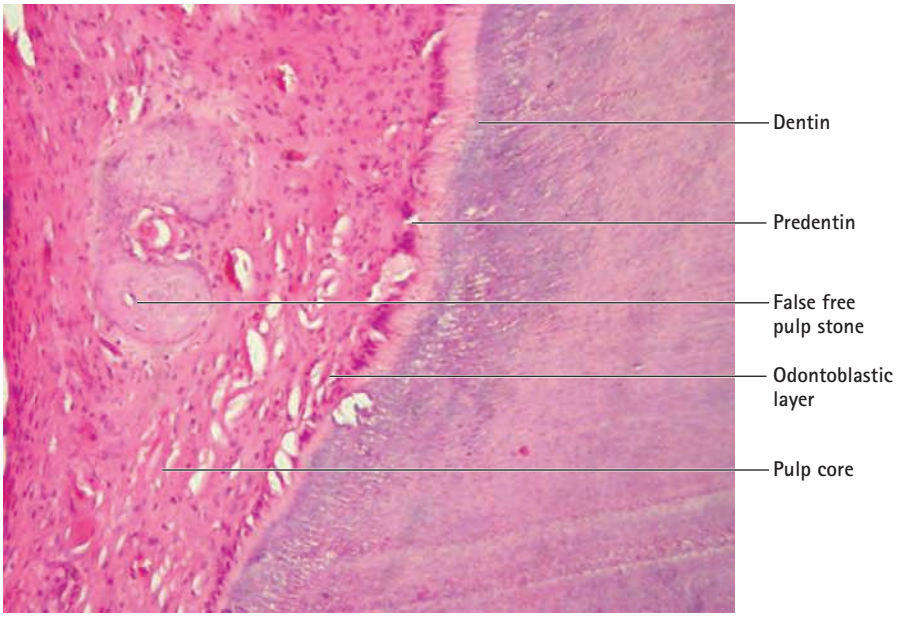


Figure 1.22 H+E-stained decalcified section of tooth showing dentin, predentin, odontoblastic layer, and false free pulp stone in pulp (10×). (*Courtesy: B. Sivapathasundharam and K. Manjunath, India.*)

vessels. Diffuse calcifications seem to be related to aging because their incidence increases with age.

Clinical Note

- The denticles predominate in the pulp chamber, whereas diffuse calcifications are predominantly found in the root canals.
- Radiographs may show denticles in the coronal chamber. This finding should alert the clinician to the possible need for removal of the denticles to obtain access into the orifices of the root canals.
- Calcifications in the root canals usually are not seen radiographically, but they are detectable during exploration of the root canal. This type of calcification may prevent the clinician from reaching the apical foramen and may therefore prevent complete instrumentation of the root canal.

EFFECTS OF AGING ON PULP

Age causes important changes in the pulp.

- The continuous deposition of secondary dentin throughout the life of the pulp and the deposition of reparative dentin in response to stimuli reduce the size of the pulp chambers and root canals and thereby decrease the pulp volume. This diminution of the pulp is called *atrophy*.
- A concomitant decrease in the diameter of the dentinal tubules by the continuous deposition of peritubular dentin also occurs.
- Some of these tubules close completely and form *sclerotic dentin*. The decrease in pulp volume reduces cellular, vascular, and neural content of the pulp. The odontoblasts undergo atrophy and may disappear completely under areas of sclerotic dentin.
- A reduction in the fluid content of the dentinal tubules is also seen. These changes make the dentin less permeable and more resistant to external stimuli.
- The fibroblasts are reduced in size and numbers, but the collagen fibers are increased in number and in size, probably because of the decrease in the collagen solubility and turnover with advancing age. This change is referred to as fibrosis. Fibrosis is more evident in the radicular portion of the pulp than elsewhere.
- The blood vessels decrease in number, and arteries undergo arteriosclerotic changes. Calcific material is deposited in the tunica adventitia and tunica media. These changes reduce the blood supply to the pulp.
- The number of nerves is also reduced.
- The ground substance undergoes metabolic changes that predispose it to mineralization. Changes in the blood vessels, nerves, and ground substance predispose the pulp to dystrophic calcifications.

PART 3: NORMAL PERIRADICULAR TISSUES

The periradicular tissues consist of the following:

- Cementum, which covers the roots of the teeth
- PDL, whose collagen fibers, embedded in the cementum of the roots and in the alveolar processes, attach the roots to the surrounding tissues (**Fig. 1.23**)
- Alveolar process, which forms the bony troughs containing the roots of the teeth

In the region of periradicular tissues, portals of entry and exit between root canals and the surrounding tissues are

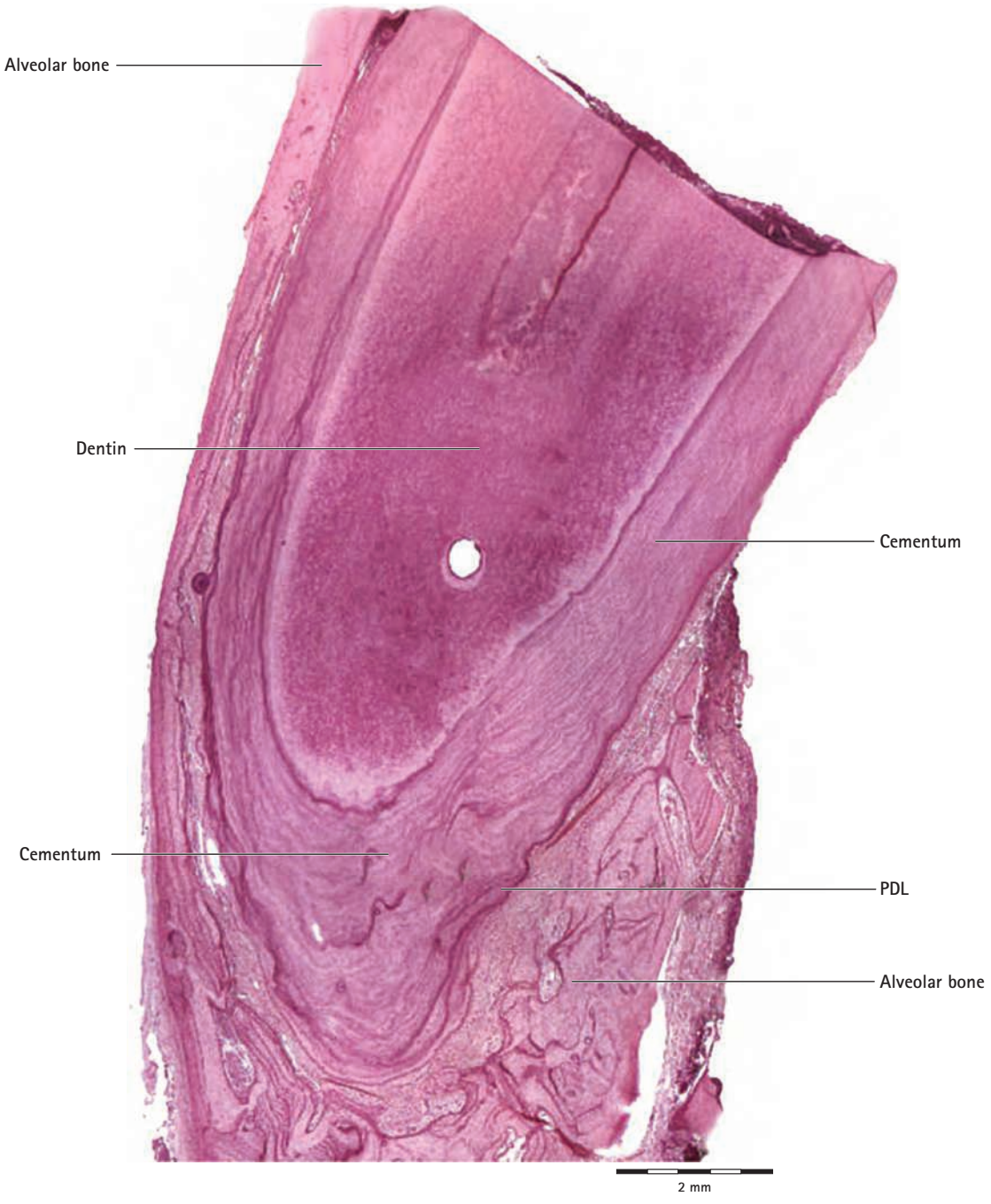


Figure 1.23 Root, apex. This is a longitudinal section of the apical part of a root. The apical supportive tissues are also shown. You may already have noticed the thick layer of cementum covering the dentin at the apex indicating that this tooth once belonged to an old individual. The cementum is mostly of the cellular type. Incremental lines can be seen and illustrate the "rhythmical" deposition of cementum (stain: H + E). (*Courtesy: Mathias Nordvi, University of Oslo, Norway.*)

located, and pathologic reactions to diseases of the pulp are manifested.

CEMENTUM

Cementum is a bone-like calcified tissue that covers the roots of the teeth. As previously discussed, it is derived from the mesenchymal cells of the dental follicle that differentiate into cementoblasts. The cementoblasts deposit a matrix, called cementoid, that is incrementally calcified and produces two types of cementum: acellular and cellular (**Fig. 1.11**).

Chronologically, the acellular cementum is deposited first against the dentin forming the cementodentinal junction, and as a rule, it covers the cervical and the middle thirds of the root. The cellular cementum is usually deposited on the acellular cementum in the apical third of the root and alternates

with layers of the acellular cementum. The cellular cementum is deposited at a greater rate than the acellular cementum and thereby entraps the cementoblasts in the matrix. These entrapped cells are called *cementocytes*. The cementocytes lie in the crypts of cementum known as lacunae (**Fig. 1.11**). From the lacunae, canals, called canaliculi, which contain protoplasmic extensions of the cementocytes and serve as pathways for nutrients to the cementocytes interlace with other canaliculi of other lacunae to form a system comparable to the Haversian system of bone. Because cementum is avascular, its nutrition comes from the PDL. As incremental layers of cementum are deposited (**Fig. 1.24**), the PDL may be further displaced, and some cementocytes may die as a result and may leave empty lacunae.



Figure 1.24 (a and b) This is a longitudinal section of the apical part of a root. Cellular and acellular cementum along with cementocytes and incremental lines can be appreciated (stain: H + E). (*Courtesy: Mathias Nordvi, University of Oslo, Norway.*)

The thickness of cementum reflects one of its functions. The greater thickness of cementum at the apex is due to its continuous deposition during the eruptive life of the tooth to preserve its height in the occlusal plane. The continuous deposition of cementum also gives form to the mature apical foramen. The foramen, as it matures, becomes conical, with the apex of the cone, called the minor diameter (constriction), facing the pulp and the base, called the major diameter, facing the PDL.

Clinical Note

- Cementum is about 20–50 µm thick at the cementoenamel junction and 20–150 µm thick in the apical third of the root.
- The continuous deposition of cementum increases the major diameter and results in an average deviation of the apical foramen of 0.2–0.5 mm from the center of the root apex.
- The minor diameter dictates the apical termination of root canal instrumentation and obturation and is located:
  - An average of 0.5 mm from the cemental surface in young teeth
  - An average of 0.75 mm from the cemental surface in mature teeth
- Although the cementodentinal junction may coincide with the minor diameter, cementum may grow unevenly and may alter this relationship.

The fibers of the PDL occur between the osteoblasts and cementoblasts and are embedded into the bone and cementum, respectively. These embedded fibers, called *Sharpey's fibers*, attach the PDL to bone and cementum.

Repair is another function of the cementum. Root fractures and resorptions are usually repaired by cementum. The closing of immature roots by apexification procedures is accomplished by deposition of cementum or cementum-like tissue. Cementum also has a protective function. It is more resistant to resorption than bone, probably because of its avascularity. As a result, orthodontic movement of roots can usually be performed with a minimum of resorptive damage. Other functions are the maintenance of the periodontal width by the continuous deposition of cementum and the sealing of accessory and apical foramina after root canal therapy.

PERIODONTAL LIGAMENT

The PDL is a dense, fibrous connective tissue that occupies the space between the cementum and the alveolar bone. It surrounds the necks and the roots of the teeth and is continuous with the pulp and gingiva (**Fig. 1.25**). The PDL is composed of ground substance, interstitial tissue, blood and lymph vessels, nerves, cells, and fiber bundles.

Variations in width occur from tooth to tooth and in different areas of the ligament in the same root. Teeth with heavy occlusal loads have wider PDLs than teeth with minimal occlusal loads, in which PDLs are thinner. With advancing age, the width of the PDL is reduced.

Clinical Note

The width of the PDL varies from 0.15 to 0.38 mm.

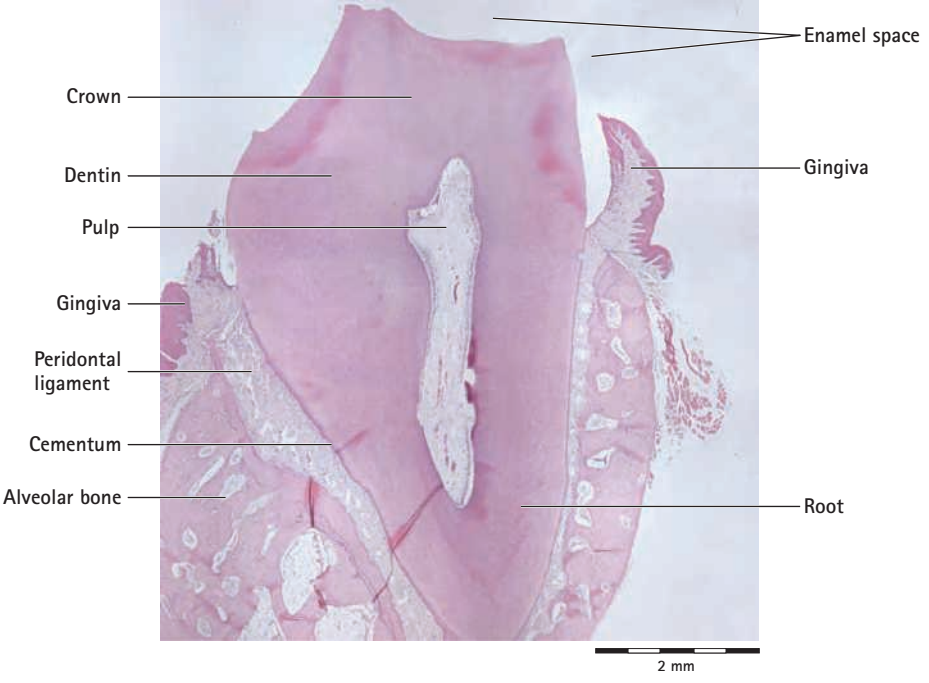


Figure 1.25 Tooth and its supportive structures. Longitudinal section: periodontal ligament, the alveolar bone, the pulp, and some parts of the gingiva (stain: H + E). (*Courtesy: Mathias Nordvi, University of Oslo, Norway.*)

INTERSTITIAL TISSUE

The interstitial tissue is the loose connective tissue that surrounds the blood vessels and the lymphatic vessels, nerves, and fiber bundles. This tissue contains collagen fibers independent of the fiber bundles of the PDL. Changes in its configuration are due to continuing changes in the fiber bundles. The spaces in the PDL, filled with interstitial tissue, blood vessels, lymph vessels, and nerves, are called interstitial spaces.

CELLS OF THE PERIODONTAL LIGAMENT

The active cells of the PDL are the fibroblasts, osteoblasts, and cementoblasts.

- *Fibroblasts* synthesize collagen and matrix and are involved in the degradation of collagen for its remodeling. The result is a constant remodeling of the principal fibers and maintenance of a healthy PDL. Because of these important functions, the fibroblasts are the most important cells of the PDL.
- *Osteoblasts*, or bone-forming cells, are found in the periphery of the PDL lining the bony socket. They are usually seen in various stages of differentiation. The function of osteoblasts is the deposition of collagen and matrix, which is deposited on the surface of the bone and to which Sharpey's fibers are attached. Calcification of the osteoid anchors Sharpey's fibers. The constant remodeling of bone provides for the continued renewal of the attachment of the PDL to bone.
- *Osteoclasts*, or bone-resorbing cells, are found in the bone periphery during periods of bone remodeling. They are multinucleated cells with a ruffle or striated border toward the area of bone resorption. As the osteoclasts demineralize and disintegrate the matrix, scooped-out areas in the bone, called Howship's lacunae, are formed. Osteoclasts are usually found in these lacunae. This pattern of resorption gives the border of the bone an irregular shape.
- *Cementoblasts*, as previously discussed, are aligned in the periphery of the PDL opposite the cementum. Their function is the deposition of a matrix consisting of collagen fibrils and ground substance called cementoid. Cementoid is found between the calcified cementum and the layer of cementoblasts that thickens in periods of activity. The fibers of the PDL are found between cementoblasts and are entrapped in the cementoid. As the cementoid calcifies, the fibers of the PDL become anchored in the newly formed cementum and are called *Sharpey's fibers*, the same as PDL fibers anchored in bone. Cementoid may protect the cementum against erosion.
- *Cementoclasts*, or cementum-resorbing cells, are not found in the normal PDL because cementum does not normally remodel. They are found only in patients with certain pathologic conditions.
- Other cells present in the normal PDL are the epithelial cell rests of Malassez, undifferentiated mesenchymal cells, mast cells, and macrophages. The *epithelial cell rests of Malassez* are remnants of the Hertwig's epithelial root sheath. These cells are located in the cementum side of the PDL. Their function is unknown, but they can proliferate to form cysts in the presence of noxious stimuli.
- *Undifferentiated mesenchymal cells* are usually stellate cells with large nuclei located near the blood vessels. These cells may differentiate into fibroblasts, odontoblasts, or cementoblasts.

PERIODONTAL FIBERS

The periodontal fibers are the principal structural components of the PDL. Two types are known: *collagen* and *oxytalan* fibers. Collagen fibrils are organized into fibers, which, in turn, are organized into bundles. The fibers that constitute the bundles are not continuous from bone to cementum, but consist of strands that can be continually and individually remodeled by fibroblasts without causing loss of the continuity of the bundles. The terminal fibers of the bundles insert into cementum on one side and bone on the other side. These terminal fibers are called *Sharpey's fibers* regardless of cementum or bone insertion. The fibers are arranged in bundles with a definite functional arrangement. These bundles follow an undulating course that allows some movement of the tooth in its alveolar socket.

The fiber bundles are arranged into principal fiber groups: trans-septal, alveolar crest, horizontal, oblique, apical, and inter-radicular.

- The *trans-septal group* is embedded into the cementum of adjacent teeth traversing the alveolar crest interproximally.
- The *alveolar crest group* is embedded into the cementum below the cementoenamel junction, is situated obliquely, and ends in the alveolar crest.
- The *horizontal group* is embedded into the cementum apical to the alveolar crest group and moves horizontally into the alveolar bone.
- The *oblique group* is embedded into the cementum apically to the horizontal group and travels obliquely in a coronal direction to be embedded into the alveolar bone.
- The *apical group* is embedded into the apical cementum and the fundus of the alveolar socket.
- The *inter-radicular group* is embedded in cementum and alveolar bone of the furca of multirooted teeth.

The functions of the fibers of the PDL are to attach the tooth to its alveolar socket, to suspend it in its socket, to protect the tooth and the alveolar socket from masticatory injuries, and to transform vertical masticatory stresses into tension on the alveolar bone.

INNERVATION

The alveolar nerves which originate in the trigeminal nerve innervate the PDL. They are divided into ascending periodontal or dental, interalveolar, and inter-radicular nerves.

The nerves of the PDL, as in any other connective tissue, follow the distribution of the arteries. The alveolar branches innervate the apical region, the interalveolar branches innervate the lateral PDL, and branches of the inter-radicular nerve innervate the furcal PDL of the posterior teeth.

The nerve endings of the PDL enable one to perceive pain, touch, pressure, and proprioception. *Proprioception*, which gives information on movement and position in space, enables one to perceive the application of forces to the teeth, movement of the teeth, and the location of foreign bodies on or between the surfaces of the teeth. This proprioceptive sense may trigger a protective reflex mechanism that opens the mandible to prevent injury to the teeth or PDL when one bites into a hard object. Proprioception permits the localization of areas of inflammation in the PDL. Such inflammatory reactions in the PDL can be identified by percussion and palpation tests.

ALVEOLAR PROCESS

The alveolar process is divided into the alveolar bone proper and the supporting alveolar bone.

ALVEOLAR BONE PROPER

The alveolar bone proper is the bone that lines the alveolus or the bony sockets that house the roots of the teeth. It begins its formation by intramembranous ossification at the initial stage of root formation. The osteoblasts at the periphery of the PDL deposit an organic matrix called osteoid, which consists of collagen fibrils and ground substance that contains glycoproteins, phosphoproteins, lipids, and proteoglycans. As the osteoblasts deposit the matrix, some are trapped in it; these cells are called osteocytes. The matrix is calcified by the deposition of hydroxyapatite crystals consisting principally of calcium and phosphates.

The osteocytes in calcified bone lie in the oval spaces, called lacunae, which communicate with each other by means of canaliculi. This system of canals brings nutrients into the osteocytes and removes their metabolic waste products.

The alveolar bone proper consists of bundle bone in the periphery of the alveoli and lamellated bone toward the center of the alveolar process. The peripheral bone is called bundle bone because Sharpey's fibers of the PDL are embedded in it. Because the peripheral Sharpey's fibers may be calcified, and because lamellae are almost indistinct, this bone is thick and has a more radiopaque appearance in radiographs than cancellous bone or PDL spaces. The radiographic image of the alveolar bone proper is called the *lamina dura*.

The alveolar bone proper can also be referred to as the cribriform plate. This term refers to the many foramina that perforate the bone. These foramina contain vessels and nerves that supply teeth, PDL, and bone.

SUPPORTING ALVEOLAR BONE

Adjacent to the alveolar bone proper is cancellous (spongy) bone covered by two outer tables of compact bone. One of the outer tables of compact bone is vestibular and the other is lingual or palatal. The cancellous bone consists of lamellated bone arranged in branches called the trabeculae. Between the trabeculae are the medullary spaces, filled with the marrow. The marrow can be fatty or hematopoietic. In adults, the marrow in the mandible and maxilla is usually fatty, but hematopoietic tissue is found in certain locations such as the maxillary tuberosity, maxillary and mandibular molar periradicular areas, and premolar periradicular areas. Hematopoietic marrow spaces appear *radiolucent i*n radiographs.

Also present in the cancellous bone are the nutrient canals. These canals contain vessels and nerves. They usually terminate in the alveolar crest in small foramina through which vessels and nerves enter the gingiva.

The amount of cancellous bone varies among areas of the maxilla and mandible and depends on the width of the alveolar process and the size and shape of the root of the teeth.

The cortical (compact) bone covers the cancellous bone and is formed by the lamellated bone. This lamellated bone has lacunae arranged in concentric circles around central canals called the Haversian system. The cortical bone comes together with the alveolar bone proper to form the alveolar crest around the necks of the teeth.

Bone serves as the calcium reservoir of the body. The body, under hormonal control, regulates and maintains calcium metabolism. Therefore, constant physiologic remodeling of bone by osteoclastic and osteoblastic activity occurs. This activity can be seen more readily in the trabeculae. The trabecular pattern is constantly altered in response to the occlusal forces. In the trabeculae are resting lines, which are characteristic of periods of osteoblastic activity, and resorptive lines, which are characteristic of periods of osteoclastic activity. Resting lines are characteristically dark lines parallel to the surface, whereas resorptive lines are scalloped and point to the areas of resorption known as Howship's lacunae.

Diseases of the pulp can affect the tissues of the periradicular area. Acute inflammatory changes in the PDL that originate in the pulp produce extrusion of the tooth. The chronic inflammatory changes of pulpal origin in the PDL can cause resorption of the lamina dura, external root resorption, areas of bone resorption, or areas of bone condensation. Systemic diseases may also produce bony changes in the periradicular area. These pathologic changes are discussed in Chapter 3 and 4.

The reader is advised that the discussions in the chapter on embryology, normal pulp, and normal periradicular tissues are intended as a review of embryology, physiology, and histology as they apply to the clinical science of endodontics. The reader is referred to standard textbooks on these subjects for more comprehensive and detailed discussion.

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2 Endodontic Microbiology

What you see is that the most outstanding feature of life's history is the constant domination by bacteria.
—Stephen Jay Gould

HISTORICAL BACKGROUND

- *1901:* **Onderdenk** suggested the need for bacteriologic examination of the root canal.
- *1910:* **Hunter** proposed the focal infection theory, in which he condemned the ill-fitting crowns and bridgework of his day that inexplicably resulted in the extraction of countless numbers of treated pulpless teeth.
- *1931:* **Coolidge** suggested that bacteriologic examination be used in treating the root canal.
- *1936:* **Fish and MacLean** demonstrated that the pulp and periapical tissues of vital healthy teeth are invariably free of the evidence of microorganisms when examined histologically.
- *1939:* Histologic studies of repair were reported by **Kronfeld**.
- *1965:* Classic study of **Kakehashi and colleagues**, who reported that exposed pulps in gnotobiotic rats healed without treatment in a germ-free environment.
- **1981: Moller** did study on monkey's teeth and proved that facultative anaerobic streptococci, coliform rods, and obligate anaerobic bacterial strains were most frequently found in necrotic pulp.
- **1987: Nair** demonstrated the presence of dense aggregates (clusters) of bacterial cells attached to the dentinal wall of the root canal in teeth associated with apical periodontitis.
- **1992: Sundqvist** studied the cooperative as well as antagonistic nature of the relationships between bacteria in the root canal.
- **2006: Anil Kishen** explained about *Enterococcus faecalis*–mediated biomineralized biofilm formation on root canal dentin.
- **2007: Chávez de Paz** studied the response to stress by root canal bacteria in biofilms.

In the last few decades, many reports have been published on the bacterial flora of the pulp and periapical and periodontal tissues, the pathways of infection, the immunologic reactions, and the inflammatory responses. Although treatment procedures have changed radically, they reflect a better understanding of the host–parasite relationship and of the way in which such reactions are managed more effectively.

Clinical Note

- Microorganisms virtually cause all the diseases of the pulpal and periapical tissues.
- Endodontic infection is the infection of the root canal system and is the major etiologic factor of apical periodontitis.
- The root canal infection usually develops after pulpal necrosis that can occur as sequelae of caries, trauma, periodontal diseases or operative procedures.

TERMINOLOGIES

- *Microbiota:* A collective term for microorganisms
- *Diversity:* Refers to the number of different species present and their relative abundance in a given ecosystem
- *Pathogenicity:* Ability of a microorganism to cause disease
- *Virulence:* Denotes the degree of pathogenicity of a microorganism
- *Virulence factors:* Microbial products, structural components, or strategies that contribute to pathogenicity
- *Obligate anaerobes:* Microorganisms that grow only in the absence of oxygen
- *Facultative anaerobes:* Microorganisms that are normally anaerobic but can also grow in the presence of oxygen
- *Microaerophilic:* Microorganisms that grow best in the presence of low oxygen tension

BACTERIAL PATHWAYS INTO THE PULP

Bacteria enter the pulp in various ways:

- *Dentinal tubules* following carious invasion
- *Crown or root* following traumatic exposure of the pulp
- *Coronal leakage* following restorative procedures and restorations
- *External or internal resorption* that can lead to pulp exposures
- *Periodontal tissue* through exposed dentinal tubules, lateral and accessory canals, or apical and lateral foramina
- *Lymphatic or hematogenous route* (anachoresis, defined as the localization of transient bacteria in the blood into an inflamed area, such as traumatized or inflamed pulp)

SEQUELAE OF MICROBIAL INFECTION OF PULP SPACE

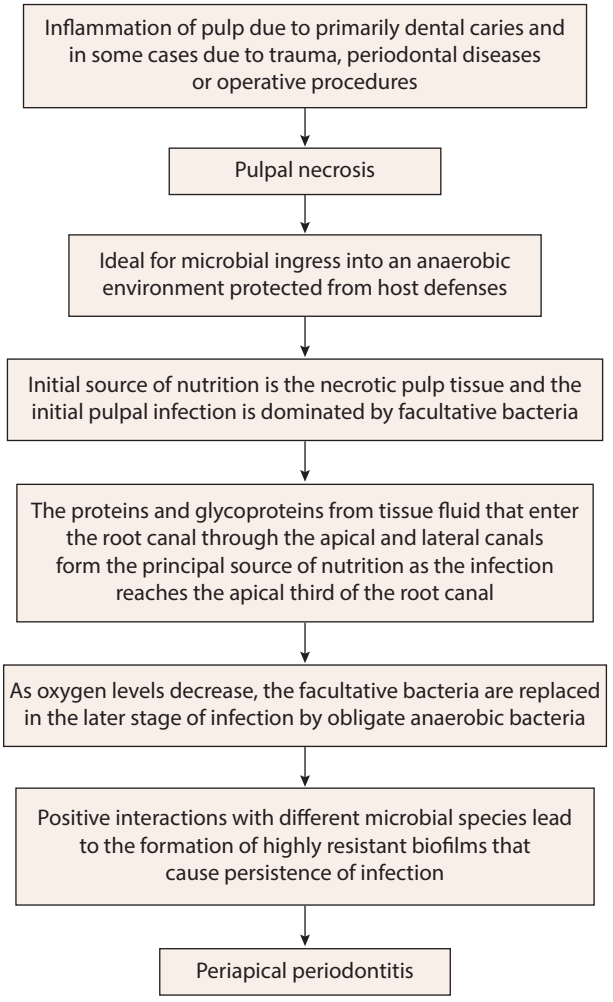
The sequelae following invasion of the pulp space by microorganisms is given in **Flowchart 2.1**.

RATE OF BACTERIAL INVASION

Nagaoka found that rate of bacterial invasion increased with the passage of time, and that it was approximately 1.6 µm/day during the first 25 days and 14 µm/day by 120 days. The deepest bacterial invasion was 3.0 mm after 210 postoperative days.

Many researchers believe that bacterial invasion from the exposed dentinal surface into the dentinal tubules is less extensive in vital teeth than in nonvital teeth. The degree of invasion is based on various suggested factors such as:

(a) Odontoblastic process and collagen fibers in the dentinal tubules:
It forms an effective physical barrier against bacterial invasion in the vital tooth but in nonvital tooth, this barrier diminishes as the processes degenerate.



Flowchart 2.1 Sequelae of microbial infection of pulp space.

(b) Dentin permeability:
It is an extremely important factor in the mechanism of bacterial invasion. It decreases with the passage of time in vital teeth due to diminishing tubular diameter but remained unchanged in the nonvital teeth.

(c) Movement of dentinal fluid:
Outward fluid flow in the dentinal tubules as a result of intrapulpal pressure may mechanically hinder bacterial growth into the dentin to a lesser extent.

ENDODONTIC MICROBIOTA

The bacterial flora of the root canal has been studied over many years. More than *300 to 700 species* of bacteria are recognized as normal inhabitants of the oral cavity with 500 species seen in endodontic infections. Out of 15 phyla in the oral cavity, 9 phyla are seen in root canal infections. Generally, all bacteria that inhabit the oral cavity have the ability to invade the pulp space during and after pulp necrosis to participate in the infection of the canal and to enter the periapical tissues, leading to periapical periodontitis.

BACTERIA

Bacterial profiles of endodontic microflora vary from individual to individual, suggesting that apical periodontitis has a heterogeneous etiology where multiple bacterial combinations can play a role in root canal disease causation.

The root canal flora is dominated by *anaerobic bacteria*, of which a restricted group is present in infected root canals.

- *Gram-positive* organisms (75%) are present in infected root canals, with most predominant being streptococci (28%), staphylococci (15%), corynebacteria (10–25%), yeasts (12%), and others.
- *Gram-negative* bacteria (24%) include spirochetes (9–12%), Neisseriae (4%), *Bacteroides* (7%), fusobacteria (3%), *Pseudomonas* (2%), coliform bacteria (1%), and others.
- Researchers have confirmed that *Tannerella forsythia* is a common member of microbiota associated with endodontic infections including abscesses, using polymerase chain reaction (PCR) techniques.
- *Fusobacterium nucleatum* has also been identified as a commonly encountered gram-negative organism with five subspecies, namely, *fusiforme*, *nucleatum*, *polymorphum*, *vincentii*, and *animalis*.

FUNGI

- Fungi are eukaryotic microorganisms that include yeasts and molds.
- The most common fungal species present in the oral cavity is from *Candida* genus, e.g., *Candida albicans*.
- Fungi are rarely seen in primary intraradicular infections and are more frequently seen in post-treatment apical periodontitis.

Clinical Note

- The average number of bacterial cells in endodontic infections is 10^3–10^8 *per root canal*.
- Modern culture techniques and molecular biology have revealed the *polymicrobial nature of endodontic infections* with a conspicuous dominance of *obligate anaerobic bacteria* in primary infections (**Box 2.1**).
- *Facultative anaerobic bacteria*, such as streptococci, are a significant part of the flora, especially in the coronal part of the root canal in carious teeth with exposed pulp chambers.
- The taxonomy of root canal flora has been reviewed and reclassified in **Box 2.2**. The black, pigmented, gram-negative anaerobic rods, formerly known as *Bacteroides*, have been reclassified:
  - Saccharolytic species has been transferred to the genus *Prevotella.*
  - Asaccharolytic species has been transferred to the genus *Porphyromonas*.

Box 2.1

Bacterial Genera Commonly Occurring in Endodontic Infections

Bacteria Morphology	Obligate Anaerobes	Facultative Anaerobes
Gram-positive cocci	*Finegoldia* *Peptoniphilus* *Peptostreptococcus*	*Enterococcus* *Staphylococcus* *Streptococcus*
Gram-negative cocci	*Veillonella*	*Neisseria*
Gram-positive rods	*Actinomyces* *Eggerthella* *Eubacterium* *Filifactor* *Lactobacillus* *Propionibacterium*	*Actinomyces* *Corynebacterium* *Lactobacillus* *Propionibacterium*
Gram-negative rods	*Alloprevotella* *Bacteroides* *Camphylobacter* *Dialister* *Fusobacterium* *Porphyromonas* *Prevotella* *Tannerella* *Treponema*	*Capnocytophaga* *Eikenella* *Haemophilus*

CLASSIFICATION OF ENDODONTIC INFECTIONS

Endodontic infections are classified according to the location of infection in relation to the root canal:

I. Intraradicular infections
II. Extraradicular infections

I. INTRARADICULAR INFECTIONS

Intraradicular infections are characterized by the presence of microorganisms within the root canal system. They are classified as primary, secondary, and persistent infections according to the time of organism entry into the canal.

Box 2.2

Taxonomic Changes for Former *Bacteroides* Species

Present Designation	Former Designation
Porphyromonas asaccharolytica	*Bacteroides asaccharolyticus*
Porphyromonas gingivalis	*Bacteroides gingivalis*
Porphyromonas endodontalis	*Bacteroides endodontalis*
Prevotella intermedia	*Bacteroides intermedius*
Prevotella melaninogenica	*Bacteroides melaninogenicus*
Prevotella denticola	*Bacteroides denticola*
Prevotella loescheii	*Bacteroides loescheii*

1. Primary Intraradicular Infections (Fig. 2.1)

Primary intraradicular infections are caused by microorganisms that initially invade and colonize the necrotic pulp tissue.

They are characterized by a mixed consortium dominated by anaerobic bacteria, particularly:

(a) Gram- negative anaerobes such as *Prevotella, Fusobacterium, Tannerella, Dialister, Porphyromonas, Campylobacter*, and *Treponema*. *Prevotella* species, especially *P. intermedia*, *P. nigrescens*, *P. tannerae*, *P. multisaccharivorax*, *P. baroniae*, and *P. denticola,* have been frequently isolated from primary endodontic infections.
(b) Gram-positive anaerobes from genera *Peptostreptococcus*, *Eubacterium*, *Actinomyces*, and facultative or microaerophilic *streptococci* can also be commonly found in primary intraradicular infections.

Bacterial cells from endodontic biofilms penetrate the dentinal tubules reaching approximately 250–300 µm in some teeth. The diameter of dentinal tubules ranges from

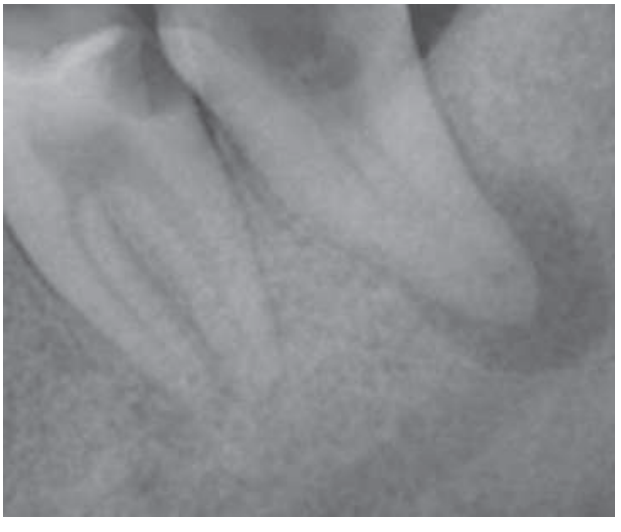


Figure 2.1 Primary intraradicular infection with periradicular radiographic changes.

0.9 µm at the dentinoenamel junction to 2.5 µm near the pulp. The small diameter of bacteria (0.3-0.8 µm for most species) allows them to penetrate into the dentinal tubules.

2. Secondary Intraradicular Infections

Secondary intraradicular infections are caused by microorganisms that were not present in the primary infection, but were introduced in the root canal at some time after professional intervention (secondary to intervention).

Pseudomonas aeruginosa, *Staphylococcus* sp., *Escherichia coli*, *Candida* sp., and *E. faecalis* are commonly found in such infections (**Box 2.3**). Microorganisms can penetrate the pulp space system even after the completion of root filling (**Fig. 2.2**).

3. Persistent Intraradicular Infections

Persistent intraradicular infections are caused by microorganisms that resisted the intracanal antimicrobial procedures. These microbes endure periods of nutrient deprivation in a prepared canal.

- However, fewer species are present than primary infections.
- Higher frequencies of fungi (*Candida* species) are present than in primary infections.
- Gram-positive facultative bacteria, particularly *E. faecalis* (**Fig. 2.3**), are predominant in such cases. Rocas et al. had detected that root-canal-treated teeth are 9 times more likely to harbor *E. faecalis* than cases of primary intraradicular infections.

Enterococcus faecalis

- *E. faecalis* is a gram-positive, facultative anaerobic coccus that is strongly associated with endodontic infections



Figure 2.2 Radiographic appearance of a secondary intraradicular infection in a root-filled tooth.

Box 2.3

Microbiota of Primary Endodontic Infections (Untreated Infected Root Canals), Secondary Endodontic Infections (Retreatment) and Extraradicular Infections

I. Microbiota in primary endodontic infections

Prevotella
- *P. intermedia, P. nigrescens, P. tannerae, P. baroniae, and P. denticola*

Porphyromonas
- *P. endodontalis, P. gingivalis*

Tannerella forsythia (Bacteroides forsythus)

Dialister

Fusobacterium
- *F. nucleatum*

Spirochetes

Treponema
- *T. denticola*
- *T. socranskii*

Streptococcus

Pseudoramibacter alactolyticus

II. Microbiota in secondary endodontic infections

Streptococci
- *S. mitis*
- *S. gordonii*
- *S. anginosus*
- *S. sanguinis*
- *S. oralis*

Actinomyces
- *A. israelii*
- *A. odontolyticus*

Propionibacterium
- *P. acnes*
- *P. propionicum*

Lactobacilli
- *L. paracasei*
- *L. acidophilus*

Enterococcus
- *E. faecalis*

Staphylococci

Fusobacterium
- *F. nucleatum*

Prevotella species

Dialister

Lesser extent

Bifidobacterium* species, *Eubacterium* species, Staphylococci, *Campylobacter rectus, Candida albicans

III. Microbiota in extraradicular infections

Actinomyces species
- *A. israelii*
- *A. odontolyticus*
- *A. naeslundii*
- *A. viscosus*

Propionibacterium
- *P. acnes*
- *P. propionicum*

Porphyromonas
- *P. gingivalis*

Prevotella
- *P. intermedia*
- *P. oralis*

Fusobacterium
- *F. nucleatum*

Spirochetes

Fungi
- *Candida albicans*

Viruses
- *Human cytomegalovirus (HCMV)*
- *Epstein–Barr virus (EBV)*



Figure 2.3 *Enterococcus faecalis*.

- *E. faecalis* is a persistent organism that, despite making up a small proportion of the flora in untreated canals, plays a major role in the etiology of persistent periradicular lesions after root canal treatment.
- It is commonly found in a high percentage of root canal failures and is able to survive in the root canal as a single organism or as a major component of the flora.
- They can grow in extremely alkaline pH, salt-concentrated environment, in a temperature range of 10–45°C, and survive a temperature of 60°C for 30 minutes.
- The prevalence of *E. faecalis* is 40% in primary endodontic infection and 24%–77% in persistent endodontic infection.
- Although *E. faecalis* possesses several virulence factors, its ability to cause periradicular disease stems from its ability to survive the effects of root canal treatment and persist as a pathogen in the root canals and dentinal tubules of teeth (**Box 2.4**).

Clinical Note

E. faecalis biofilm is 1000 times more resistant to phagocytosis, antibodies, and antimicrobials. (intracanal dressings like calcium hydroxide)

II. EXTRARADICULAR INFECTIONS

If microorganisms invade the periradicular tissues overcoming the defense mechanisms of the body, then extraradicular infection occurs.

The most common species are *Actinomyces, Streptococcus, and P. propionicum.*

The extraradicular infection is dependent on or independent of intraradicular infection:

(a) **Extraradicular infection dependent on intraradicular infection**
This infection occurs if microorganisms invade the periradicular tissues overcoming the defense mechanisms of the body or debris extrusion due to over-instrumentation. Acute alveolar abscess is an example of extraradicular extension or a sequel to intraradicular infection.

(b) **Extraradicular infection independent of intraradicular infection**
Actinomyces species have been found in association with unhealed periapical lesions and may be one of the causes of extraradicular infection, e.g., periapical actinomycosis.

Box 2.4

Survival and Virulence Factors of *E. faecalis*

- Endures prolonged periods of nutritional deprivation [viable but not cultivable (VBNC) state]
- Binds to dentin and invades dentinal tubules
- Alters host responses
- Suppresses the action of lymphocytes
- Possesses lytic enzymes, cytolysin, aggregation substance, pheromones, and lipoteichoic acid
- Utilizes serum as a nutritional source
- Resists intracanal medicaments [i.e., $Ca(OH)_2$]
- Competes with other cells
- Forms a biofilm
- Virulence factors—hemolysin, gelatinase, extracellular superoxide, and aggregation substance

BIOFILMS

Definition: *Biofilm is defined as a community of microcolonies of microorganisms in an aqueous solution that is surrounded by a matrix made of glycocalyx, which also attaches the bacterial cells to a solid substratum* (**Fig. 2.4**).

Composition: A biofilm consists of approximately 15% of microorganism colonies and 85% of extracellular polymeric

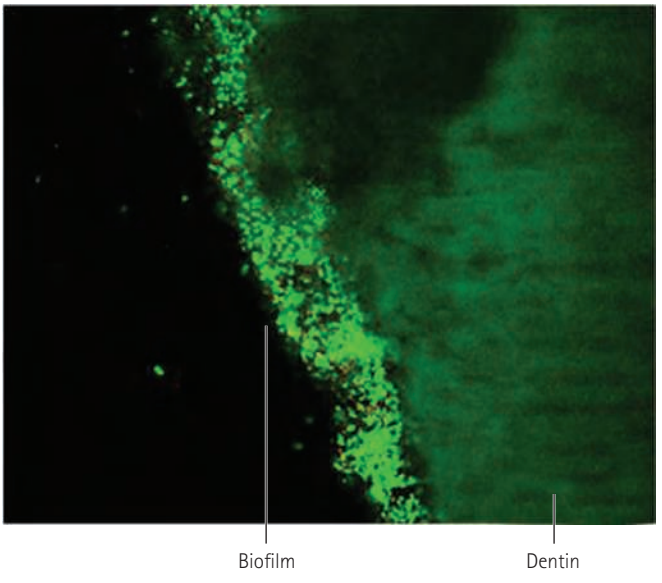


Figure 2.4 Laser scanning confocal microscopy showing intracanal biofilm of *E. faecalis*. (*Courtesy: Anil Kishen, University of Toronto.*)

substance (EPS) matrix. Microbes produce EPS such as proteins (<1–2% including enzymes), DNA (<1%), polysaccharides (1–2%), and RNA (<1%), and in addition to these components, water (up to 97%) is the major part of biofilm which is responsible for the flow of nutrients inside biofilm matrix.

There are four distinct stages in the development of a biofilm, namely:

- Formation of a conditioning layer
- Planktonic bacterial cell attachment
- Detachment (seeding dispersal)
- Bacterial growth and biofilm expansion

CLASSIFICATION OF BIOFILMS

Endodontic biofilms can be classified as follows:

I. **Intracanal biofilms**
II. **Extraradicular biofilms**
III. **Periapical biofilms**
IV. **Biomaterial-centered infections**

I. Intracanal Microbial Biofilms

These are biofilms that are formed on the radicular dentin in an endodontically infected tooth (**Fig. 2.5**). Various distinct types of bacteria can develop these biofilms, but *E. faecalis* is responsible for one of the most therapy- resistant and prevalent endodontic biofilms.

II. Extraradicular Microbial Biofilms

Root surface biofilms are those that form on the cemental surface around the root apex of an endodontically infected tooth (**Fig. 2.6**).

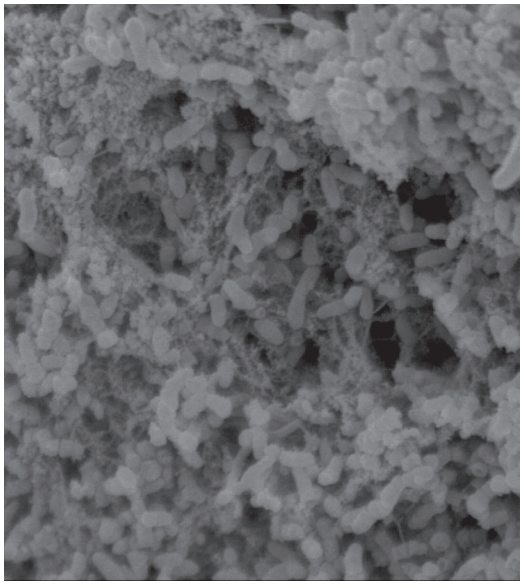


Figure 2.5 Scanning electron microscopic (SEM) image of a bacterial biofilm. (*Courtesy: Anil Kishen, University of Toronto.*)

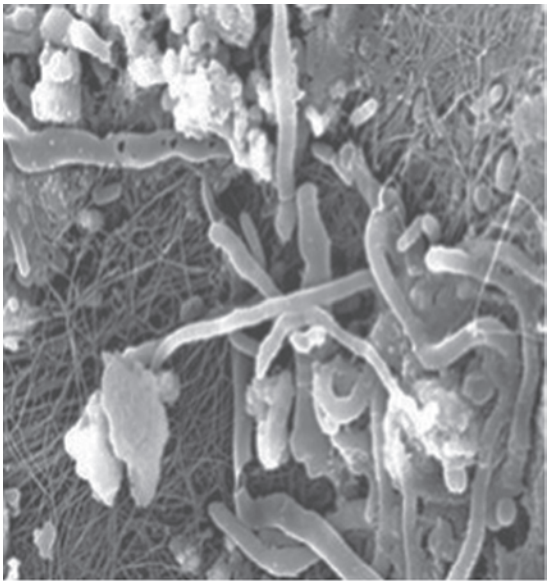


Figure 2.6 Scanning electron microscopic (SEM) image of an extraradicular biofilm: multi species biofilm on cementum. (*Courtesy: Anil Kishen, University of Toronto.*)

III. Periapical Microbial Biofilms

These are isolated biofilms which are independent of the internal or external surface of the root canal. *Actinomyces* and *P. propionicum* have been shown to form periapical lesions resistant to endodontic therapy.

IV. Biomaterial-Centered Infection

These kind of biofilms occur when bacteria adhere to an artificial biomaterial surface and form biofilm structures. It is also known as foreign body–centered biofilm.

ENDODONTIC BIOFILMS

Endodontic biofilms are therapeutically significant as they are one of the basic survival methods employed by bacteria in times of starvation. Thus, these biofilms are responsible for endodontic failures. Endodontic biofilms help the bacteria to survive because of the following qualities:

i. Ability to protect the bacteria from the environment
ii. Ability to entrap nutrients for the growth of microbial constituents
iii. They offer a safe environment for the exchange of genetic material among the constituent bacterial colonies
iv. The biofilm structure offers an inherent resistance to antimicrobial agents such as endodontic irrigants and intracanal medicaments

Antimicrobial Resistance of Biofilm

A biofilm has the following attributes that make it resistant to clinical therapy:

i. **Slow penetration of antimicrobial agents:** The polysaccharide matrix (EPS) in biofilms retards diffusion of antimicrobial agents.

ii. **Enhanced tolerance to antimicrobials:** Higher density of cells (Quorum sensing)/persister (dormant/resistant) cells.
iii. **Arrangement of cells:** Microorganisms interiorly are protected from medicaments that act on the microorganisms in the biofilm's periphery.
iv. **Growth rate of cells in biofilm:**
    - Reduced growth rate and nutrition requirement of the resistant cells

Clinical Note

Quorum sensing
Quorum sensing is a process of cell–cell communication (bacterial talk) that allows bacteria to share information about cell density and adjust gene expression. Using chemical signaling molecules called autoinducers (AIs), bacteria are able to communicate with one another.

METHODS OF MICROBIAL IDENTIFICATION

I. Culture methods
II. Molecular biology methods
III. Others
    (a) Microscopy
    (b) Immunologic methods

I. CULTURE OF MICROORGANISMS

- Culturing the microbial organisms has been the traditional means of examining endodontic microbiota. It is the cultivation and propagation of microorganisms in artificial and favorable laboratory conditions. The currently available culture media and techniques used to grow root canal microorganisms may not be perfect when compared to newer molecular biology methods (**Table 2.1**).
- *Culture media:* Brain heart infusion broth with 0.1% agar, trypticase soy broth with 0.1% agar (TSA), thioglycolate, and glucose ascites broth.

Table 2.1 Comparison of Microbial Identification Methods

Culture Methods	Molecular Biology
Advantages	
• Broad range in nature • Allow quantification of cultivable microorganisms • Widely available	• High specificity and sensitivity • Detects both cultivable and as-yet uncultivable species • Does not require anaerobic conditions
Disadvantages	
• Technique sensitive • Expertise and specialized equipment required • Time consuming	• Most assays detect one or few species at a time • Laborious • Expensive

Advantages

Widely available and, because of their broad-range nature, can help in the identification of unexpected species. They remain as valuable tools that guide and improve our understanding of the pathogenesis of diseases.

Limitations

Low sensitivity and is an error-prone technique due to the problem of sample contamination. This technique is time consuming and laborious in identifying most anaerobic bacteria.

Clinical Note

A microorganism culture of the root canal prior to obturation is *no longer recommended in clinical practice* for the following reasons:
- Studies have shown no significant difference between success rates of cases where obturation was done after obtaining a negative culture and cases where obturation was done without taking a culture.
- Culture taking is a sensitive and time-consuming procedure that prevents the completion of a root canal therapy in one appointment.
- There are more chances of false-positive and false-negative cultures due to sampling errors.
- Advances in instrumentation techniques and a better understanding of pulpoperiradicular pathophysiology have made endodontics more predictable without the need of a culture assessment.

II. MOLECULAR BIOLOGY METHODS

Molecular biology methods are based on the identification of specific biological markers present in the genes of microorganisms that aid in the precise phylogenetic classification and identification of microorganisms. The following are the most accurate molecular biological techniques available:

1. Polymerase chain reaction (PCR) and its derivatives
    (a) Broad-range PCR
    (b) Real-time PCR
    (c) Nested PCR
    (d) Reverse transcriptase PCR
    (e) Multiplex PCR
    (f) PCR-based microbial typing
    (g) Touchdown PCR
2. DNA–DNA hybridization
3. FISH protocol

Clinical Note

- Among the various methods available, broad-range PCR tests are very accurate in unraveling the microbial diversity.
- The PCR methodology is at least 10–100 times more sensitive than other identification methods.

Advantages

Advantages of molecular diagnostic methods are as follows:

- They detect both cultivated and as-yet cultivated species.
- They have high specificity and accurate identification.
- They are highly sensitive.
- They are rapid, while most assays take a few minutes to few hours to identify the organism.
- They can be used during antimicrobial treatment.
- They can detect dead organisms.
- Anaerobic handling and expertise are not required.

Disadvantages

Molecular diagnostic methods have the following limitations:

- Most assays are qualitative or semiquantitative.
- Most assays detect one species or a few different species at a time (exception being broad-range PCR).
- Some assays can be laborious.
- They can be very expensive.

POST-TREATMENT SEQUELAE

- *Healing in spite of the presence of bacteria:* Bacteria might persist even after completion of the root canal therapy. Healing might take place even when bacteria are found to persist in the root canal due to the following reasons:
  - The quantity of residual bacteria may not be sufficient to sustain periradicular infection and inflammation.
  - Residual bacteria might remain in intraradicular locations which are not accessible to the periradicular tissues.
  - The residual bacteria may die due to lack of nutrients or irreparable changes to the bacterial biofilm ecology.
- *Disease due to the presence of bacteria:* Residual bacteria that are present at the time of root canal obturation can cause failure due to the following reasons:
  - They are present in a quantity that can sustain periradicular infection.
  - Residual bacteria that can gain access to the periradicular tissues can cause failures.
  - Residual bacteria which have the ability to withstand long periods of nutrient scarcity and changes in bacterial biofilm ecology can remain dormant and cause an infection in future when favorable conditions are presented.

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3 Rationale of Endodontic Treatment

When the only tool you own is a hammer, every problem begins to resemble a nail.
—Abraham Maslow

Injury to the calcified structure of teeth and to the supporting tissues by noxious stimuli may cause changes in the pulp and the periradicular tissues. Noxious stimuli can be physical, chemical, or bacterial. They can produce changes that are either reversible or irreversible, depending on duration, intensity, and pathogenicity of the stimulus and the host's ability to resist the stimulus and to repair tissue damage. On the basis of these premises, we can generalize that mild-to-moderate noxious stimuli to the pulp may produce sclerosis of the dentinal tubules, formation of reparative dentin, or reversible inflammation. Irreversible inflammatory changes caused by severe injury can lead to necrosis of the pulp and subsequent pathologic changes in the periradicular tissues.

As the pulp is encased in hard tissues with limited portals of entry, it is an organ of terminal and limited circulation with no efficient collateral circulation and with limited space to expand during the inflammatory reaction. A clear concept of the fundamentals of inflammation is necessary for the understanding of the diseases of the pulp and their extension to the periradicular tissues.

INFLAMMATION

Inflammation is the local physiologic reaction of the body to noxious stimuli or irritants. Any irritant, whether of traumatic, chemical, or bacterial origin, produces a sequence of basic physiologic and morphologic reactions in vascular, lymphatic, and connective tissues. Host-resistance factors and intensity, duration, and virulence of the irritant modify the ultimate character, extent, and severity of the tissue changes and, to some degree, the clinical manifestations.

Inflammation brings to the area phagocytic cells to digest bacteria or cellular debris; antibodies to recognize, attack, and destroy foreign matter; edema or fluid to dilute and neutralize the irritant; and fibrin to limit the spread of inflammation.

The injurious agent may cause reversible or irreversible changes to the tissues. Irreversible damage leads to tissue necrosis, whereas reversible damage leads to repair. Repair, or the return of the tissue to normal structure and function, begins as the tissue becomes involved in the inflammatory process. Removal of the irritant, exudate, and cellular debris and return of the vascular bed to normal enhance the reparative process. Fibroblasts from adjacent connective tissue and capillary buds from adjacent blood vessels proliferate in the area. The result is the production of new collagen fibers, matrix, and a rich supply of blood vessels to the area of injury. This reparative tissue, which contains new blood vessels, fibroblasts, collagen fibers, and inflammatory cells, is called *granulation tissue*. The inflammatory process resolves when repair has been completed.

Clinical Note

- The objective of inflammation is to remove or destroy the irritant and repair damage to the tissue.
- Repair of the tissues depends on the severity of injury and host resistance.

SYMPTOMS

Inflammation produces the following symptoms:

- *Pain*, from the action of cytotoxic agents released from humoral, cellular, and microbial elements on the nerve endings
- *Swelling*, produced by filtration of macromolecules and fluids into the affected tissues
- *Redness*
- *Heat,* produced by vasodilatation of the vessels and the rushing of blood to the affected tissues
- *Disturbance of function*, resulting from changes in the affected tissues

In an inflamed pulp too, as in any other inflamed organ of the body, these symptoms occur, but only pain and disturbance of function are recognized clinically because of the encasement of the pulp by unyielding tissues. In acute inflammation involving the periapical tissues, all symptoms of inflammation may be recognized clinically.

In the dental pulp and periradicular tissues, inflammation may be either *symptomatic* or *asymptomatic*. These two stages can be recognized only at the histologic level and depend on the preponderant type of cells in the lesion.

- The main cell of a symptomatic acute inflammatory lesion is the *polymorphonuclear neutrophil.*
- In asymptomatic chronic inflammation, *lymphocytes, plasma cells, monocytes*, and *macrophages* are predominant.

- As a rule, no definite demarcation exists between acute and chronic inflammation. Lesions usually have both types of cells, with either acute or chronic cells predominating.

CELLULAR MEDIATORS OF INFLAMMATION

Inflammation and its sequelae are mediated by specific kinds of cells and the following section presents a brief understanding of the role of each of these cells.

POLYMORPHONUCLEAR NEUTROPHILS

The polymorphonuclear neutrophils morphologically consist of a nucleus with three or more connected lobules and cytoplasm containing lysosomal and specific granules. They are present during the acute or early stages of inflammation, and although their main function is to phagocytize bacteria, they may also phagocytize and lyse fibrin and cellular debris. They are attracted to the area of inflammation by chemotactic factors produced by bacteria or by complement. Serum factors of complement and immunoglobulins called *opsonins* bind bacteria to the surfaces of the polymorphonuclear neutrophils. In the binding sites, the bacteria are encapsulated in vacuoles that move into the cytoplasm of the polymorphonuclear neutrophils and come in contact with the lysosomal granules. These lysosomal granules degranulate and release lysosomal enzymes inside the vacuoles for lysis of the bacteria. The polymorphonuclear neutrophils have a narrow range of life; they are destroyed in the inflammatory site when the tissue fluids fall to a pH of 6.5. This tissue change is due to the increased production of lactic acid during phagocytosis and the release of this product into the tissues during the death of the polymorphonuclear neutrophils. Destruction of the polymorphonuclear neutrophils also causes the release of the proteolytic enzymes pepsin and cathepsin, with resulting tissue lysis. The polymorphonuclear neutrophils, with the products of cellular lysis and debris, are the principal constituents of pus.



Clinical Note

Polymorphonuclear neutrophils are the first cells to migrate from the vessels to the site of inflammation.

MACROPHAGES

Macrophages are derived from *circulating monocytes*. Immature monocytes in extravascular areas, such as areas of inflammation, differentiate into macrophages. Macrophages are phagocytic cells that ingest cellular debris, microorganisms, and particulate matter. They secrete certain mediators of inflammation, such as lysosomal enzymes, complement proteins, and prostaglandins.

Macrophages enhance the immunologic reaction by ingesting, processing, and degrading antigen before it is presented to the lymphocytes. Their capacity to remove debris from the area facilitates repair. Macrophages are mononucleated cells that, in periods of great activity, may fuse with other macrophages to produce a multinucleated giant cell.

LYMPHOCYTES

Small lymphocytes appear in the chronic stage of the inflammatory reaction. These lymphocytes are intimately related to the immunologic system of the organism. Small lymphocytes have a large, spherical, or slightly indented nucleus surrounded by a thin band of cytoplasm containing small granules. Two types of small lymphocytes, *B cells* and *T cells*, are known. Both are derived from the pluripotential hemopoietic stem cells. Stem cells are carried by the blood to the thymus, where they become immunologically competent T cells. B cells, in contrast, are believed to become immunocompetent in the bone marrow (**Fig. 3.1**).

T cells have a long life span and are the most common cells of the lymphocytic series in the blood. They are responsible for cell-mediated immunity and for the immunosurveillance of the human organism. They recirculate through the lymphoid tissues and organs of the body, except the thymus, and are found in the paracortical areas of the lymph nodes. When T cells are stimulated by an antigen, a foreign substance, they develop into sensitized T lymphocytes. These T lymphocytes have various immunologic manifestations as follows:

- *Memory T cells*, which speed the immunologic reaction in subsequent encounters with the same antigen
- *Helper or suppressor T cells*, which stimulate or suppress the development of effector T or B cells
- *Effector T cells*, which may produce cell-mediated immune reactions, such as delayed hypersensitivity

The sensitized T lymphocytes also release chemical mediators called *lymphokines*. Lymphokines may activate macrophages, polymorphonuclear leukocytes, and nonsensitized T cells, or they may produce interferon, which inhibits viral replication as needed by the immune response.

B cells have a shorter life span than T cells. They are found in the blood in lesser numbers than T cells and in the cortical areas of the lymph nodes. When activated by an antigen, B cells become larger cells, called plasmablasts, which divide to form *plasma cells* and *memory B cells*. The memory B cells speed the immunologic reaction in subsequent encounters with the same antigen. The B cells are responsible for the *humoral immunity* of the human organism.

The *plasma cells* are large, oval, or round cells with eccentric nuclei containing chromatin arranged in cartwheel form. The plasma cells produce immunoglobulins. Immunoglobulins are called antibodies when the antigen that triggers their production is known.

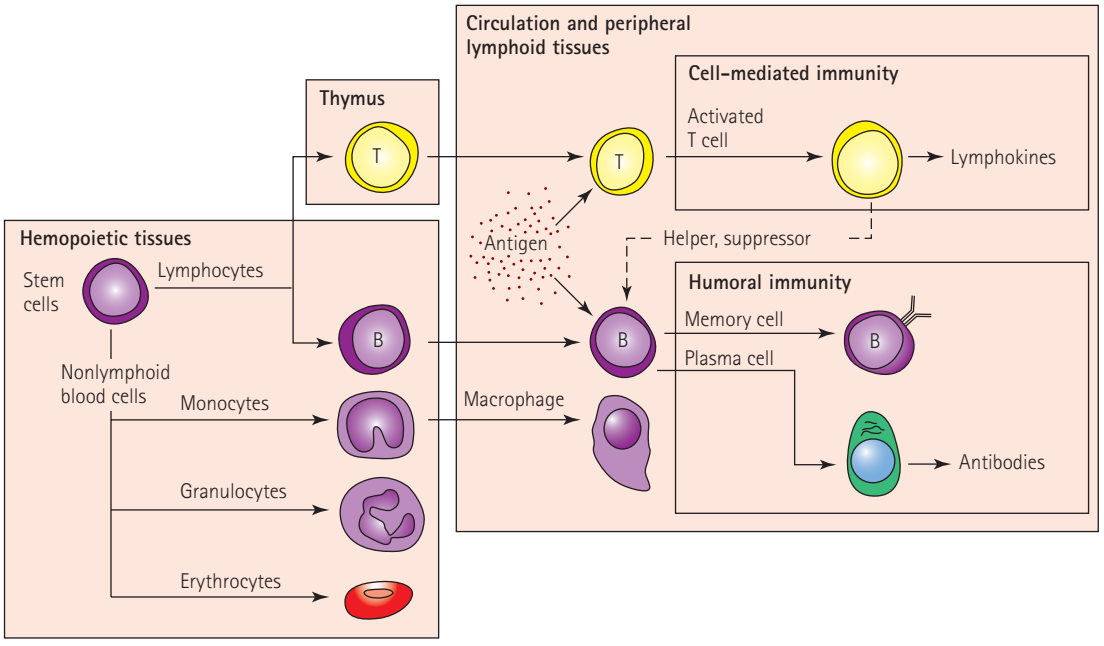


Figure 3.1 Differentiation of lymphocytes.

The *immunoglobulins*, of which the five major classes are *IgM, IgG, IgA, IgD,* and *IgE,* are involved in different defense reactions. These reactions include the following:

- Neutralization of bacterial toxins by antitoxins
- Coating of bacteria by antibodies, or opsonization, to facilitate phagocytosis
- Lysis of bacteria by complement activation
- Agglutination of bacteria
- Combining of the antibody with viruses to prevent their entry into the cells

EOSINOPHILS, BASOPHILS, AND MAST CELLS

Other cells found in the pulp and periradicular tissue during the inflammatory response are eosinophilic leukocytes, basophilic leukocytes, and mast cells. The eosinophils are found in allergic and parasitic reactions. During the immune response, they are involved in phagocytosis of the antigen–antibody complexes and detoxification of histamine. Basophils and mast cells are considered similar cells; basophils are found in the hemopoietic system and mast cells are found in tissue. Both of them contain granules that, when stimulated by tissue injury or antigen, degranulate and release chemical mediators, such as histamine, a vasodilator, and heparin, an anticoagulant which can initiate an inflammatory or allergic response.

CYTOKINES

Cytokines are low-molecular-weight proteins that stimulate or inhibit the proliferation, differentiation, or function of immune cells. They play an important role in modulating the inflammatory response of the immune system.

- Proinflammatory cytokines, e.g., TNF-α, IL-1, and IL-6
- Anti-inflammatory cytokines, e.g., IL-4, IL-5, IL-10, and IL-13

VASCULAR CHANGES DURING INFLAMMATION

Injury, regardless of the cause or intensity, causes two fundamental vascular changes:

- Vasodilatation
- Increased capillary permeability, which, in turn, leads to a series of interrelated physiologic and morphologic changes characteristic of the inflammatory response

A brief vasoconstriction is followed by vasodilatation of the arterioles caused by the relaxation of the arteriolar and capillary sphincters. This process is followed by the opening of dormant capillary beds which increases the blood supply to the affected area. Proteolytic enzymes released from injured cells, bacterial toxins, and traumatic mechanical forces are some of the injurious agents that may release histamine from mast cells to start the vasodilatation of the vessels. This vasodilatation is accompanied by an increased rate of blood flow through the vessels, a reduction in vascular reactivity, and a decrease in flow resistance. These changes increase intravascular pressure, blood flow, and permeability of capillaries.

Histamine enhances the permeability reaction by contracting the endothelial cells of the venules and producing intracellular gaps. This process favors the filtration of plasma and macromolecules from the venules. The blood plasma escaping through the vessel walls is usually less viscous and

contains less protein than blood plasma remaining in the blood vessels. In inflammation, the blood plasma that leaks into the tissues contains plasma proteins such as albumins, fibrinogen, and immunoglobulins and is called *inflammatory exudate*. Blood plasma containing macromolecules brings the chemical mediators and cells of inflammation into the inflammatory site to start the inflammatory reaction; this plasma also dilutes bacterial toxins, thereby reducing the potential of tissue damage, and helps to form fibrin to contain the inflammatory reaction.

Hageman factor or *factor XII* of the blood clotting system is released into the tissues in the inflammatory exudate. This factor is activated by collagen, by damaged basement membrane of blood vessels, or by an antigen–antibody complex, and reacts with prekallikrein of the plasma or tissues to produce kinins. The kinins, such as *bradykinin*, produce dilatation and permeability of blood vessels. The Hageman factor also activates the fibrinolytic and blood-coagulating systems. Fibrinogen in the inflammatory exudate is acted on by the Hageman factor to produce fibrin, which confines the inflammatory reaction to a limited area. Plasminogen from the plasma found in the inflammatory exudate is activated to plasmin. Plasmin may activate the complement system. Moreover, it digests fibrin and thereby aids in the removal of blood clots or fibrin plugs, or it may activate the kinin system. The inactive serum proteins of complement are also released from the blood in the inflammatory exudate. Immunoglobulins activate the complement cascade and produce anaphylatoxin, which acts on mast cells and causes the release of histamine. Complement activation also results in the release of a chemotactic factor, which aids in leukocytosis and lysis of bacteria.

The fluid leaked from the vessels into the tissues accumulates, producing *edema*. The subsequent increase in tissue pressure causes the venules to collapse and reduces both the venous drainage from the area and the blood flow. The stasis of blood in the venules due to increased viscosity of blood from loss of fluid and the increased pressure resistance of the venules cause the leukocytes to migrate from the center of the blood vessels to the periphery. This process is called *margination of leukocytes*. After margination, the leukocytes adhere to the vessel walls. This adherence is termed *pavementation of leukocytes*. The next step in the inflammatory reaction is the emigration of the leukocytes. The leukocytes are attracted by complement to the site of inflammation and migrate through the vessel walls by ameboid movement. This migration process is called *chemotaxis*. The polymorphonuclear neutrophils migrate first, followed by the monocytes and lymphocytes. Complement, prostaglandins, kallikrein, and bacterial products all may produce chemotaxis.

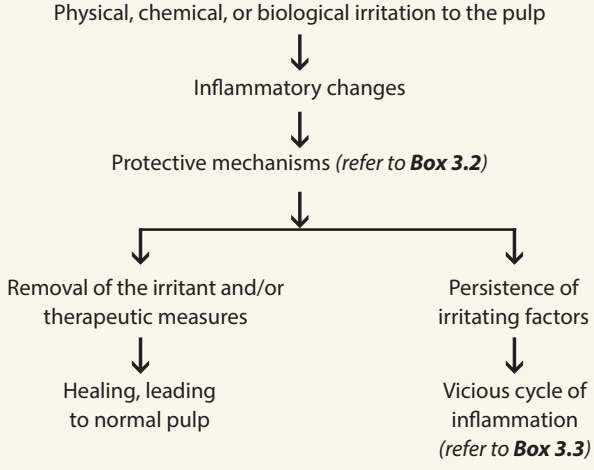
The presence of complement, kallikrein, and bacterial products in the inflammatory site has been previously discussed. Prostaglandins, mediators of inflammation, produce vasodilatation, vascular permeability, and pain. They are derived from the cell membrane phospholipids. Phospholipase, a lysosomal enzyme produced by polymorphonuclear leukocytes, reacts with the cell membrane phospholipids to produce arachidonic acid, which, in turn, produces prostaglandins, thromboxanes, and leukotrienes. The polymorphonuclear neutrophils also produce lysosomal enzymes which give rise to chemotactic substances that attract more leukocytes to the area of inflammation.

The vascular response continues with the aggregation of red blood cells in the vessels. This aggregation increases the resistance of the blood to flow. This resistance, along with the increase in blood viscosity produced by the loss of plasma, causes metabolic changes, such as a decrease in the oxygen concentration, an increase in carbon dioxide levels, and a lower pH in the inflammatory site. These changes are detrimental to the metabolism of the pulpal tissue, as elsewhere in the body, because they prevent the removal of waste products. **Box 3.1** illustrates the sequelae of pulpal inflammation.

Box 3.2 depicts the protective mechanisms involved in limiting the pressure increase within the affected pulpal area.

Box 3.1

Sequelae of Pulpal Inflammation



Box 3.2

Protective Mechanisms in Limiting the Pressure Increase within the Affected Pulp

- The locally increased pressure in the inflamed area will favor net absorption of interstitial fluid from adjacent capillaries in uninflamed tissues.
- Increased interstitial fluid pressure increases lymphatic drainage.
- Increased interstitial fluid pressure will lower the transcapillary hydrostatic pressure difference and oppose further filtration.
- Discontinuity in the endothelium and fenestration of pulpal capillaries may facilitate exchange mechanisms.
- Proper functioning of the feedback mechanisms will limit the increased tissue fluid pressure to the affected area, corresponding to that shown histopathologically.

Box 3.3

Mechanism of Vicious Cycle of Pulpal Inflammation (Kim S. [1985] and Van Hassel H.J. [1971])

Irritation
(Dental caries, trauma, or operative procedures)
↓
Localized inflammation
- Vasodilatation
- Increased local tissue pressure

↓
Localized necrosis
- Venous collapse
- Reduced blood flow
- Waste product accumulation

↓
Progression of inflammation
- Wider zone of inflammation
- Spread of vascular disturbance

↓
Generalized necrosis
- Necrosis of additional tissue
- Release of lysozomal enzymes
- Extensive collagen destruction

↓
Irreversible pulpitis

The vicious cycle of inflammation may lead to total necrosis of the pulp. This phenomenon is illustrated in **Box 3.3**.

The migration of monocytes and lymphocytes renders the inflammatory site capable of an immunologic reaction. As the inflammatory reaction progresses, the following cells are found in the inflammatory site:

1. Macrophages that are necessary to process the antigen
2. Plasma cells that are derived from B lymphocytes and synthesizers of immunoglobulin
3. Lymphocyte mediators of the immune response

Extravascular immunoglobulins found in inflamed pulp tissues, as well as those in plasma cells, are predominantly IgG, although IgA-, IgE-, and IgM-containing plasma cells are present. The presence of these immunoglobulins indicates that the pulp possesses the mechanism for immunologic reactions, which in themselves contribute to pulpal and periradicular disorders.

The recovery of the pulp may be explained by some unique vascular responses. Arteriovenous anastomoses and "U-turn" loops open in the pulpal vasculature to reduce the flow to the area of inflammation and thereby decrease the vascular pressure. The increased tissue pressure plays a role in the recovery of the pulp by allowing return of macromolecules and fluids to the venules. These two changes return vascular pressure and tissue pressure to normal and stimulate the repair process.

PERIRADICULAR MANIFESTATIONS

If the inflammatory response overwhelms the pulp, with resulting partial or total necrosis, the root canal will serve as a pathway to the periradicular area for the noxious products of tissue necrosis and antigenic agents. The inflammatory and immunologic responses in the periradicular area occur as in the pulp. On reaching the periradicular area, these noxious products cause bone resorption and initiate the formation of granulation tissue in place of normal periradicular tissues.

The periradicular pathologic tissues contain polymorphonuclear neutrophils, lymphocytes, plasma cells, macrophages, and mast cells, along with immunoglobulins IgG, IgA, IgM, and IgE, and complement. In the presence of inflammatory cells, immunoglobulins, and complement in the periradicular tissues, anaphylactic, cytotoxic, antigen–antibody complex, and delayed hypersensitivity reactions may occur. Reports indicate that some endodontic flare-ups are mediated by IgE reactions and that bone resorption is mediated by a lymphokine called osteoclast-activating factor. These findings point to the important role that immunologic reactions play in the physiology and pathology of the periradicular tissues.

TISSUE CHANGES FOLLOWING INFLAMMATION

Tissue changes following inflammation are either degenerative or proliferative.

DEGENERATIVE CHANGES

Degenerative changes in the pulp may be one of the following:

- Fibrous
- Resorptive
- Calcific

If the degeneration continues, necrosis will result, especially if thrombosis of the blood vessels occurs, or if leukotoxin is released as a result of damage to the tissue cells. Another form of degeneration is *suppuration*. When the polymorphonuclear cells are injured, they release proteolytic enzymes, with resulting liquefaction of the dead tissue. This process is suppuration or formation of pus. Three requisites are necessary for suppuration:

1. Necrosis of tissue cells
2. A sufficient number of polymorphonuclear leukocytes
3. Digestion of the dead material by proteolytic enzymes

If the reaction is not great enough, because the irritant is weak, an exudation consisting chiefly of serum, lymph, and fibrin (serous exudate) will result.

All dead cells, particularly polymorphonuclear cells, liberate proteolytic enzymes. In this way, an abscess is formed because the enzymes digest not only the leukocytes but also the adjacent dead tissue. *Microorganisms are not necessary for the development of an abscess.* For example, a sterile abscess may result from chemical or physical irritation in the absence of microorganisms.

PROLIFERATIVE CHANGES

Proliferative changes are produced by irritants mild enough to act as stimulants. Within the same area, a substance may be both an irritant and a stimulant, such as calcium hydroxide and its effect on the adjacent tissue. In the center of the inflammatory area, the irritant may be strong enough to produce degeneration or destruction, whereas at the periphery, the irritant may be mild enough to stimulate proliferation. Generally, if the tissue is in apposition, as in the case of an incision for root resection, fibroblastic repair will take place. When a gap is present between the tissue parts, repair is made with granulation tissue. Granulation tissue is resistant to infection. The principal cells of repair are the fibroblasts which lay down cellular fibrous tissue. In some cases, collagen fibers may be substituted; dense acellular tissue is then formed. In either case, fibrous repair is the result. Destroyed bone is not always replaced by new bone, but it may be replaced by fibrous tissue.

ENDODONTIC IMPLICATIONS

The reaction of the periradicular tissues to noxious products of tissue necrosis, bacterial products, and antigenic agents from the root canal has been described by Fish. He established experimental foci of infection in the jaws of guinea pigs by drilling openings in the bone and packing in wool fibers saturated with a broth culture of microorganisms. Four well-defined zones of reaction were found:

I. Zone of infection
II. Zone of contamination
III. Zone of irritation
IV. Zone of stimulation

I. ZONE OF INFECTION

This zone is characterized by polymorphonuclear leukocytes. In Fish's study, infection was present in the center of the lesion, and microorganisms were found only in that area. The only microorganisms not disposed of by polymorphonuclear leukocytes were found in Haversian canals or in fissures in the bone matrix made by the bur.

II. ZONE OF CONTAMINATION

This zone is characterized by round cell infiltration. Around the central zone, Fish observed cellular destruction, not from bacteria themselves, but from toxins discharged from the central zone. It was not established whether the toxins were tissue breakdown products or exotoxins. In this area, bone cells had died and had undergone autolysis, so the lacunae appeared empty. Lymphocytes were prevalent everywhere.

III. ZONE OF IRRITATION

This zone is characterized by macrophages and osteoclasts. Fish found evidence of irritation further from the central lesion as the toxins became more diluted. In this area, also distinguished by small, round cells, normal bone cells and osteoclasts could just about survive. The collagen framework was digested by phagocytic cells, the macrophages, while osteoclasts attacked the bone tissue. In this area, the histologic picture is the one that signifies a body's attempt to initiate repair.

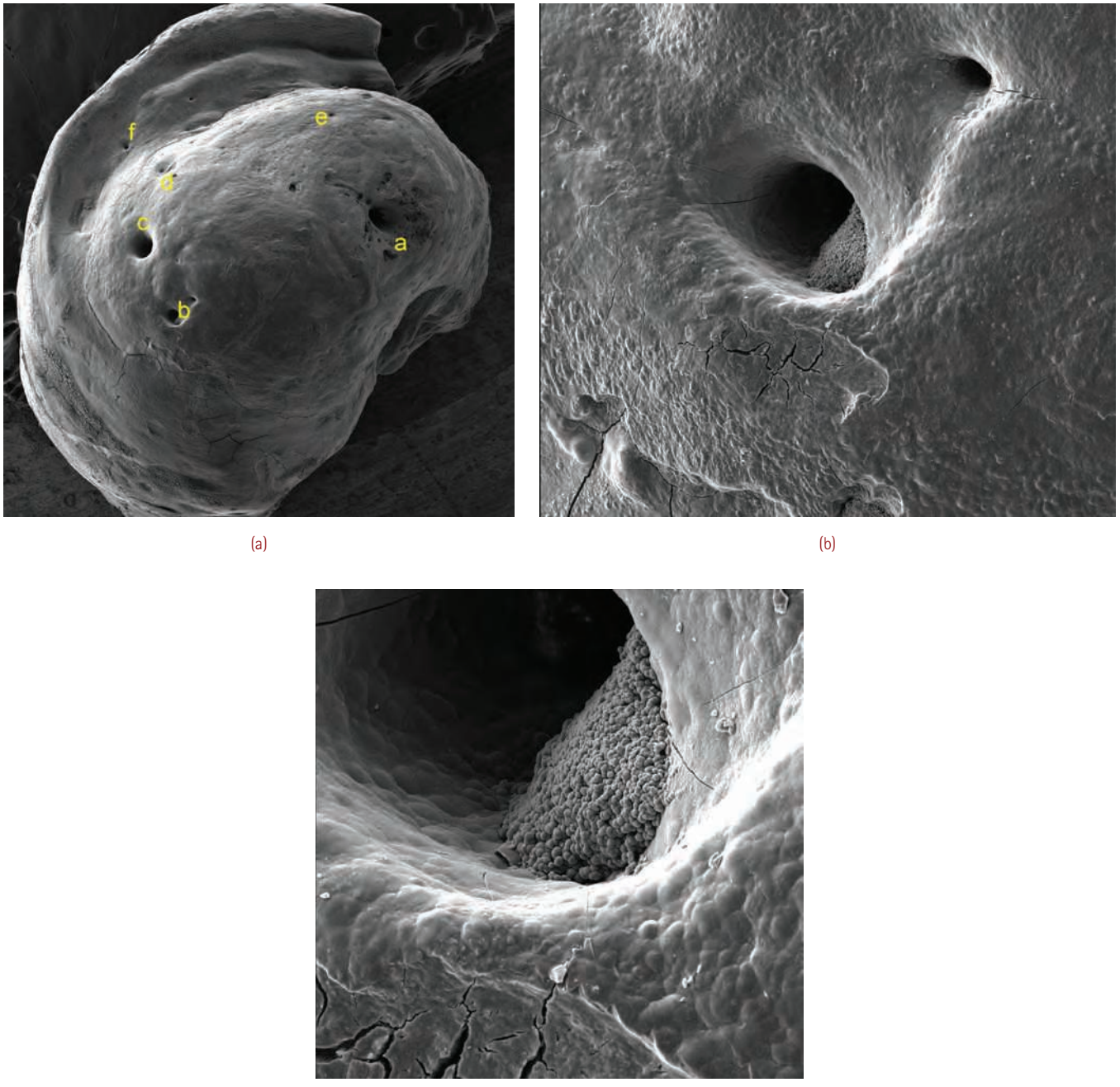
IV. ZONE OF STIMULATION

This zone is characterized by fibroblasts and osteoblasts. At the periphery, Fish noted that the toxin was mild enough to be a stimulant. In response to this stimulation, collagen fibers were laid down by the fibroblasts, which acted both as a wall of defense around the zone of irritation and as a scaffolding on which the osteoblasts built new bone. This new bone was built in irregular fashion.

The root canal is the site of infection. The microorganisms in the root canal are rarely motile and do not move from the root canal to the periradicular tissues; however, they can multiply sufficiently to grow out of the root canal (**Fig. 3.2**), or the metabolic products of these microorganisms or the toxic products of tissue necrosis may be diffused to the periradicular tissues. As the microorganisms gain access to the periradicular area, they are destroyed by the polymorphonuclear leukocytes. When the microorganisms are sufficiently virulent, or when enough are present, they overwhelm the defensive mechanism, and a *periradicular lesion* results. When they are of low virulence and numbers, however, a stalemate occurs. The polymorphonuclear leukocytes destroy the microorganisms as rapidly as they gain access to the periradicular tissues. The result is a *chronic abscess*. The toxic products of the microorganisms and the necrotic pulp in the root canal are irritating and destructive to the periradicular tissue and, together with the proteolytic enzymes released by the dead polymorphonuclear leukocytes, help to produce pus. By analogy, we can apply the knowledge gained in Fish's experiment to understand better the reaction of the periradicular tissues to a pulpless tooth (**Fig. 3.3**).

At the periphery of the destroyed area of osseous tissue, toxic bacterial products may be diluted enough to act as a stimulant. The toxic products from the root canal diffuse from the apical foramen and destroy bone in the immediate vicinity of the root apex; further away, the toxins are so diluted that they act as a stimulant and form a granuloma. Fibroblasts then build fibrous tissue, and osteoblasts delimit the area with a wall of sclerotic bone. If, in addition, the epithelial rests of Malassez are stimulated, a cyst will form.

Microorganisms are usually transient in periradicular tissue, even when an area of rarefaction is present radiographically. These transient invaders are destroyed by the polymorphonuclear leukocytes in the manner already described. Although this phenomenon explains the development of



(a) (b)

(c)

Figure 3.2 (a) SEM view of the apical surface of mesio-buccal root of maxillary first molar. Each alphabet is denoting portal of exit of the root canal. (b) SEM view under higher magnification of one of the portals of exit (B) of the root canal (Fig. 3.2a) showing colonies of coccus bacteria. (c) SEM view under higher magnification of Fig 3.2(b) showing colonies of coccus bacteria. (*Courtesy: Volodymyr Kovtun, Ukraine.*)

radiolucent areas as a result of infection of the pulp, it does not altogether explain the development of such areas following trauma. The pulp may be sterile, but a radiolucent area develops nevertheless because of tissue breakdown products of the pulp that irritate the periradicular tissues.

Clinical Note

When the root canal has been treated, the reservoir of bacteria or noxious products gets eliminated; when the root canal is cleaned and obturated, the destroyed periradicular bone will undergo repair.

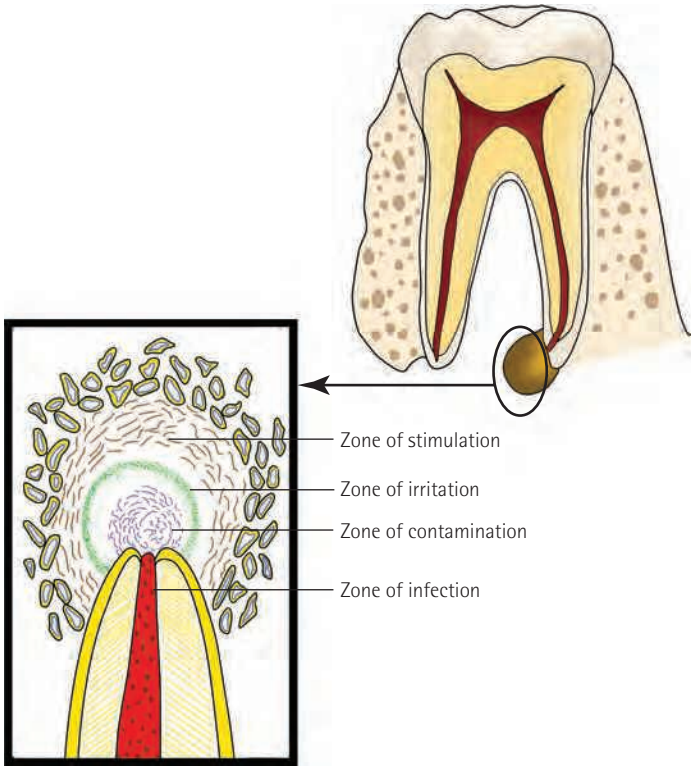


Figure 3.3 Schematic diagram showing bacteria in the root canal and the zones of infection, contamination, irritation, and stimulation.

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4 Diseases of the Dental Pulp

For there was never yet a philosopher who could endure the toothache patiently.
—William Shakespeare, *Much Ado About Nothing, Act V*

The pulp is the formative organ of the tooth. It builds primary dentin during the development of the tooth, secondary dentin after tooth eruption, and reparative dentin in response to stimulation as long as the odontoblasts remain intact (**Fig. 4.1a** and **4.1b**).

The pulp has been described as a highly resistant organ and as an organ with little resistance or healing ability. Its resistance depends on cellular activity, nutritional supply, age, and other metabolic and physiologic parameters. This variability has led to the remark that "*some pulps will die if you look crossly at them, while others can't be killed with an axe.*" On the whole, the resistance of the pulp to injury is slight in certain cases, but evidence of unusual persistence of vitality following injury has also been observed.

Accurate pulpal diagnosis is the key to all endodontic treatments. Unfortunately, there has been a poor correlation between the clinical symptoms and the histopathology of the pulp. Previous attempts that have been made to diagnose the condition of the pulp based on clinical signs (or symptoms), electric pulp test, and/or thermal tests and radiography have not always been successful. The endodontist is expected to understand the various causative factors of pulpal diseases, collect information about the presentation and history of symptoms, and conduct many practical tests before formulating the final diagnosis.

Clinical Note

The value of the pulp as an integral part of the tooth, both anatomic and functional, should be recognized and every effort made to conserve it.

CAUSES OF PULP DISEASE

The causes of pulp disease are physical, chemical, and bacterial. They may be grouped as given in **Box 4.1**.

I. PHYSICAL CAUSES

Physical causes include mechanical or thermal injuries.

Box 4.1

Causes of Pulp Disease

1. Physical
   - (a) Mechanical
     - (i) Trauma
       - Accidental (contact sports)
       - Iatrogenic dental procedures (during cavity or crown preparation)
     - (ii) Pathologic wear (attrition, abrasion, etc.)
     - (iii) Crack through body of tooth (Crown Originating Fracture)
     - (iv) Barometric changes (barodontalgia)
   - (b) Thermal
     - (i) Heat from tooth preparation, at either low or high speed
     - (ii) Exothermic heat from the setting of cement
     - (iii) Conduction of heat and cold through deep fillings without a protective base
     - (iv) Frictional heat caused by polishing a restoration
   - (c) Electrical (galvanic current from dissimilar metallic fillings)
2. Chemical
   - (a) Phosphoric acid, acrylic monomer, etc.
   - (b) Erosion (acids)
3. Bacterial
   - (a) Toxins associated with caries
   - (b) Direct invasion of pulp from caries or trauma
   - (c) Microbial colonization in the pulp by blood-borne microorganisms (anachoresis)

A. Mechanical Injuries

These injuries are usually due to either trauma or pathologic wear of teeth.

i. Trauma

Traumatic injury may or may not be accompanied by fracture of the crown or root. Trauma is less frequently the cause of pulp injury in adults than in children. Traumatic injury of the pulp may be due to the following reasons:

- A violent blow to the tooth during a fight, sports, automobile accident, or household accident (**Fig. 4.2**)
- Habits such as opening bobby pins with the teeth and nail biting (**Fig. 4.3**) that may also cause pulpal injury

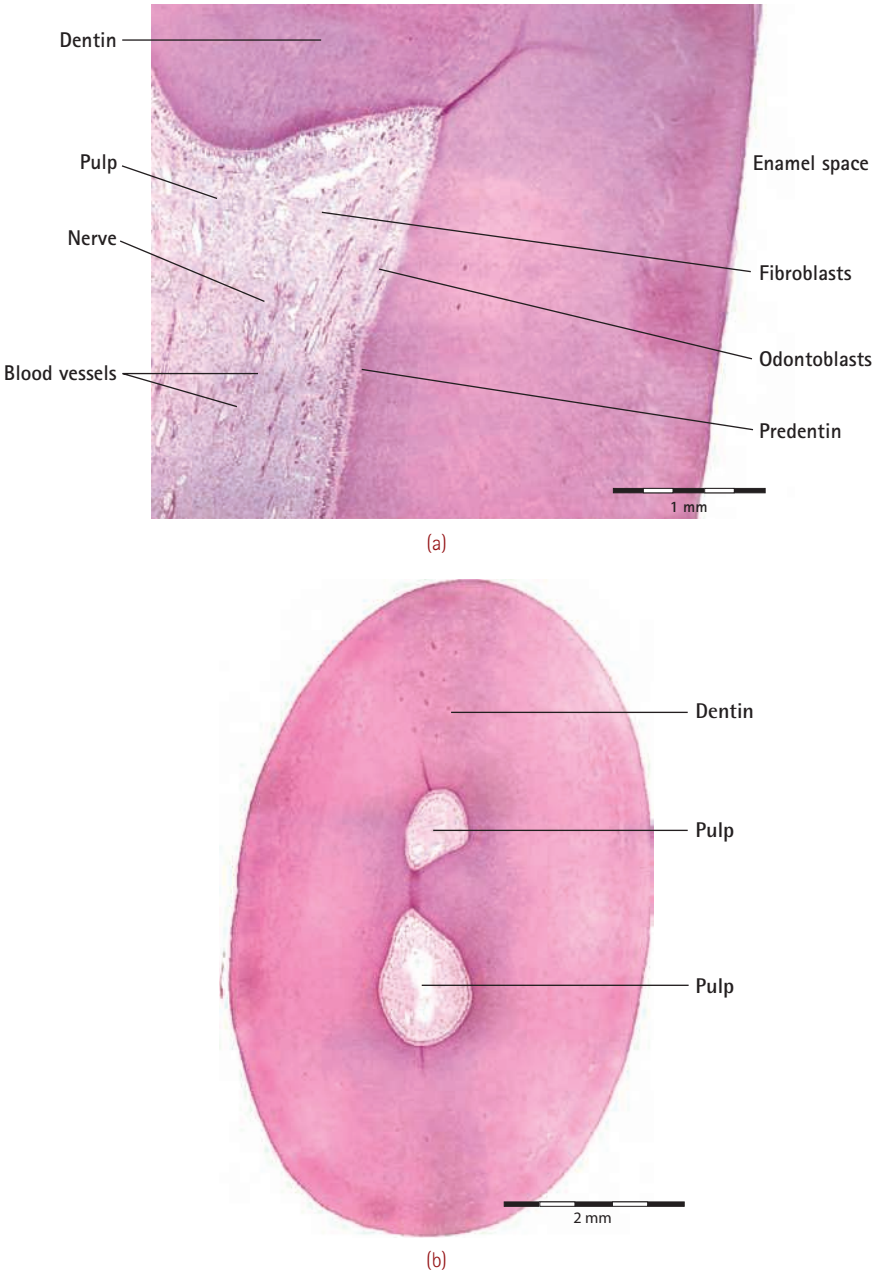


Figure 4.1 (a) Demineralized tooth, longitudinal section: this is a section through a premolar. The pulp comprises loose connective tissue, blood vessels, and nerves (stain: H + E). (b) Demineralized tooth, cross-section: this is a section through the coronal part of a premolar. The enamel has been lost during the preparation of the section. The pulp is visible at the center of the tooth (stain: H + E). *(Courtesy: Mathias Nordvi, University of Oslo, Norway.)*

ii. Pathologic Wear

The pulp may also become exposed or nearly exposed by pathologic wear of the teeth from any of the following:

- Attrition (**Fig. 4.4a** and **4.4b**)
- Abrasion (**Fig. 4.5**)
- Bruxism (**Fig. 4.6**)
- Abfraction

If secondary dentin is not deposited rapidly enough, occlusal trauma may also injure the pulp because of repeated irritation to the neurovascular bundle in the periradicular area.

In addition, certain dental procedures occasionally injure the pulp. Some are avoidable; others are not. The iatrogenic causes of dental injuries include the following:

- Accidental exposure of the pulp during excavation of carious tooth structure
- Too-rapid movement of teeth during orthodontic treatment

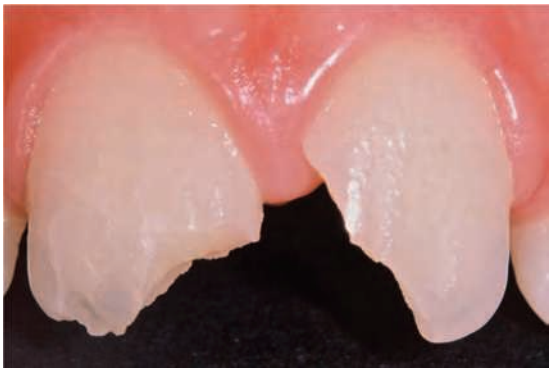


Figure 4.2 Traumatic injury leading to crown fracture in the maxillary central incisors.



Figure 4.3 Incisal notching in the maxillary central incisor due to nail biting habit.



(a)



(b)

Figure 4.4 (a) Attrition in mandibular posterior teeth. (b) Attrition in mandibular anterior teeth.



Figure 4.5 Abrasion of the maxillary posterior teeth.



Figure 4.6 Bruxism leading to wear of the mandibular posterior tooth surface.

- Rapid separation of teeth by means of a mechanical separator
- The use of pins for mechanical retention of amalgam or other restoration

iii. Crown Originating Fracture : COF : (previously known as Cracked Tooth Syndrome)

Incomplete fractures through the body of the tooth may cause pain of apparently idiopathic origin. This is referred to as the *cracked tooth syndrome*. The reader is referred to Chapter 7 for more details.

iv. Barodontalgia

The list of physical causes of pulp injury would not be complete without a consideration of high-altitude changes on the pulp. Barodontalgia, also known as *aerodontalgia*, denotes toothache occurring at low atmospheric pressure experienced either during flight or during a test run in a decompression chamber. It has generally been observed in altitudes over 5,000 feet, but it is more likely to occur at 10,000 feet or above.

Clinical Note

A tooth with irreversible pulpitis can be symptomless at the ground level, but it may cause pain at high altitude because of reduced pressure.

B. Thermal Injuries

Thermal causes of pulp injury are uncommon.

i. Heat from Tooth Preparation

Tooth preparation also produces temperature changes, with an increase of 20°C in temperature during *dry tooth preparation* 1 mm from the pulp and a 30°C increase 0.5 mm from the pulp. The sensation of pain, a warning signal that the pulp is endangered, is a protective reaction, as it is elsewhere in the body.

The chief offender is heat developed by a tungsten carbide bur or diamond during tooth preparation. High-speed tungsten carbide burs or diamonds may reduce the operating time but may also accelerate pulp death if used *without a coolant*. The heat generated may be sufficient to cause irreparable pulp damage.

Special care must be exercised when the preparation is large, or when the tooth is being prepared for a full-coverage crown, because cutting of dentin is extensive and many dentinal tubules are exposed.

Evidence suggests that pulpal damage is repaired more rapidly when tooth preparation is done under a water spray. When a preparation is prepared with an air turbine and water spray, the pulp shows little or no response to the cutting. The dentinal tubules remain open or are unaffected for a longer period of time. In comparison with preparation at low speed, it takes longer for reparative or secondary dentin to develop, if it develops at all.

Extensive research studies on high-speed preparation have shown that

- The stream of water or air–water spray must be directed onto the cutting surface of the bur for maximum cooling
- The water stream is deflected in a centripetal direction by the rotation of the bur
- Burns in the dentin may occur from overheating because of malfunction of the water spray or stream, with a corresponding reaction in the pulp
- Aspiration of odontoblast nuclei occurs with inadequate water spray
- Dry tooth preparation causes not only burns in dentin but also migration of odontoblasts, migration of erythrocytes, and hyperemia of the pulp. It was found experimentally that the greater the length of time the dentin was dried, the greater was the severity of odontoblast displacement

Clinical Note

- Studies of sound human teeth in which tooth preparations were done at 200,000 RPM or higher with an air turbine, with adequate water cooling of the tooth, showed *less injury* to the pulp tissue than when cavities were prepared at speeds between 6,000 and 20,000 RPM, without a coolant.
- Damage and abscess formation of the pulp occur when a water spray is not used.

ii. Heat Conduction by Fillings

Metallic fillings close to the pulp without an intermediate cement base may conduct temperature changes rapidly to the pulp and may eventually cause irreversible changes. Sudden changes in temperature from foodstuffs, such as eating ice cream, drinking coffee, or chewing ice cubes, may also contribute to pulp injury.

Clinical Note

Remaining dentin thickness (RDT) under the restoration (**Fig. 4.7**) is the key factor which would determine whether the pulpal changes would be reversible or irreversible in nature.

iii. Frictional Heat During Polishing

Enough heat may also be generated during polishing of a filling (**Fig. 4.8**) or during setting of cement to cause at least a transient pulp injury. These injuries are usually reversible in nature.

Clinical Note

- The pulp responds to hot and cold stimuli that are perceived only as pain.
- Heat at temperatures between 60°F (16°C) and 130°F (55°C) when applied directly to an intact tooth surface is usually well tolerated by the pulp, but foodstuffs and beverages above and below this temperature range can also be endured.



Figure 4.7 Cross-section of a tooth restored with amalgam showing varying remaining dentin thickness (RDT) at different levels of the pulpal floor.



Figure 4.8 Polishing procedures might cause a transient and reversible damage to the pulp and must be executed properly.

II. CHEMICALS

Chemical causes of pulp injury are probably the least common.

The key factors which determine the pulpal reaction to a restorative filling material are as follows:

- Acidity (pH of the material)
- Heat generated during the setting reaction
- Absorption of water during the setting reaction
- Remaining dentin thickness (RDT)
- Poor marginal adaptation of the material which might contribute to bacterial leakage

Fillings made of silver amalgam, or composites, may produce some pulpal reaction when they are inserted in cavities with very less RDT. The deeper the cavity, the greater the damage caused, but in most cases the pulp recovers from these injuries.

Clinical Note

The long-term prognosis of a restorative filling would be determined by its ability to inhibit microleakage and pulpal bacterial contamination.

III. BACTERIA

In 1894, W.D. Miller suggested that bacteria were a possible cause of inflammation in the pulp. *The most common cause of pulp injury is bacterial*. Bacteria or their products may enter the pulp through a break in the dentin, from caries or accidental exposure, from developmental grooves (**Figs 4.9** and **4.10**), from percolation around a restoration, from extension of infection, from the gingiva, or by way of the blood.

Microorganisms play an important role in the genesis of pulpal disease (**Fig. 4.11**). Despite food impaction, dentinal bridging occurs in the pulps of gnotobiotic (germ-free) rats after pulp exposure. On the other hand, pulpal necrosis, abscess formation, and granulomas develop in exposed pulps of rats kept under ordinary laboratory conditions.

The species of bacteria recovered from inflamed or infected pulps are many and varied. Although lactobacilli (acidogenic organisms) are commonly found in carious dentin, they are seldom recovered from the pulp because of their low degree of invasiveness. Microorganisms need not be present in the pulp to produce inflammation: the by-products of bacteria in the dentin may be sufficiently irritating to cause an inflammatory reaction.

The bacteria most often recovered from infected vital pulps are *streptococci* and *staphylococci*, but many other microorganisms including anaerobes have also been isolated. With the introduction of improved methods of molecular identification of pathogens, many new organisms have been identified by researchers. Species that have been found significantly include *Porphyromonas gingivalis*, *Porphyromonas endodontalis*, *Fusobacterium nucleatum*, and others. Polymerase chain reaction (PCR) methods show higher prevalence of



Figure 4.9 Developmental palatogingival groove in maxillary lateral incisor acts as a pathway for carious invasion of the pulp space.



Figure 4.10 Radiographic evidence of pulpal involvement along with periradicular changes.



Figure 4.11 Mandibular molar with clinical evidence of carious pulpal exposure.

Treponema denticola, a recognized periodontal pathogen, in association with *Tannerella forsythia* and *P. gingivalis.*

Clinical Note

- The presence or absence of bacterial irritation is the determining factor in pulp survival once the pulp has been mechanically exposed.
- Once bacteria have invaded the pulp, the damage is almost always irreparable.

Reaction of the Pulp to Bacterial Invasion

One should consider the mechanism of pulp injury and the resulting changes. Once the pulp is exposed by caries or trauma, it is considered infected because microorganisms gain access to it almost immediately. The invading bacteria, however, may be confined entirely to the small area of pulp exposure. At first, the infection is localized to a small area of the pulp, just as infection following a scratch of the arm is localized. Although the coronal area of the pulp may be involved by a mild or even severe infective process, the body and apical portion of the pulp may remain normal. The reaction of the pulp in the involved area is an inflammatory response.

Polymorphonuclear leukocytes reach the area, and further dissemination of bacteria deeper into the pulp is prevented. Because some microorganisms enter the dentinal tubules, they may gain a foothold that is difficult to dislodge. In this respect, injury of the pulp and injury of the arm or some other parts of the body differ; in the latter, microorganisms are more readily reached by tissue defenses. The reaction in an inflamed pulp also differs from that in an inflamed arm or other organ in that little or no room is provided during the inflammatory state for swelling of the pulp because the pulp is entirely enclosed in a hard, unyielding dentinal wall, except at the apical foramen. If the inflammatory process is severe, it will extend deeper into the pulp and all the symptoms of an acute reaction will be manifested.

Considerable inflammatory exudate accumulates and causes pain from pressure on the nerve endings. Areas of necrosis develop, owing to disturbance in nutritional supply, many of the polymorphonuclear leukocytes die, and pus forms, further irritating the nerve cells. If the process is less severe, lymphocytes and plasma cells will replace the polymorphonuclear leukocytes in numbers, and the inflammatory reaction may be confined to the surface of the pulp. Such a chronic inflammatory state may be localized for a long time unless the microorganisms penetrate deeper into the pulp and cause an acute reaction manifested by a clinical *flare-up*. On the other hand, the chronic process may continue until most of or all the pulp is involved, ultimately leading to its death. In the course of this development, the organisms may be killed, but more commonly they survive and set up a reaction in the periapical tissue by their products of metabolism.



Figure 4.12 Discoloration in a maxillary central incisor with a history of trauma.

During the inflammatory reaction, *tissue pressure* is increased. Stasis occurs with resulting necrosis of the pulp. In some cases, the necrotic but sterile pulp tissue causes no symptoms and remains quiescent for years. This situation is an exception, because in most cases the microorganisms survive, and if virulent, multiply rapidly and reach the periapical tissue, where they continue their destruction and produce an acute alveolar abscess. If they are less virulent, the microorganisms will remain in the root canal and, by their toxic products, will gradually and quietly produce a chronic abscess without giving rise to subjective symptoms other than those associated with a sinus tract, if one develops. When the defensive forces of the periradicular tissues are adequate, a ring of granulation tissue is formed to delimit the bacteria and neutralize their toxins. In some cases, such low-grade irritation stimulates the epithelial rests and causes a cyst.

Meanwhile, during this process, the dentinal tubules may become infiltrated with products of blood decomposition, bacteria, and, occasionally, food debris, and the dentin becomes discolored (**Fig. 4.12**). Such discoloration of tooth structure is sometimes the first clinical sign that the pulp has died.

DISEASES OF THE PULP

I. INFLAMMATORY DISEASES OF THE PULP

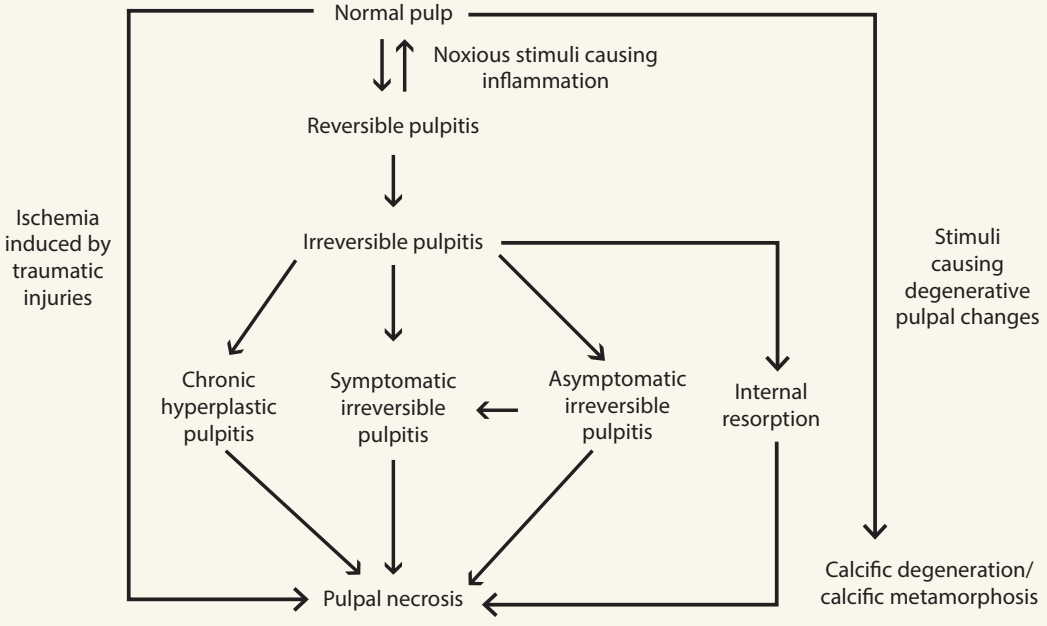
Pulpitis or inflammation of the pulp may be reversible or irreversible, symptomatic (acute) or asymptomatic (chronic), partial or total, and the pulp may be infected or sterile. The extent of inflammation, whether partial or total, cannot be determined histologically, and the bacteriologic state, whether the tissue is infected or sterile, cannot be determined except by smear or culture. The only clinical differentiation possible in pulpitis is between the symptomatic and asymptomatic stages of the disease.

The sequelae of the various diseases of the pulp are depicted in **Box 4.2**.

The clinical classification of pulpal diseases is based *primarily on symptoms*. No correlation exists between histopathologic findings and the existing symptoms. The value of the clinical classification lies in its use by the clinician to determine the appropriate care and treatment, the endodontic

Box 4.2

Sequelae of Pulpal Diseases



prognosis, and probably the restorative needs of the tooth. The demarcation between irritation of the pulp leading to productive stimulation of secondary dentin formation and that leading to pulpitis is indistinct.

Clinical Note

The reaction of the pulp depends not only on the degree of irritation but also on the individual makeup and resistance of the pulp tissue to injury. In one case, a slight degree of irritation produces a symptomless productive reaction of the pulp, in another it produces hyperemia, and in still another, acute pulpitis may result.

The diseases of the pulp may be clinically classified as given in **Box 4.3**.

A. Reversible Pulpitis

Definition: *Reversible pulpitis is a mild-to-moderate inflammatory condition of the pulp caused by noxious stimuli in which the pulp is capable of returning to the uninflamed state following removal of the stimuli.*

Types

- *Acute reversible pulpitis*: The pain has been present for a short time (e.g., a few hours or days); however, it immediately ceases on removal of the aggravating stimuli.
- *Chronic reversible pulpitis*: The pain has been present for a long time (e.g., months); however, it immediately ceases on removal of the aggravating stimuli.

Box 4.3

Clinical Classification of the Diseases of the Pulp

1. Inflammatory diseases of the dental pulp
   - (a) Reversible pulpitis
     - (i) Acute reversible pulpitis
     - (ii) Chronic reversible pulpitis
   - (b) Irreversible pulpitis
     - (i) Symptomatic irreversible pulpitis (previously known as acute irreversible pulpitis)
     - (ii) Asymptomatic irreversible pulpitis (previously known as chronic irreversible pulpitis)
     - (iii) Chronic hyperplastic pulpitis (also known as pulpal hyperplasia)
     - (iv) Internal resorption
2. Pulp degeneration
   - (a) Calcific degeneration (radiographic diagnosis)
   - (b) Fibrous degeneration
3. Pulp necrosis
   - (a) Pulp necrobiosis (part of pulp is necrotic and infected; the rest is irreversibly inflamed)
   - (b) Pulp necrosis with no signs of infection
   - (c) Necrotic and infected pulp

Cause

Reversible pulpitis may be caused by any agent that is capable of injuring the pulp. Specifically, the cause may be any of the following:

- Trauma, as from a blow or from a disturbed occlusal relationship
- Thermal shock, as from preparing a cavity with a dull bur or keeping the bur in contact with the tooth for too long, or as from overheating during polishing a filling

- Excessive dehydration of a cavity or irritation of exposed dentin at the neck of a tooth
- Placement of a fresh amalgam filling in contact with, or occluding, a cast restoration
- Chemical stimulus, as from sweet or sour foodstuffs or from irritation of a filling; or bacteria, as from caries

Following insertion of a restoration, patients often complain of mild sensitivity to temperature changes, especially cold. Such sensitivity may last 2–3 days or a week, or even longer, but it gradually subsides. This sensitivity is symptomatic of reversible pulpitis. Circulatory disturbances, such as those accompanying menstruation or pregnancy, may also result in a transient periodic hyperemia. Local vascular congestion associated with common cold or with sinus disease can cause a generalized transient hyperemia of the pulp of the maxillary posterior teeth. The irritant that causes hyperemia or mild inflammation in one pulp may produce secondary dentin in another if the irritant is mild enough or if the pulp is vigorous enough to protect itself.

Symptoms

- Symptomatic reversible pulpitis is characterized by *short, sharp pain lasting for a moment*.
- This pain is always *specific to a stimulus*.
- The pain is *instantly relieved on removal of the stimulus*.
- It is more often brought on by cold than by hot food or beverages and by cold air. It does not occur spontaneously and does not continue when the cause has been removed. The clinical difference between reversible and irreversible pulpitis is quantitative; the pain of irreversible pulpitis is more severe and lasts longer. In reversible pulpitis, the cause of the pain is generally traceable to a stimulus, such as cold water or a draft of air, whereas in irreversible pulpitis, the pain may come without any apparent stimulus (**Fig. 4.13**).

Diagnosis

Diagnosis is by a study of the patient's symptoms and by clinical tests. The pain is sharp, lasts but a few seconds, and generally disappears when the stimulus is removed. Cold, sweet, or sour usually causes it. Pain may become chronic. Although each paroxysm may be of short duration, the paroxysms may continue for weeks or even months. The pulp may recover completely, or the pain may last longer each time, and intervals of relief may become shorter, until the pulp finally succumbs. Because the pulp is sensitive to temperature changes, particularly cold, application of cold is an excellent method of locating and diagnosing the involved tooth. A tooth with reversible pulpitis reacts normally to percussion, palpation, and mobility, and the periapical tissue is normal on radiographic examination.

Differential Diagnosis

In reversible pulpitis, the pain is generally transitory, lasting a matter of seconds, whereas in irreversible pulpitis, the pain may last several minutes or longer. The patient's description of the pain, particularly regarding its onset, character, and duration, is often of inestimable help in arriving at a correct differential diagnosis. Thermal tests are useful in locating the affected tooth if unknown. The electric pulp test, using less current than on a control tooth, is an excellent corroborating test.

Histopathology

Reversible pulpitis may range from hyperemia to mild-to-moderate inflammatory changes limited to the area of the involved dentinal tubules, such as dentinal caries. Microscopically, one sees reparative dentin, disruption of the odontoblast layer, dilated blood vessels, extravasation of edema fluid, and presence of immunologically competent chronic inflammatory cells. Although chronic inflammatory cells predominate, one may see acute inflammatory cells.

Treatment

The best treatment for reversible pulpitis is *prevention*. Periodic care to prevent the development of caries, early insertion of a filling if a cavity has developed, desensitization of the necks of teeth where gingival recession is marked, use of a cavity varnish or cement base before insertion of a filling, and care in tooth preparation and polishing are recommended to prevent pulpitis.

When reversible pulpitis is present, removal of the noxious stimuli will usually bring the pulp back to a healthy state. Once the symptoms have subsided, the tooth should be tested for vitality to make sure that pulpal necrosis has not occurred. When pain persists despite proper treatment, the pulpal inflammation should be regarded as irreversible, the treatment for which is pulp extirpation.

Prognosis

The prognosis for the pulp is favorable if the irritant is removed early enough; otherwise, the condition may develop into irreversible pulpitis.

B. Irreversible Pulpitis

Definition: *Irreversible pulpitis is a persistent inflammatory condition of the pulp, symptomatic or asymptomatic in nature with the pulp becoming incapable of healing.*

Types

- Asymptomatic irreversible pulpitis
- Symptomatic irreversible pulpitis



Figure 4.13 Upper molar with clinically good amalgam restoration: (a) Tooth was symptomatic for biting forces and cold application. (b) After amalgam removal. (c) After restoration with direct composite and total etch technique. (d) Symptomless, vital tooth after 5 years. *(Courtesy: Niek Opdam, Netherlands.)*

Cause

The most common cause of irreversible pulpitis is bacterial involvement of the pulp through caries, although any clinical factor, chemical, thermal, or mechanical, already mentioned as a cause of pulp disease, may also cause pulpitis. As previously stated, reversible pulpitis may deteriorate into irreversible pulpitis.

Symptoms

- In the early stages of irreversible pulpitis, a paroxysm of pain may be caused by the following: sudden temperature changes, particularly cold; sweet or acid foodstuffs; and pressure from packing food into a cavity or suction exerted by the tongue or cheek.
- Symptomatic irreversible pulpitis exhibits pain usually caused by a hot or cold stimulus, or pain that occurs

spontaneously. The pain persists for several minutes to hours, *lingering* after removal of the thermal stimulus.

- The pain often continues when the cause has been removed, and it may come and go *spontaneously,* without an apparent cause.
- The patient may describe the pain as *sharp, piercing, or shooting*, and it is generally severe.
- It may be *intermittent or continuous*, depending on the degree of pulpal involvement and on whether it is related to an external stimulus.
- The patient may also complain of *postural pain*, i.e., change of position (bending over or lying down) exacerbates the pain. This is due to the increase in intrapulpal pressure when the patient changes position from a standing posture to a supine (lying down) posture.
- The patient may also have pain *referred* to adjacent teeth, to the temple or sinuses when an upper posterior tooth is involved, or to the ear when a lower posterior tooth is affected.
- In later stages, the pain is more severe and is generally described as *boring, gnawing, or throbbing*, or as if the tooth was under constant pressure. The pulp need not be macroscopically exposed, but a slight exposure is generally present, or else the pulp is covered with a layer of soft, leathery decay. When no outlet is present, whether because of a covering of decay or a filling or because of food packed into a small exposure in the dentin, pain can be most intense.
- Patients are often kept awake at night by the pain *(nocturnal pain)*, which continues to be intolerable despite all their efforts at analgesia. Pain is increased by heat and is sometimes relieved by cold, although continued cold may intensify the pain. After exposure and drainage of the pulp, pain may be slight, manifesting itself as a dull consciousness, or may be entirely absent. Pain can return if food packs into the cavity or underneath a leaky filling; it may not be as intense because of degeneration of the superficial nerve fibers.
- Apical periodontitis is absent, except in the later stages, when inflammation or infection extends to the periodontal ligament.

Diagnosis

Inspection generally discloses a deep cavity extending to the pulp or decay under a filling (**Fig. 4.14**). The pulp may already be exposed. On gaining access to the exposure, one may see a grayish, scum-like layer over the exposed pulp and the surrounding dentin. This layer is composed of food debris, degenerated polymorphonuclear leukocytes, microorganisms, and blood cells. The surface of the pulp is eroded. An odor of decomposition is frequently present in this area. Probing into the area is not painful to the patient until the deeper areas of the pulp are reached. At this level, both pain and hemorrhage may occur. If the pulp is not exposed by the carious process, a drop of pus may be expressed when one gains access to the pulp chamber.



Figure 4.14 Fractured restoration with secondary caries showing clinical signs of irreversible pulpitis.

Radiographic examination may not show anything of significance that is not already known clinically. It may disclose an interproximal cavity not seen visually or may suggest involvement of a pulp horn (**Fig. 4.15**). A radiograph may also show exposure of the pulp, caries under a filling, or a deep cavity or filling threatening the integrity of the pulp. In the early stages of irreversible pulpitis, the thermal test may elicit pain that persists after removal of the thermal stimulus. In the late stages, when the pulp is exposed, it may respond normally to a thermal stimulus, but generally it reacts feebly to heat and cold. The electric pulp test induces a response with a marked variation in current from the normal. Results of examination for mobility and percussion and palpation tests are negative.

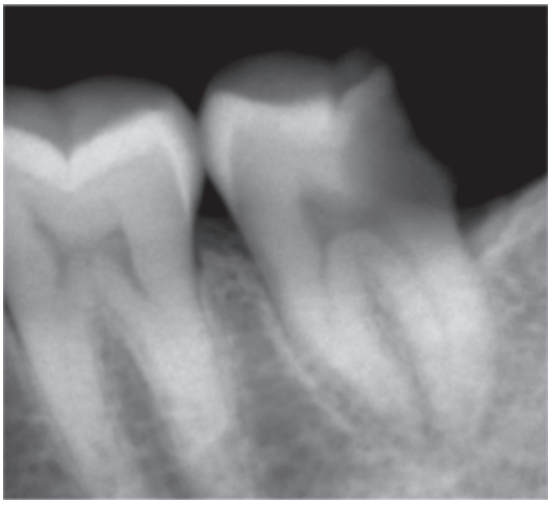


Figure 4.15 Radiographic evidence of decay involving the distal pulp horn in a mandibular molar with clinical signs of irreversible pulpitis. Note the lack of any periradicular radiographic changes.

Differential Diagnosis

One must distinguish between reversible and irreversible pulpitis.

Clinical Note

In reversible pulpitis, the pain produced by a thermal stimulus disappears as soon as the stimulus is removed, whereas in irreversible pulpitis, the pain lingers after the stimulus is removed, or it can occur spontaneously.

In the asymptomatic stage of irreversible pulpitis, the exposed pulp exhibits little or no pain, except when food is packed into the cavity. More current is required to elicit a response to the electric pulp test than in a control tooth.

In the early symptomatic stage, less current than what is normal is needed to elicit a response to the electric pulp tester, and the pulp is often abnormally responsive to a cold stimulus. The induced or spontaneous pain that occurs is sharp, piercing, and readily identified with a specific tooth. Other symptoms may develop, such as diffuse, dull, constant pain, characterized by throbbing and gnawing, and the tooth may respond abnormally and severely to heat. This response is generally indicative of a later stage of irreversible pulpitis. In this stage of irreversible pulpitis, the symptoms may simulate those of an acute alveolar abscess.

Such an abscess, however, causes at least some of the following symptoms, which help to differentiate it from irreversible pulpitis: swelling, tenderness on palpation, tenderness on percussion, mobility of the tooth, and lack of response to pulp-vitality tests. In addition, the patient may have symptoms of systemic toxicity such as fever and nausea.

The pain of pulpitis is easy to localize by the patient at the onset. Once discomfort increases, the patient loses the ability to identify a particular tooth in the quadrant. A previous history of pain may help one to localize the origin of the pulpalgia. When pulpal pain is difficult to localize, the application of heat with a consequent abnormal response is indicative of irreversible pulpitis in that tooth.

Histopathology

This disorder has chronic and acute inflammatory stages in the pulp. Irreversible pulpitis may be caused by a long-standing noxious stimulus such as caries. As it penetrates the dentin, caries causes a chronic inflammatory response previously discussed with regard to reversible pulpitis. If the caries is not removed, the inflammatory changes in the pulp will increase in severity as the decay approaches the pulp. The postcapillary venules become congested, as previously discussed, and affect the circulation within the pulp, causing pathologic changes such as necrosis. These necrotic areas attract polymorphonuclear leukocytes by chemotaxis and start an acute inflammatory reaction. Phagocytosis by the polymorphonuclear leukocytes of the area of necrosis ensues. After phagocytosis, the polymorphonuclear leukocytes, which have a short life span, die and release lysosomal enzymes. The lysosomal enzymes lyse some of the pulp stroma and, together with the cellular debris of the dead polymorphonuclear leukocytes, form a purulent exudate (pus).

This inflammatory reaction produces microabscesses (acute pulpitis). The pulp, trying to protect itself, walls off the areas of the microabscesses with fibrous connective tissue. Microscopically, one sees the area of the abscess and a zone of necrotic tissue, with microorganisms present in the late carious state, along with lymphocytes, plasma cells, and macrophages. No microorganisms are found in the center of the abscess because of the phagocytic activity of the polymorphonuclear leukocytes. If the carious process continues to advance and penetrates the pulp, the histologic picture changes. One then sees an area of ulceration (chronic ulcerative pulpitis) that drains through the carious exposure into the oral cavity and reduces the intrapulpal pressure and, therefore, the pain. Histologically, one sees an area of necrotic tissue, a zone of infiltration by polymorphonuclear leukocytes, and a zone of proliferating fibroblasts forming the wall of the lesion, where calcific masses may be present. The areas beyond the abscess or the ulceration may be normal or may undergo inflammatory changes.

Irreversible pulpitis progresses to necrosis, as discussed later in this chapter.

Treatment

Treatment consists of complete removal of the pulp or pulpectomy. In posterior teeth, in which time is a factor, the removal of the coronal pulp or pulpotomy should be performed as an emergency procedure. Surgical removal should be considered if the tooth is not restorable.

Prognosis

The prognosis of the tooth is favorable if the pulp is removed and if the tooth undergoes proper endodontic therapy and an appropriate postendodontic restoration.

The characteristic features distinguishing reversible and irreversible pulpitis are given in **Table 4.1**.

C. Chronic Hyperplastic Pulpitis

Definition: *Chronic hyperplastic pulpitis, also known as pulpal hyperplasia or pulp polyp, is a productive pulpal inflammation due to an extensive carious exposure of a young pulp*. This disorder is characterized by the development of granulation tissue, covered at times with epithelium and resulting from long-standing, low-grade irritation.

Cause

Slow, progressive carious exposure of the pulp is the cause. For the development of hyperplastic pulpitis, a large, open cavity; a young, resistant pulp; and a chronic, low-grade

Table 4.1 Characteristic Distinguishing Features of Pulpal Diseases

Features	Reversible Pulpitis	Symptomatic Irreversible Pulpitis	Asymptomatic Irreversible Pulpitis
Description	A pulpal inflammation reversible in nature, which is commonly induced by dental caries and operative procedures, in which the patient responds to thermal or osmotic stimuli, but the symptoms disappear when the etiology is eliminated	A pulpal inflammation irreversible in nature, which is usually caused by deep dental caries or restorations. Spontaneous pain may occur or be precipitated by thermal or other stimuli. The pain is lingering and lasts for several minutes to hours.	A pulpal inflammation irreversible in nature, which is usually caused by deep dental caries or restorations. The tooth is asymptomatic and if left untreated will become symptomatic irreversible pulpitis, or the pulp might become necrotic.
Clinical features	Symptomatic in nature Nature of pain is moderate to sharp in response to thermal, sweet, or sour stimuli and is • Specific in response to stimuli, • Sharp and short in duration, and • Relieved on removal of stimuli	Symptomatic in nature Nature of pain is sharp, exaggerated, painful in response to thermal stimulus and is either one or a combination of the following symptoms: • Spontaneous • Continuous • Lingering • Nocturnal	Asymptomatic in nature
Key finding diagnosis	Nature of pain: Sharp, short pain that is relieved immediately on removal of stimuli	Nature of pain: Dull pain that lingers even after the removal of the stimuli	Patient is asymptomatic
Pain on percussion	Negative	Negative	Negative
Radiographic features	Radiographs show no periradicular changes	Radiographs show no periradicular changes	Radiographs show no periradicular changes
Treatment	Removal of causative agent	Pulpectomy	Pulpectomy

stimulus are necessary. Mechanical irritation from chewing and bacterial infection often provide the stimulus.

Symptoms

Chronic hyperplastic pulpitis is symptomless, except during mastication, when pressure of the food bolus may cause discomfort.

Diagnosis

This disorder is generally seen only in the teeth of *children* and *young adults*. The appearance of the polypoid tissue is clinically characteristic; a fleshy, reddish pulpal mass fills most of the pulp chamber or cavity or even extends beyond the confines of the tooth (**Fig. 4.16a** and **4.16b**). At times, the mass is large enough to interfere with comfortable closure of the teeth, although in the early stages of development, it may be the size of a pin. Polypoid tissue is less sensitive than normal pulp tissue and more sensitive than gingival tissue. Cutting of this tissue produces no pain, but pressure thereby transmitted to the apical end of the pulp does cause pain. This tissue bleeds easily because of a rich network of blood vessels. If the hyperplastic pulp tissue extends beyond the cavity of a tooth, it may appear as if the gum tissue is growing into the cavity. *To differentiate a pulp polyp from proliferating gingival tissue, one should raise and trace the stalk of the tissue back to its origin, the pulp chamber.*

It should not be difficult to diagnose chronic hyperplastic pulpitis by clinical examination alone. The hyperplastic pulp tissue in the pulp chamber or cavity of a tooth is characteristic in appearance. Radiographs generally show a large, open cavity with direct access to the pulp chamber (**Fig. 4.16c**). The tooth may respond feebly or not at all to the thermal test, unless one uses extreme cold, as from an ethyl chloride spray. More current than what is normal may be required to elicit a response by means of the electric pulp tester.

Differential Diagnosis

The appearance of hyperplastic pulpitis is characteristic and should be easily recognized. The disorder must be distinguished from proliferating gingival tissue.

Histopathology

Histopathologically, the surface of the pulp polyp is usually covered by stratified squamous epithelium. The pulp polyps of deciduous teeth are more likely to be covered with stratified squamous epithelium than those of permanent teeth. Such epithelium may be derived from the gingiva or from freshly desquamated epithelial cells of the mucosa or tongue.



(a) (b) (c)

Figure 4.16 (a and b) Chronic hyperplastic pulpitis with a characteristic polypoid tissue growth. (c) Radiographic appearance of a mandibular molar exhibiting chronic hyperplastic pulpitis.

The tissue in the pulp chamber is often transformed into granulation tissue, which projects from the pulp into the carious lesion. The granulation tissue is a young, vascular connective tissue containing polymorphonuclear neutrophils, lymphocytes, and plasma cells. The pulp tissue is chronically inflamed. Nerve fibers may be found in the epithelial layer.

Treatment

Treatment should be directed toward elimination of the polypoid tissue followed by extirpation of the pulp, provided the tooth can be restored. When the hyperplastic pulpal mass has been removed with a periodontal curette or spoon excavator, the bleeding can be controlled with pressure. The pulp tissue of the chamber is then completely removed, and a temporary dressing is sealed in contact with the radicular pulp tissue. The radicular pulp is extirpated at a later visit. If time permits, the entire procedure, pulpectomy, can be completed in a single visit.

Prognosis

The prognosis for the pulp is unfavorable. The prognosis for the tooth is favorable after endodontic treatment and adequate restoration.

D. Internal Resorption

Definition: *Resorption is defined as a condition associated with either a physiologic or a pathologic process resulting in loss of dentin, cementum, or bone.*

Internal resorption is an idiopathic slow or fast progressive resorptive process occurring in the dentin of the pulp chamber or in the root canals of the teeth.

Cause

The cause of internal resorption is not known, but such patients often have a history of trauma.

Symptoms

Internal resorption in the root of a tooth is asymptomatic. In the crown of the tooth, internal resorption may be manifested as a reddish area called *pink spot*. This reddish area represents the granulation tissue showing through the resorbed area of the crown.

Diagnosis

Internal resorption may affect either the crown (**Fig. 4.17**) or the root (**Fig. 4.18**) of the tooth, or it may be extensive enough to involve both (**Fig. 4.19**).

It may be a slow, progressive, intermittent process extending over 1 or 2 years; it may develop rapidly and may perforate the tooth within a matter of months. Although any tooth in the mouth can be involved, those most readily recognized are the maxillary anterior teeth. Usually, internal resorption is diagnosed during routine radiographic examination. The appearance of the *"pink spot"* occurs late in the resorptive process, when the integrity of the crown has been compromised. The radiograph usually shows a change in the appearance of the wall in the root canal or pulp chamber, with a round or ovoid radiolucent area.

Differential Diagnosis

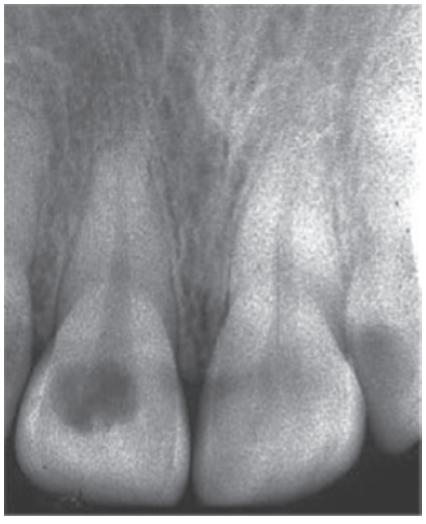
When internal resorption progresses into the periodontal space, a perforation of the root occurs; it is difficult to differentiate from external resorption; in internal resorption, the resorptive defect is more extensive in the pulpal wall than on the root surface. This defect usually is recognized by means of a radiograph.

Histopathology

Unlike caries, the internal resorption is the result of osteoclastic activity. The resorptive process is characterized by lacunae, which may be filled in by osteoid tissue. The osteoid tissue may be regarded as an attempt at repair. The presence of granulation tissue accounts for profuse bleeding when



(a)



(b)

Figure 4.17 (a) "Pink spot" indicative of an internal resorptive defect seen in the palatal aspect of the crown of the maxillary central incisor. (b) Radiographic image of the same tooth showing an internal resorptive defect with intact crown margins.

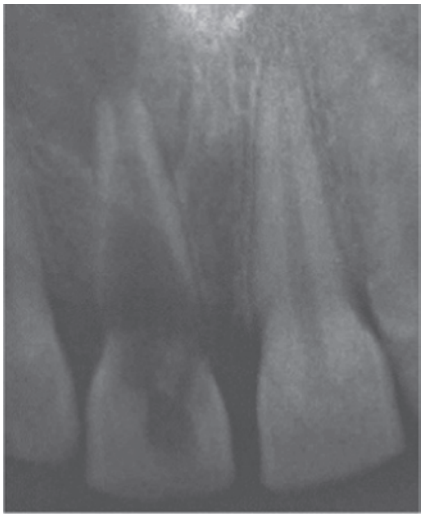


Figure 4.18 An extracted tooth showing evidence of internal resorption causing root perforation. *(Courtesy: Martin S. Spiller, USA.)*

the pulp is removed. Multinucleated giant cells or dentinoclasts are present. The pulp usually is chronically inflamed.



(a)



(b)

Figure 4.19 (a and b) Radiographic image of maxillary central incisors showing an internal resorptive defect with perforation of the root margin.

Metaplasia of the pulp, i.e., transformation to another type of tissue such as bone or cementum, sometimes occurs.

Treatment

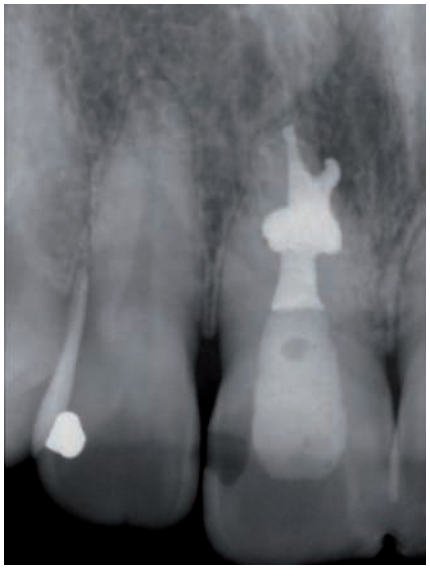
Extirpation of the pulp stops the internal resorptive process. Routine endodontic treatment is indicated, but obturation of the defect requires a special effort, preferably with a plasticized gutta-percha method. In many patients, however, the condition progresses unobserved because it is painless, until the root is perforated. In such a case, mineral trioxide aggregate (MTA) is recommended to repair the defect. When repair has been completed, the canal with its defect is obturated with plasticized gutta-percha (**Fig. 4.20**).

Prognosis

The prognosis is best before perforation of the root or crown occurs. In the event of a root–crown perforation, the



(a)



(b)

Figure 4.20 (a) Internal resorption in a maxillary incisor. (b) Postoperative view. *(Courtesy: Clifford Ruddle, USA.)*

prognosis is guarded and depends on the access to the perforation that permits surgical repair. (*Refer to Chapter 22 for surgical management of internal resorption.*)

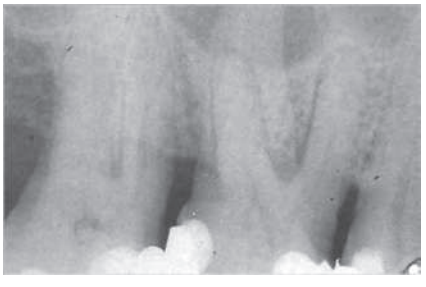
II. PULP DEGENERATION

Although degeneration of the pulp, as such, is seldom recognized clinically, the types of pulp degeneration should be included in a description of diseases of the pulp. Degeneration is generally present in the teeth of older people. It may also be the result of persistent, mild irritation in teeth of younger people, as in calcific degeneration of the pulp. It is not necessarily related to infection or caries, although a cavity or filling may be present in the affected tooth. The early stage of pulp degeneration does not usually cause definite clinical symptoms. The tooth is not discolored, and the pulp may react normally to electric and thermal tests. As degeneration of the pulp progresses, the tooth may become discolored, and the pulp will not respond to stimulation. The specific types of pulp degeneration are discussed in the following text.

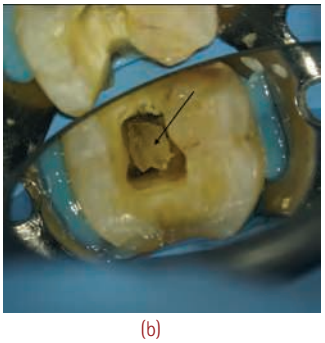
A. Calcific Degeneration

In calcific degeneration, part of the pulp tissue is replaced by calcific material, i.e., pulp stones or denticles. Calcification may occur either within the pulp chamber or within the root canal, but it is generally present in the pulp chamber (**Fig. 4.21**). The calcified material has a laminated structure, like the skin of an onion, and lies unattached within the body of the pulp. A denticle or pulp stone may become large enough to give an impression of the pulp cavity when the calcified mass is removed. In another type of calcification, the calcified material is attached to the wall of the pulp cavity and is an integral part of it. It is not always possible to distinguish one type from another on a radiograph. It is estimated that pulp stones are present in more than 60% of adult teeth. They are considered to be harmless concretions, although referred pain in a few patients has been ascribed to the presence of these calcifications in the pulp.

The calcific degeneration of the complete pulp space when it occurs as a sequela to a traumatic injury is known as *calcific metamorphosis*. This is a type of a pulpal response to trauma characterized by rapid deposition of hard tissue within the canal space. Such teeth usually remain clinically



(a)



(b)

Figure 4.21 (a) Radiographic appearance of a maxillary molar indicating extensive pulp chamber calcification. (b) Clinical photograph showing a pulp stone.



Figure 4.22 Calcific metamorphosis: complete obliteration of the pulp space seen in this maxillary central incisor with a history of trauma.

asymptomatic and may exhibit discoloration of the clinical crown. Obliteration of the pulp space is evident radiographically as an intracanal radio-opacity similar to the surrounding dentin (**Fig. 4.22**).

Clinical Note

Clinical management of a case of calcific metamorphosis is given below:

- Asymptomatic tooth
  - Esthetic management of the discolored tooth with a full-coverage restoration or laminate restoration
- Symptomatic tooth
  - Endodontic therapy using a microsurgical retrograde approach is recommended.
  - Endodontic therapy is not recommended unless the tooth is symptomatic.

B. Fibrous Degeneration

This form of degeneration of the pulp is characterized by replacement of the cellular elements by fibrous connective tissue. On removal from the root canal, such a pulp has the characteristic appearance of a leathery fiber (**Fig. 4.23**). This disorder causes no distinguishing symptoms to aid in the clinical diagnosis.

III. NECROSIS OF PULP

Necrosis is death of the pulp. It may be partial or total, depending on whether part of or the entire pulp is involved. Necrosis, although a sequel to inflammation, can also occur following a traumatic injury in which the pulp is destroyed



(a) (b) (c)

Figure 4.23 (a) Intact pulp after extirpation from the canal. (b) Extirpated pulp showing coronal calcification with an intact uninflamed radicular pulp. (*Courtesy: Jason Hales, USA.*) (c) Extirpated pulp showing calcific degeneration in the coronal third with fibrous degeneration in the remaining radicular pulp. (*Courtesy: Hemalatha Hiremath, India.*)

before an inflammatory reaction takes place. As a result, an ischemic infarction can develop and may cause a dry gangrenous necrotic pulp.

Types

A. *Pulp necrobiosis:* A tooth with necrobiosis has both inflamed (acute irreversible pulpitis) and necrotic (usually infected) pulp tissue.

   Grossman suggested the term "necrobiosis" because it accurately indicates the condition with "necro-" indicating necrosis and "-bio-" indicating the presence of vital tissue. The pulp sensibility tests usually do not correlate with the patient's symptoms

   The key diagnostic feature would be that the patient would report with mixed symptoms (i.e., symptoms of pulpitis and an infected root canal system at the same time).

B. *Pulp necrosis with no signs of infection:* In cases of necrosis without infection, there will be no periapical tissue response. Hence, there will be no apical periodontitis

   The key diagnostic feature would be that there would be no symptoms, no response to pulp sensibility tests, and no other abnormal findings.

C. *Necrotic and infected pulp:* When a pulp necroses as a result of bacterial invasion of the tooth, it will become infected over time. The patient would report with no pulp-related symptoms (i.e., no thermal sensitivity) may be no symptoms at all; any symptoms will be from the periapical tissues—hence, symptoms depend on the periapical status.

   The key diagnostic feature would be that there would be no response to pulp sensibility tests and there will be a periapical radiolucency.

Cause

Necrosis of the pulp can be caused by any noxious insult injurious to the pulp, such as bacteria, trauma, and chemical irritation.

Symptoms

An otherwise normal tooth with a necrotic pulp causes no painful symptoms. Frequently, discoloration of the tooth is the first indication that the pulp is dead. The dull or opaque appearance of the crown may be merely due to a lack of normal translucency. At other times, however, the tooth may have a definite grayish or brownish discoloration and may lack its usual brilliance and luster. The presence of a necrotic pulp may be discovered only by chance because such a tooth is asymptomatic, and the radiograph is nondiagnostic. Teeth with partial necrosis can respond to thermal changes, owing to the presence of vital nerve fibers passing through the adjacent inflamed tissue.

Diagnosis

Radiographs generally show a large cavity or filling, an open approach to the root canal, and a thickening of the periodontal ligament. Some teeth have neither a cavity nor a filling, and the pulp has died as a result of trauma. A few patients have a history of severe pain lasting from a few minutes to a few hours, followed by complete and sudden cessation of pain. In other cases, the patient is unaware that the pulp has died slowly and silently, without causing symptoms. A tooth with a necrotic pulp does not respond to cold, the electric pulp test, or the test cavity. In rare cases, however, a minimal response to the maximum current of an electric pulp tester occurs when the electric current is conducted through the moisture present in a root canal following liquefaction necrosis to neighboring vital tissue. In other patients, a few apical nerve fibers survive and respond similarly. Nerve fibers are resistant to inflammatory changes. A correlation of cold and electric tests and a history of pain, in conjunction with a thorough clinical examination, should establish a correct diagnosis.

Treatment

Treatment consists of complete removal of pulp (pulpectomy) and obturation of the root canals.

Histopathology

Histopathologically, necrosis is of two general types:

1. *Coagulation necrosis* results in the soluble portion of the tissue being precipitated or converted into a solid material.
   - *Caseation necrosis* is a form of coagulation necrosis in which the tissue is converted into a cheesy mass consisting chiefly of coagulated proteins, fats, and water.
2. *Liquefaction necrosis* results when proteolytic enzymes convert the tissue into a softened mass, a liquid, or amorphous debris.

The end products of pulp decomposition are those of protein decomposition, namely, hydrogen sulfide, ammonia, fatty substances, indican, ptomaines, water, and carbon dioxide. The intermediate products, such as indole, skatole, putrescine, and cadaverine, contribute to the unpleasant odor sometimes emanating from a root canal.

Necrotic pulp tissue, cellular debris, and microorganisms may be seen in the pulp cavity. The periapical tissue may be normal or slight evidence of inflammation of the apical periodontal ligament may be present.

Prognosis

The prognosis for the tooth is favorable if proper endodontic therapy is instituted.

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5 Diseases of the Periradicular Tissues

Life tells you nothing ... it shows you everything.
—Richard Bach

PERIRADICULAR DISEASES

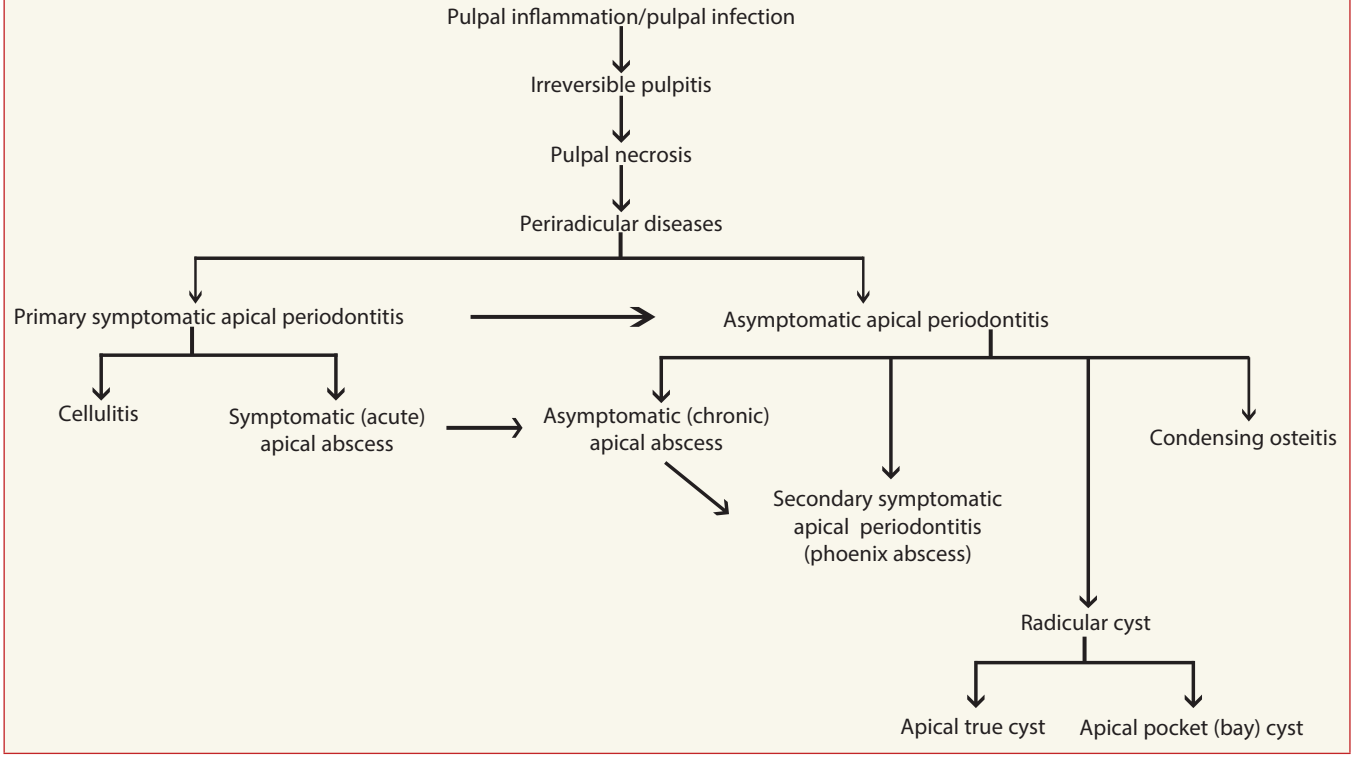
Pulpal disease is only one of the several possible causes of diseases of the periradicular tissues. Because of the inter-relationship between the pulp and the periradicular tissues, pulpal inflammation causes inflammatory changes in the periodontal ligament even before the pulp becomes totally necrotic. Bacteria and their toxins, immunologic agents, tissue debris, and products of tissue necrosis from the pulp reach the periradicular area through the various foramina of the root canals and give rise to inflammatory and immunologic reactions. Neoplastic disorders, periodontal conditions, developmental factors, and trauma can also cause periradicular diseases. The sequelae of periradicular diseases are given in **Box 5.1**.

The diseases of periradicular tissues can be classified on the basis of the etiology, symptoms, and histopathologic features. The clinical classification of the diseases of the periradicular tissues is given in **Box 5.2**. The post-treatment sequelae of periradicular diseases are given in **Box 5.3**.

The clinical markers to differentiate various periradicular diseases are given in **Table 5.1**.

Box 5.1

Sequelae of Periradicular Diseases



Box 5.2

Classification of Diseases of Periradicular Tissues

I. Clinical classification of periradicular diseases
   1. Symptomatic periradicular diseases
      (a) Primary symptomatic apical periodontitis (*previously known as acute apical periodontitis*)
      (b) Secondary symptomatic apical periodontitis (acute exacerbation of asymptomatic apical periodontitis or phoenix abscess)
      (c) Symptomatic (acute) alveolar abscess
   2. Asymptomatic periradicular diseases
      (a) Asymptomatic apical periodontitis (*previously known as chronic apical periodontitis*)
      (b) Asymptomatic (chronic) alveolar abscess
      (c) Condensing osteitis
   3. Persistent apical periodontitis
   4. External root resorption
   5. Diseases of the periradicular tissues of nonendodontic origin

II. Histopathologic classification of periradicular diseases:
   1. Apical granuloma
   2. Apical abscess
   3. Apical cyst

CLINICAL CLASSIFICATION OF PERIRADICULAR DISEASES

I. SYMPTOMATIC PERIRADICULAR DISEASES

These disorders include symptomatic apical periodontitis, acute alveolar abscess, and acute exacerbation of a chronic lesion (phoenix abscess).

1. Primary Symptomatic Apical Periodontitis (Previously known as Acute Apical Periodontitis)

Definition: *Primary symptomatic apical periodontitis is a painful inflammation of the periodontium as a result of trauma, irritation, or infection through the root canal,* ***regardless of whether the pulp is vital or non-vital****, producing clinical symptoms including painful response to biting and percussion.*

Causes

- Primary symptomatic apical periodontitis may occur in a ***vital tooth*** that has experienced occlusal trauma caused by
  - Abnormal occlusal contacts
  - Recently inserted restoration extending beyond the occlusal plane
  - Wedging of a foreign object between the teeth, such as a toothpick or food
  - Traumatic blow to the teeth
- Primary symptomatic apical periodontitis may also be associated with the ***nonvital tooth***. It may be caused by
  - Sequelae of pulpal diseases, i.e., the diffusion of bacteria and noxious products from an inflamed or necrotic pulp
  - Iatrogenic causes that include the following:
    - Root canal instrumentation forcing bacteria or debris inadvertently through the apical foramen
    - Forcing of irritating irrigants or medicaments through the apical foramen
    - Extension of obturating material through the apical foramen to impinge on periradicular tissues
    - Perforation of the root
    - Overinstrumentation during shaping and cleaning of root canals

Symptoms

- The symptoms of primary symptomatic apical periodontitis are *pain* and *tenderness* of the tooth.
- The tooth may be slightly sore, sometimes only when it is percussed in a certain direction, or the soreness may be severe.
- The tooth may feel extruded and the patient may have pain on closure and mastication.

Diagnosis

- *Pain on percussion* is the classical diagnostic feature of primary symptomatic apical periodontitis.
- The symptoms are either the result of irritation originating from endodontic treatment, caused by overinstrumentation (**Fig. 5.1**), medicinal irritants, or overfilling, in which case the tooth is pulpless, or the result of noxious stimuli irritating the periodontal ligament, in which case the pulp is vital.
- The tooth is tender on percussion or slight pressure, whereas the mucosa overlying the root apex may or may not be tender to palpation.



Figure 5.1 Overinstrumentation beyond the apex causing primary symptomatic apical periodontitis.

Table 5.1 Clinical Markers to Differentiate Periradicular Diseases

	Symptomatic Apical Periodontitis (Acute)		Asymptomatic Apical Periodontitis (Chronic)	Asymptomatic (Chronic) Apical Abscess	Symptomatic (Acute) Apical Abscess
	Primary	Secondary			
History	• Pain present for short time (few days or less) • Pain usually quite severe • Pain to biting and pressure on tooth • Pain to even light touch on tooth	• Pain present for short time (few days or less) • Pain usually quite severe • Pain to biting and pressure on tooth • No thermal sensitivity	• Usually no symptoms • Patient may report a history of occasional "awareness" of tooth feeling different	• Usually no symptoms • Draining sinus (patients refer to "gum boil," "lump," "ulcer") • Draining sinus usually intraoral (on the oral mucosa), may be extra oral (on the face) • Patient may report with previous history of pulp-related symptoms, endodontic treatment	• Pain present for short time (few days or less) • Swelling has rapid onset (hours or less than 1 day) • Pus will be present • Pain is severe • Pain to biting and pressure on tooth • Pain to touch even with light pressure • Occasionally patient may complain of feeling unwell and having fever
Diagnostic Findings	• No radiographic periapical changes • Pain is recent and severe • Pain on touching the tooth, with pressure and on percussion	• Periapical radiolucency • Pain is recent and severe • Pain with pressure and on percussion	• Periapical radiolucency • No pain or only occasional "awareness" of tooth	• Draining sinus • Periapical radiolucency • No pain or occasional "awareness"	• No radiographic periapical changes • Swelling present • Pain is recent and severe • Pain on touching the tooth, with pressure and on percussion
Radiographic Findings	• Caries seen if extensive enough • Normal PDL space, lamina dura • No periapical radiolucency	• Caries seen if extensive enough • Periapical radiolucency present indicates that asymptomatic apical periodontitis has been present for some time	• Caries seen if extensive enough • Periapical radiolucency will be present • Some cases will have evidence of previous endodontic treatment	• Caries seen if extensive enough • Periapical radiolucency will be present • A gutta-percha point inserted into draining sinus can trace its origin to infected tooth	• Caries seen if extensive enough • Normal PDL space, lamina dura • No periapical radiolucency, if present rarely due to extrusion of tooth from normal position
Clinical Findings	• Due to caries, restoration breaking down or crack • Severe pain to percussion • Pain when pushing the tooth • No response to pulp sensibility test • Sometimes due to traumatic occlusion, the tooth being extruded from normal position resulting in periapical inflammation	• Due to caries, restoration breaking down or crack • Very tender to percussion • No response to pulp sensibility test	• Due to caries, restoration breaking down or crack • Tooth is not tender to percussion but will sometimes feel "different" to percussion • No response to pulp sensibility to tests	• Due to caries, restoration breaking down or crack • Tooth is not tender to percussion • May feel "different" to percussion • No response to pulp sensibility tests • Draining sinus evident-Intra oral or extra oral • Palpation or pressure on the tissues overlying the periapical region may cause pus to extrude from the draining sinus • Often insert gutta-percha point into draining sinus to trace it radiographically	• Due to caries, restoration breaking down or crack • Swelling associated with tooth • Pain to percussion • Pain when pushing the tooth • No response to pulp sensibility test • Sometimes due to traumatic occlusion, the tooth being extruded from normal position resulting in periapical inflammation • Occasionally patient would have fever, malaise, lymphadenopathy



Figure 5.2 Minimal periradicular radiographic changes in a carious tooth with pulpal involvement showing signs and symptoms of primary symptomatic apical periodontitis.



Figure 5.3 Normal periradicular tissue in a vital tooth with primary symptomatic apical periodontitis after the placement of a deep restoration with abnormal occlusal contacts.

Radiographic changes are dependent on the pulp vitality status of the involved tooth.

- *Nonvital tooth:* A slight widening of the apical periodontal ligament space and loss of the apical lamina dura of the involved pulpless tooth may be seen (**Fig. 5.2**).
- *Vital tooth:* No radiographic changes are seen with normal periradicular structures (**Fig. 5.3**).

Differential Diagnosis

- The key diagnostic difference between primary symptomatic apical periodontitis and secondary symptomatic apical periodontitis are the following:
  - *Absence of a periradicular radiolucency:* Primary symptomatic apical periodontitis
  - *Presence of a periradicular radiolucency:* Secondary symptomatic apical periodontitis
- The key diagnostic difference between primary symptomatic apical periodontitis and symptomatic (acute) apical abscess would be extreme clinical symptoms of swelling and pain that is associated with the breakdown of periradicular tissue, rather than merely an inflammatory reaction of the periodontal ligament. The patient's history, symptoms, and clinical test results help the clinician to differentiate these diseases.

Clinical Note

- *Pain on percussion* is the diagnostic feature of primary symptomatic apical periodontitis.
- It is distinguishable from asymptomatic apical periodontitis in which the tooth has no pain on percussion and has distinct radiographic periradicular bone changes.

Bacteriology

The pulp and periradicular tissues may be sterile if periodontitis is due to a blow, occlusal trauma, or chemical or mechanical irritation during endodontic treatment. Bacteria or toxic bacterial products present in the root canal may either be forced through or grow beyond the apical foramen and may irritate the apical periodontal tissues.

Histopathology

An inflammatory reaction occurs in the apical periodontal ligament. The blood vessels are dilated, polymorphonuclear leukocytes are present, and an accumulation of serous exudate distends the periodontal ligament and extrudes the tooth slightly. If the irritation is severe and continued, osteoclasts may become active and may break down the periradicular bone; the next developmental stage, namely, acute alveolar abscess, may follow.

Treatment

- Treatment of primary symptomatic apical periodontitis consists of determining the cause and relieving the symptoms.
- It is particularly important to determine whether apical periodontitis is associated with a vital or a pulpless tooth.
- Adjustment of high points (in hyperocclusion cases) and removal of irritants (in case of nonvital infected pulp) is the immediate line of management. When the acute phase has subsided, the tooth is treated by conservative means.

Prognosis

The prognosis for the tooth is generally favorable. The occurrence of symptoms of primary symptomatic apical periodontitis during endodontic treatment in no way affects the ultimate outcome of the treatment.

2. Secondary Symptomatic Apical Periodontitis (Acute Exacerbation of Asymptomatic Apical Periodontitis or Phoenix Abscess)

Definition: *This condition is an acute inflammatory reaction superimposed on an existing asymptomatic apical periodontitis.*

Synonyms

Acute exacerbation of asymptomatic apical periodontitis and *phoenix abscess.*

Causes

When chronic periradicular diseases, such as asymptomatic apical periodontitis, are in a state of equilibrium, the periradicular tissues are asymptomatic. Sometimes, noxious stimulus from a diseased pulp can cause acute inflammatory response in these dormant lesions.

- Lowering of body's defenses due to influx of bacterial toxins from the root canal may lead to acute inflammatory response.
- Irritation during root canal instrumentation may also trigger acute inflammatory response in a previously asymptomatic tooth.

Symptoms

Initially, the tooth may be tender on palpation. As inflammation progresses, the tooth gets elevated from its socket and becomes sensitive. The mucosa over the radicular area may appear red and swollen and is sensitive to palpation.

Diagnosis

- The exacerbation of a chronic lesion is most commonly associated with the initiation of root canal therapy in a completely asymptomatic tooth with a well-defined periradicular lesion (**Fig. 5.4**).



Figure 5.4 Well-defined periradicular lesion evident in a case of secondary symptomatic apical periodontitis.

- The patient may also have a history of trauma that leads to discoloring of the tooth over a period of time or a postoperative pain that had subsided until then.
- Lack of response to vitality tests diagnoses a necrotic pulp. On rare occasions, a tooth may respond to the electric pulp test because of fluid in the root canal or in a multi-rooted tooth.

Differential Diagnosis

An acute exacerbation of a chronic lesion causes symptoms similar to those of a symptomatic (acute) alveolar abscess. Because the treatment of both lesions is the same, no differential diagnosis is needed. This tooth can be distinguished from a tooth with painful pulpitis by testing for pulp vitality.

Clinical Note

- A secondary symptomatic apical periodontitits is an acute symptomatic abscess with distinct periradicular radiographic changes.
- It can be differentiated from a symptomatic (acute) apical abscess in which widening of the periodontal ligament space is the only radiographic change seen.

Bacteriology

An abscess usually forms as a result of microbial infection, although some abscesses, called *sterile abscesses*, form in the absence of bacteria. The periradicular lesions are usually devoid of bacteria, except for transient bacteria.

Histopathology

Areas of liquefaction necrosis with disintegrating polymorphonuclear neutrophils and cellular debris (pus) are observed. These areas are surrounded by infiltration of macrophages and some lymphocytes and plasma cells.

Treatment

The treatment of acute exacerbation of a chronic lesion is the same as that of a symptomatic (acute) apical abscess.

Prognosis

The prognosis for the tooth is good once the symptoms have subsided.

3. Symptomatic (Acute) Apical Abscess

Definition: *A symptomatic (acute) apical abscess is an inflammatory reaction to pulpal infection and necrosis characterized by rapid onset, spontaneous pain, tenderness of the tooth to pressure, pus formation, and eventual swelling of associated tissues.*

Synonyms

Acute abscess, acute alveolar abscess, acute dentoalveolar abscess, acute periapical abscess, and acute radicular abscess.

Causes

- Although a symptomatic (acute) abscess may be the result of trauma or of chemical or mechanical irritation, the immediate cause is generally bacterial invasion of dead pulp tissue.
- At times, neither a cavity nor a restoration is present in the tooth, but the patient has a history of trauma.
- Because the pulp tissue is solidly enclosed, no drainage is possible and the infection continues to extend in the direction of least resistance, i.e., through the apical foramen, and thereby involves the periodontal ligament and the periradicular bone.

Symptoms

- The first symptom may be a mere tenderness of the tooth that may be relieved by continued slight pressure on the extruded tooth to push it back into the alveolus.
- Later, the patient has severe, throbbing pain, with attendant swelling of the overlying soft tissue. As the infection progresses, the swelling becomes more pronounced and extends beyond the original site. The tooth becomes more painful, elongated, and mobile.
- At times, the pain may subside or cease entirely while the adjacent tissue continues to swell.
  If left unattended, the infection may progress to asymptomatic (chronic) apical abscess wherein the contained pus may break through to form a sinus tract, usually opening in the labial or buccal mucosa. It may further progress on to osteitis, periosteitis, cellulitis, or osteomyelitis.
- Swelling is usually seen in the adjacent tissues close to the affected tooth. When swelling becomes extensive, the resulting cellulitis may distort the patient's appearance grotesquely. At times, such swelling extends beyond the immediate vicinity of the diseased periradicular tissues.
  The tissue at the surface of the swelling appears taut and inflamed; pus starts to form beneath it. Such liquefaction is the result of activity of proteolytic enzymes such as *trypsin* and *cathepsin*. The surface tissues become distended from the pressure of the underlying pus and finally rupture from this pressure and lack of resistance caused by continued liquefaction. The pus may extrude through a tiny opening, which becomes larger with time, or from two or more openings, depending on the degree of softening of the tissues and on the amount of pressure from the contained pus. *This process is the beginning of an asymptomatic (chronic) alveolar abscess.* The sinus tract ultimately heals by granulation after the elimination of the infection in the root canal.
- In addition to the localized symptoms of a symptomatic (acute) alveolar abscess, a general systemic reaction of greater or lesser severity may occur. The patient may appear *pale, irritable*, and weakened from pain and loss of sleep, as well as from absorption of septic products. Patients with mild cases may have only a slight *rise in temperature* (99–100°F), whereas in those with severe cases, the temperature may reach several degrees above normal (102–103°F). The fever is often preceded or accompanied by chills. Intestinal stasis can occur, manifesting itself orally by a coated tongue and foul breath. The patient may complain of *headache* and *malaise*.

Clinical Note

- When a maxillary anterior tooth is involved, particularly a cuspid, swelling of the upper lip may extend to one or both the eyelids.
- When a maxillary posterior tooth is affected, the cheek may swell to an immense size, distorting the patient's facial features (**Fig. 5.5**).
- In the case of a mandibular anterior tooth, the swelling can involve the lower lip and chin, and in severe cases, the neck.
- When a mandibular posterior tooth is involved, swelling of the cheek may extend to the ear or even around the border of the jaw into the submaxillary region.

Diagnosis

- The diagnosis is generally made quickly and accurately from the clinical examination and from the subjective history given by the patient.
- In the early stages, however, it may be difficult to locate the tooth because of the absence of clinical signs and the presence of diffuse, annoying pain.
  The tooth is easily located when the infection has progressed to the point of periodontitis and extrusion of the tooth; a radiograph may help the clinician to determine the tooth affected by showing a cavity, a defective restoration, or slight widening of the apical periodontal ligament space of the involved tooth.
- A diagnosis may be confirmed by means of the electric pulp test and by thermal tests. The affected pulp is necrotic and does not respond to electric current or to application of cold. The tooth may be tender to percussion, or the patient may state that it hurts to chew with the tooth,



Figure 5.5 Extraoral swelling in symptomatic (acute) alveolar abscess.

the apical mucosa is tender to palpation, and the tooth may be mobile and extruded.

Clinical Note

- A symptomatic (acute) alveolar abscess is painful and rapidly progressing sequelae of symptomatic apical periodontitis.
- A slight widening of the apical periodontal ligament space and loss of the apical lamina dura of the involved pulpless tooth may be the only radiographic changes that are seen (**Fig. 5.6**).

Differential Diagnosis

- Symptomatic (acute) alveolar abscess should be differentiated from periodontal abscess.
  A periodontal abscess is an accumulation of pus along the root surface of a tooth that originates from infection in the supporting structures of the tooth. It is associated with a periodontal pocket and is manifested by swelling and mild pain. On pressure, pus may exude near the edematous tissue or through the sulcus. The swelling is usually located opposite the midsection of the root and gingival border, rather than opposite the root apex or beyond it (**Fig. 5.7**). A periodontal abscess is generally associated with vital rather than with pulpless teeth, in contrast to an acute alveolar abscess, in which the pulp is dead. *Tests for pulp vitality are useful in establishing a correct diagnosis.*
- Symptomatic (acute) alveolar abscess should be differentiated from asymptomatic (chronic) alveolar abscess. The diagnostic feature of an asymptomatic (chronic) apical abscess is the ***presence of a sinus opening*** that allows the acute symptoms to subside due to drainage of the pus.

Bacteriology

In an abscess, the concentration of microorganisms is unusually large. Streptococci and staphylococci are generally recovered, but if the purulent material is collected as it drains out of the root canal, it may be sterile because it will consist chiefly of dead leukocytes and dead bacteria. An analysis of 100 consecutive cases of acute alveolar abscess failed to show a relationship between any specific type of organism and the abscess.

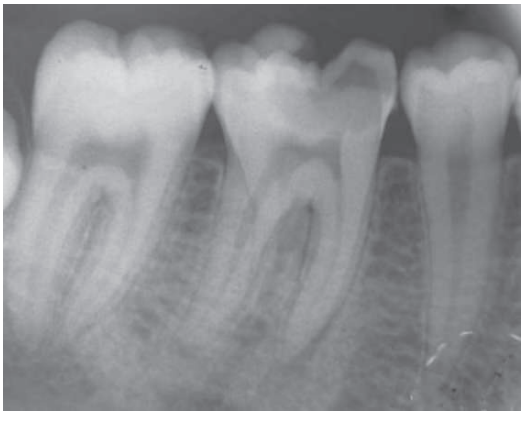


Figure 5.6 Early radiographic changes seen in a mandibular molar with symptomatic (acute) alveolar abscess.

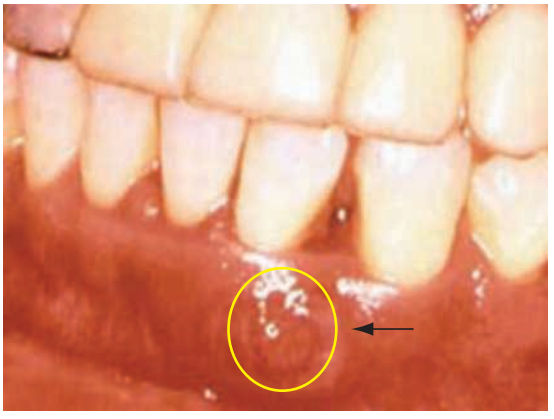


Figure 5.7 Periodontal abscess between the right mandibular, the lateral incisor, and the cuspid.

Histopathology

The marked infiltration of polymorphonuclear leukocytes and the rapid accumulation of inflammatory exudate in response to an active infection distend the periodontal ligament and thereby elongate the tooth. If the process continues, the periodontal fibers will separate and the tooth will become mobile. Although some mononuclear cells may be found, the chief inflammatory cells are polymorphonuclear leukocytes. As the bony tissue in the region of the root apex is resorbed, and as more and more of the polymorphonuclear leukocytes die in their battle with the microorganisms, pus is formed. Microscopically, one sees an empty space or spaces, where suppuration has occurred, surrounded by polymorphonuclear and some mononuclear cells. The root canal itself may appear to be devoid of tissue, and instead, clumps of microorganisms and debris may be observed.

Treatment

The immediate treatment consists of establishing drainage and controlling the systemic reaction. The management of a symptomatic (acute) alveolar abscess is given in Chapter 7 (**Fig. 5.8**).

Prognosis

The prognosis for the tooth is generally favorable, depending on the degree of local involvement and the amount of tissue destruction. Although the symptoms of a symptomatic (acute) alveolar abscess may be severe, pain and swelling generally subside if adequate drainage is established. In most cases, the tooth can be saved by endodontic treatment, and the severity of the symptoms need not bear any relation to the ease or difficulty of treatment. When purulent material has been discharged through the gingival sulcus and the periodontium has been extensively destroyed, the prognosis is guarded.

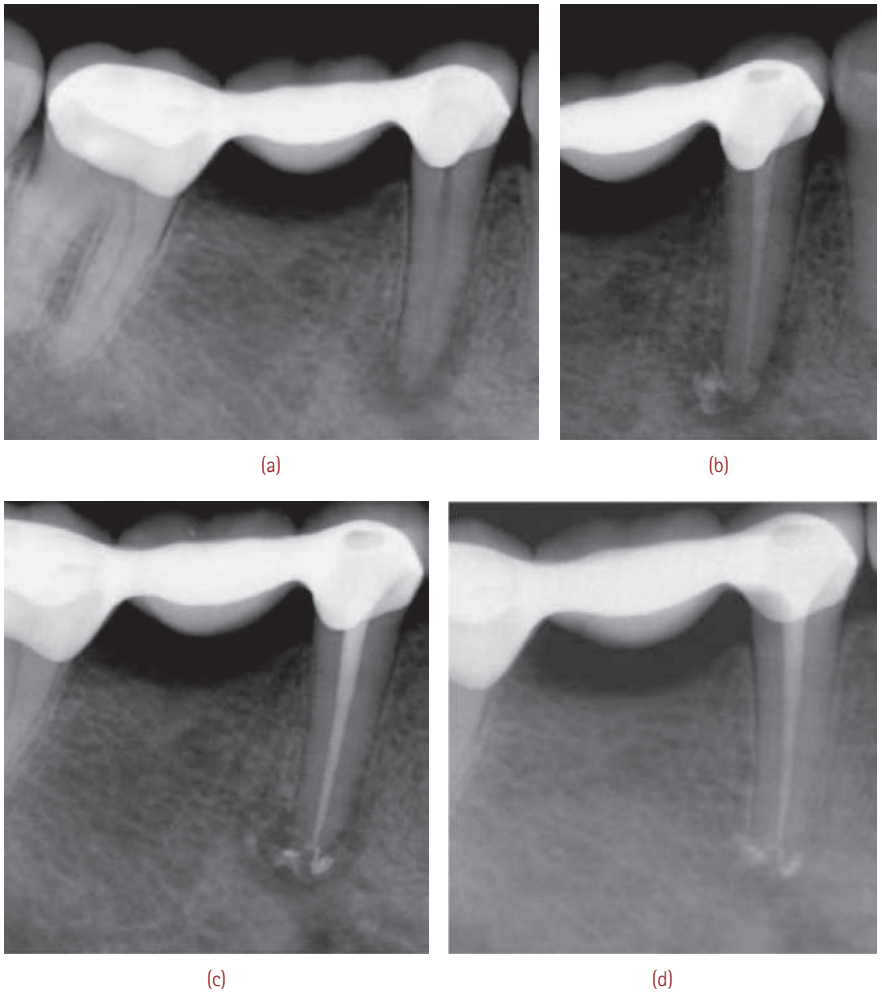


Figure 5.8 (a) Symptomatic (acute) alveolar abscess in relation to a mandibular premolar which is an abutment for a fixed partial denture. (b) Canal irrigated and intracanal calcium hydroxide placed for a period of 2 weeks. (c) Root canal obturation after thorough cleaning and shaping. (d) Two-year follow-up showing healing of the periradicular tissues.

In selected cases, combined periodontal and endodontic treatment will restore the tooth to functional health.

II. ASYMPTOMATIC PERIRADICULAR DISEASES

1. Asymptomatic Apical Periodontitis (Previously known as Chronic Apical Periodontitis)

Definition: *Asymptomatic apical periodontitis is the symptomless sequelae of symptomatic apical periodontitis and is characterized radiographically by periradicular radiolucent changes (**Fig. 5.9**) and histologically by the lesion dominated with macrophages, lymphocytes, and plasma cells.*

Causes

The cause of an asymptomatic apical periodontitis is death of the pulp, followed by a continued, mild infection or irritation of the periradicular tissue that stimulates a productive cellular reaction. Asymptomatic apical periodontitis may be

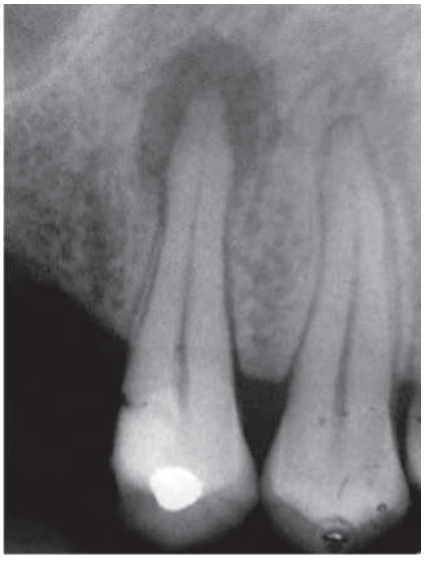


Figure 5.9 Characteristic periradicular radiolucency seen in a maxillary premolar with asymptomatic apical periodontitis.

seen as a *chronic, low-grade defensive reaction of the alveolar bone to the irritation from the root canal.*

Asymptomatic apical periodontitis develops only some time after the pulp has died. In some cases, it progresses to become a chronic alveolar abscess. Experimental evidence has shown that *asymptomatic apical periodontitis is a cell-mediated response to pulpal bacterial products.*

Symptoms

Asymptomatic apical periodontitis is clinically asymptomatic and may not produce any subjective reaction, except in rare cases when it breaks down and undergoes suppuration.

Diagnosis

The presence of asymptomatic apical periodontitis is generally discovered by routine radiographic examination. The area of rarefaction is well defined, with lack of continuity of the lamina dura. An exact diagnosis can be made only by microscopic examination, however. The mucosa over the root apex may or may not be tender to palpation. The tooth does not respond to thermal or electric pulp tests. The patient may give a history of pulpalgia that subsided.

Differential Diagnosis

Asymptomatic apical periodontitis cannot be differentiated from other periradicular diseases unless the tissue is examined histologically. Fortunately, the periradicular diseases are all treated alike, usually endodontically, and do not have to be differentiated. Thus, a necrotic pulp and a periapical area of rarefaction on a radiograph are usually sufficient evidence of the presence of periradicular disease.



Clinical Note

- A tooth with asymptomatic apical periodontitis is generally *not tender to percussion*, and this characteristically *differentiates* it from symptomatic apical periodontitis.
- A tooth with asymptomatic apical periodontitis will also be characterized with *distinct periradicular radiographic changes* while a tooth with symptomatic apical periodontitis will either have no radiographic changes or have mild widening of the periodontal ligament space only.

Bacteriology

The periapical tissue is sterile in most cases, even though microorganisms may be present in the root canal. Bacteriologic examination of the periradicular tissues has shown that bacteria, although found in the apical area of the root canal, are seldom present in the periradicular area.

Treatment

Root canal therapy may suffice for the treatment of asymptomatic apical periodontitis. Removal of the cause of inflammation is usually followed by resorption of the granulomatous tissue and repair with trabeculated bone (**Fig. 5.10**).

Prognosis

The prognosis for long-term retention of the tooth is excellent.

2. Asymptomatic (Chronic) Apical Abscess

Definition: *An asymptomatic (chronic) apical abscess is a longstanding, low-grade infection of the periradicular alveolar bone, generally symptomless and characterized by the presence of an abscess draining through a sinus tract.*

Synonyms

Chronic suppurative apical periodontitis, chronic alveolar abscess, chronic periradicular abscess, chronic peri-apical abscess.

Causes

The source of the infection is in the root canal. Chronic alveolar abscess is a natural sequela of death of the pulp with extension of the infective process periapically, or it may result from a preexisting acute abscess.

Symptoms

A tooth with a chronic alveolar abscess is generally asymptomatic, or only mildly painful. At times, such an abscess is detected only during routine radiographic examination or because of the presence of a sinus tract, which can be either intraoral (**Fig. 5.11a and 5.11c**) or extraoral (**Fig. 5.12**). The sinus tract usually prevents exacerbation or swelling by providing continual drainage of the periradicular lesion.

Diagnosis

- Clinical examination may show a cavity, a composite or metallic restoration, or a full-coverage crown under which the pulp may have died without causing symptoms. The radiograph often shows a diffuse area of bone rarefaction, but the radiographic appearance of the lesion is nondiagnostic. The periodontal ligament is thickened. The rarefied area may be so diffuse as to fade indistinctly into normal bone. When asked, the patient may remember a sudden, sharp pain that subsided and has not recurred, or he or she may relate a history of traumatic injury.
- The first sign of osseous breakdown is radiographic evidence seen during routine examination or discoloration of the crown of the tooth.
- A radiograph taken after the insertion of a guttapercha cone into the sinus tract often shows the involved tooth by tracing the sinus tract to its origin (**Fig. 5.13**). *At times, the sinus tract is several teeth away from the cause.*
- When an open cavity is present in the tooth, drainage may occur by way of the root canal.
- In other cases, the patient may complain of slight pain in relation to the tooth, particularly during mastication. The tooth does not react to the electric pulp test or to thermal tests.



(a) (b) (c)

Figure 5.10 (a) Asymptomatic apical periodontitis in a poorly obturated mandibular molar. (b) Radiographic view after completion of retreatment and obturation of the root canals. (c) Two-year follow-up shows complete resolution of the periradicular pathology. (*Courtesy: Julian Webber, England.*)

Clinical Note

The point at which the pus breaks into the mouth depends on the thickness of the alveolar bone and the overlying soft tissues. Obviously, the confined pus takes the path of least resistance.

- In the upper jaw, this path is generally along the labial alveolar plate (**Fig. 5.11a**) which is thinner than the palatal plate of bone.
- Suppuration from the upper lateral incisors or from the palatal root of a maxillary molar may occur palatally because these roots lie in closer proximity to the palatal plate of bone (**Fig. 5.11b**).
- In the lower jaw, swelling generally takes place in the vestibule of the mouth along the buccal alveolar plate (**Fig. 5.11c**), but it may occur along the lingual alveolar wall in the case of lower molars because of the position of the roots in their alveoli.

Differential Diagnosis

Clinically, it is impossible to establish an accurate diagnosis among the periradicular diseases with radiographs alone. Historically, the presence of a diffuse area indicated an abscess, a circumscribed area indicated an asymptomatic apical periodontitis, and a sclerotic bony outline was a sign of a cyst; however, all attempts to correlate the radiographic appearance of an area with its histopathologic features failed. As a result, a proper and accurate diagnosis can be made only when a tissue specimen has been examined histologically.

Histopathology

As the infective process extends to the periradicular tissues or as toxic products diffuse through the apical foramen, some of the periodontal fibers at the root apex are detached or lost, followed by destruction of the apical periodontal ligament. The apical cementum may also become affected. Lymphocytes and plasma cells are generally found towards the periphery of the abscessed area, with variable numbers of polymorphonuclear leukocytes at the center. Mononuclear cells may also be present. Fibroblasts may start to form a capsule at the periphery. The root canal itself may appear to be empty, or cellular debris may be present.

The suppurative material from the interior of the abscess is discharged on the mucosa or gingiva. The drainage may or may not be continuous. When the drainage is intermittent, the discharge is preceded by swelling of the area due to closure of the sinus opening. When pressure from the contained pus is sufficient to rupture the thin wall of soft tissue, the suppurative material is discharged into the mouth through a small

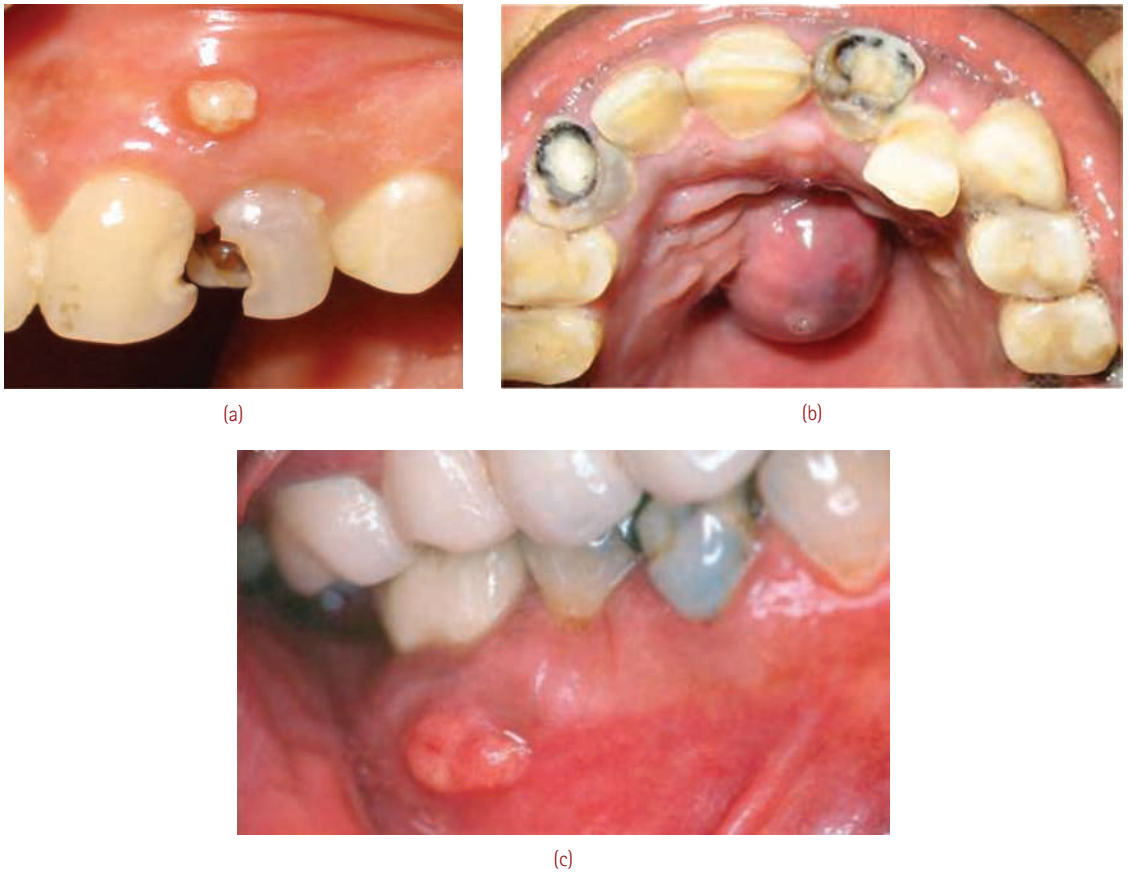


Figure 5.11 (a) Intraoral labial sinus opening in relation to the carious maxillary lateral incisor. (b) Intraoral palatal sinus opening in relation to the carious maxillary central incisor. (c) Intraoral buccal sinus opening in relation to the carious mandibular premolar.



Figure 5.12 Extraoral sinus opening. (*Courtesy: Karthiga Kannan, India.*)

opening or stoma (foramen). The opening may heal and may close again only to be reopened when pressure from the contained pus overcomes the resistance of the undermined layer of soft tissue. This small elevation of the mucosa is often referred to as a *"gumboil"* by the layman and is frequently observed in conjunction with infection of the deciduous and permanent teeth (**Fig. 5.14**). Although the sinus opening is usually opposite the root apex on the labial or buccal mucosa, it may be far removed from the affected tooth.

A sinus tract may develop on the surface of the face in a patient with a chronic alveolar abscess, particularly in a young person. When a sinus tract associated with lower anterior teeth opens into the face, it generally opens near the symphysis of the jaw, whereas a sinus tract associated with posterior teeth, chiefly the first molar, generally opens along the inferior border of the mandible in the region of the affected tooth. In rare cases, the purulent material encounters least resistance along the root and passes by way of a sinus tract into the gingival sulcus, where it exits creating the impression of a pocket of periodontal origin.

If a sinus tract is present, it will close up and disappear without any special treatment as soon as the root canal has been cleaned and shaped and an intracanal medicament has been sealed in to reduce the bacterial flora.

Treatment

Treatment consists of elimination of infection in the root canal. Once this end is accomplished and the root canal is filled, repair of the periradicular tissues generally takes place (**Fig. 5.15**).

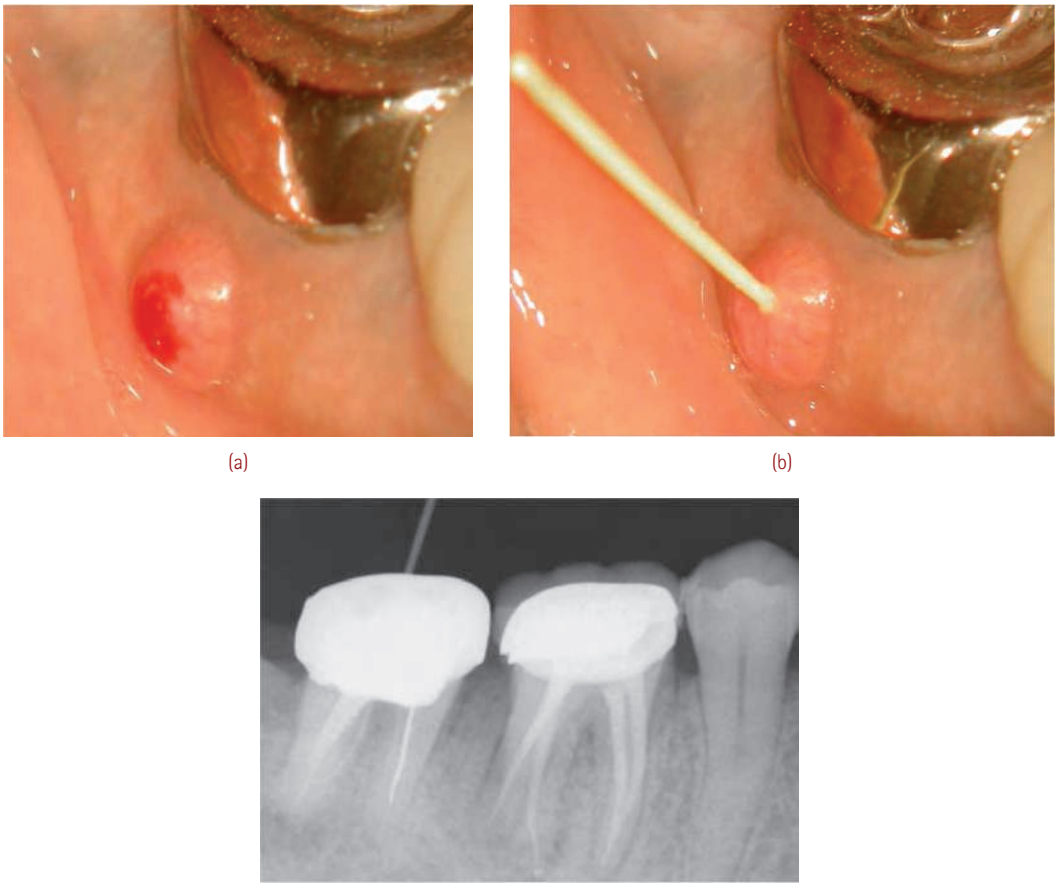


Figure 5.13 (a) Asymptomatic (chronic) alveolar abscess with a buccal sinus drainage in relation to root canal–treated mandibular first and second molars. (b) Gutta-percha tracing being done to locate the source of infection. (c) Gutta-percha cone is radio-graphically seen tracing the source of infection to the distal root of the root canal–treated mandibular second molar.



Figure 5.14 Repeated episodes of sinus discharge lead to a fibrous thickening and elevation of the mucosa. (*Courtesy: (a)* A.R. *Pradeep Kumar, India*.)



Figure 5.15 (a) Asymptomatic (chronic) apical abscess in relation to a maxillary central incisor with a history of surgical endodontic therapy. (b) Gutta-percha tracing being done through the labial sinus opening. (c) Tracing indicative of periradicular infection in relation to the apical third of the involved tooth. (d) Retreatment of the root canal completed. (e) Complete resolution of the sinus after completion of the treatment. (f) Three-year follow-up radiograph showing healing of the periradicular region. (*Courtesy: Jeeraphat Jantarat, Thailand.*)

Prognosis

The prognosis for the tooth depends on proper cleaning, shaping, and obturation of the root canals. In addition, other factors such as the periodontal status, restorative needs, and potential for functional rehabilitation help to determine the prognosis.

3. Condensing Osteitis

Definition: *Condensing osteitis is a diffuse radiopaque lesion believed to represent a localized bony reaction to a low-grade inflammatory stimulus, usually seen at the apex of a tooth in which there has been a long-standing pulpal pathosis.*

Causes

Condensing osteitis is a mild irritation from pulpal disease that stimulates osteoblastic activity in the alveolar bone.

Symptoms

This disorder is usually asymptomatic. It is discovered during routine radiographic examination.

Diagnosis

The diagnosis is made from radiographs. Condensing osteitis appears in radiographs as a localized area of *radiopacity* surrounding the affected root. It is an area of dense bone with reduced trabecular pattern (**Fig. 5.16**). The mandibular posterior teeth are most frequently affected.

Histopathology

Microscopically, condensing osteitis appears as an area of dense bone with reduced trabecular borders lined with osteoblasts. Chronic inflammatory cells, plasma cells, and lymphocytes are seen in the scant bone marrow.



Figure 5.16 Condensing osteitis: characteristic radiopacity in relation to the mesial root of this mandibular molar.

Treatment

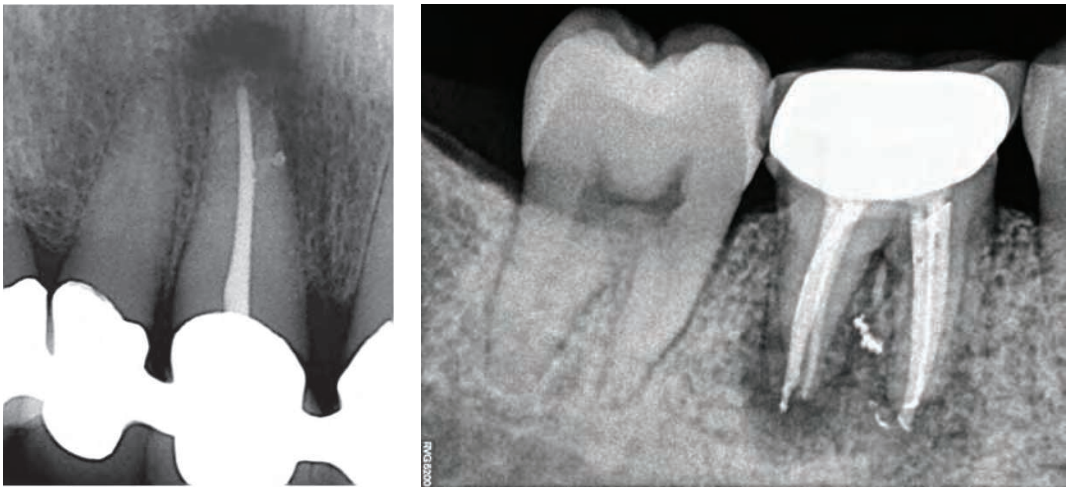
Removal of the irritant stimulus is recommended. Endodontic treatment should be initiated if signs and symptoms of irreversible pulpitis are diagnosed.

Prognosis

The prognosis for long-term retention of the tooth is excellent if root canal therapy is performed and if the tooth is restored satisfactorily. Lesions of condensing osteitis may persist after endodontic treatment.

III. PERSISTENT APICAL PERIODONTITIS

Persistent apical periodontitis is a post-treatment apical periodontitis in an endodontically treated tooth (**Fig. 5.17**).



(a) (b)

Figure 5.17 (a) Persistent apical periodontitis in an endodontically treated maxillary central incisor. (b) Persistent apical periodontitis in an endodontically treated mandibular molar.

Causes

Even with meticulous observation of clinical procedures, apical periodontitis may persist basically because of anatomical complexity of pulp space system with regions that cannot be reached with instruments or with irrigants or intracanal medicaments. In addition, these areas cannot be obturated with conventional techniques. Moreover, Nair had highlighted certain extraradicular factors that contribute to persistent apical periodontitis. These include:

- Apical biofilms (periapical plaque) (**Fig. 5.18**)
- Actinomycosis infection
- Cholesterol crystals (**Fig. 5.19**)
- Foreign body reaction to gutta-percha
- Cellulose granuloma
- Periapical scar tissue

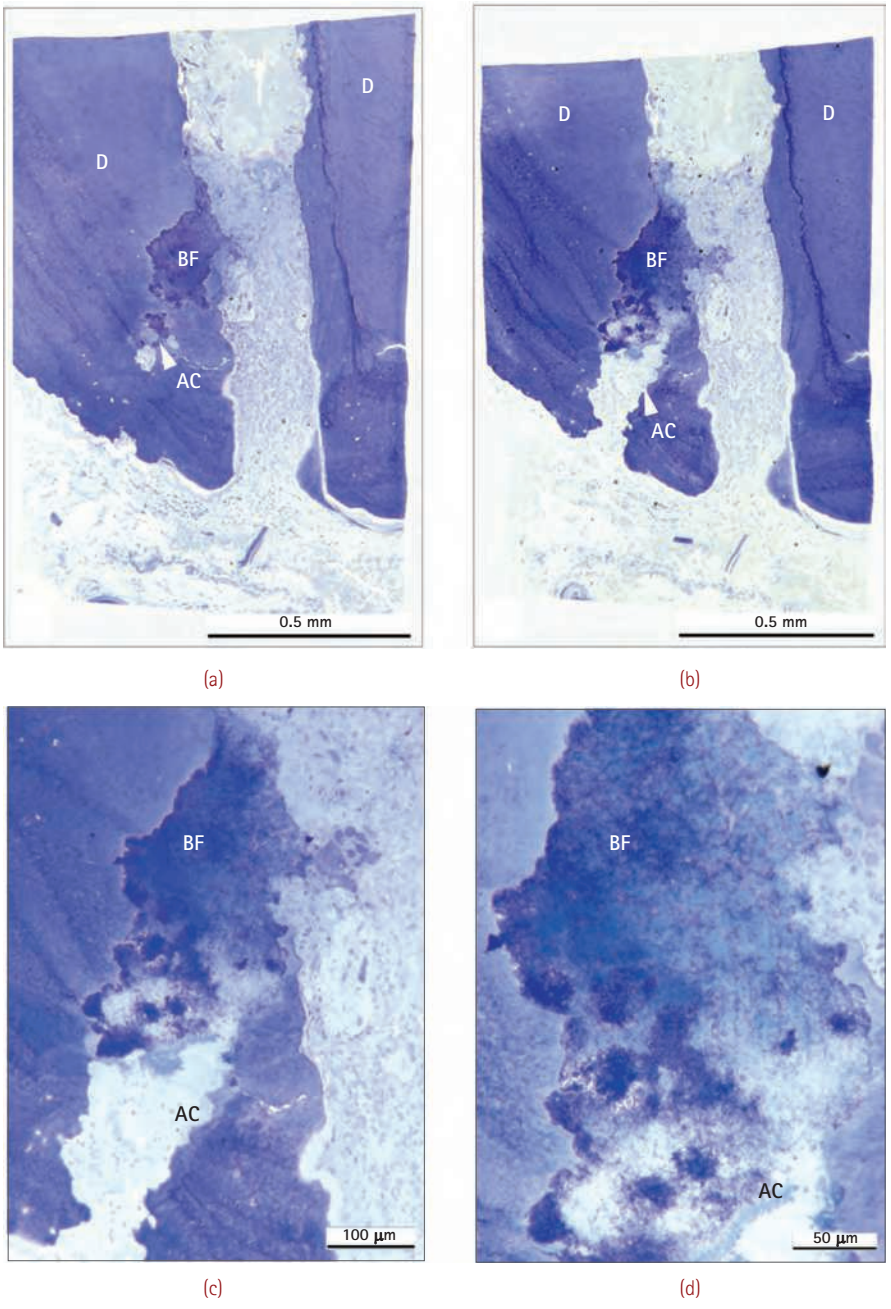


Figure 5.18 Photomicrographs of axial semithin sections through the surgically removed apical portion of the root with a persistent apical periodontitis. Note the adhesive biofilm (BF) in the root canal. Consecutive sections [(a)–(b)] reveal the emerging widened profile of an accessory canal (AC) that is clogged with the biofilm. The AC and the biofilm are magnified in (c) and (d), respectively. Magnifications: (a) ×75, (b) ×70, (c) ×110, and (d) ×300. (Adapted from Nair, P.N.R., et al.: Intraradicular bacteria and fungi in root-filled, asymptomatic human teeth with therapy-resistant periapical lesions: A long-term light and electron microscopic follow-up study. *J. Endod.*, **16**:580–88, 1990.)

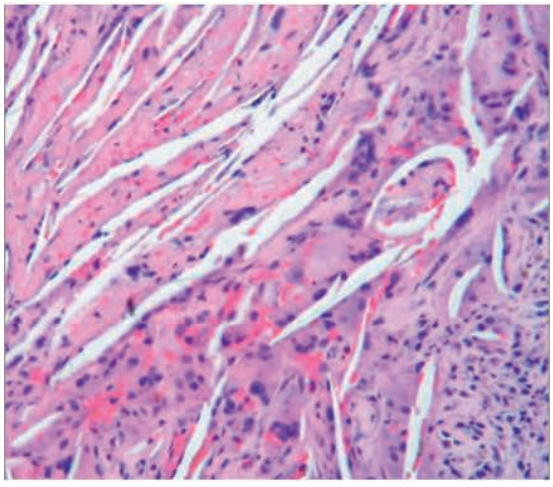
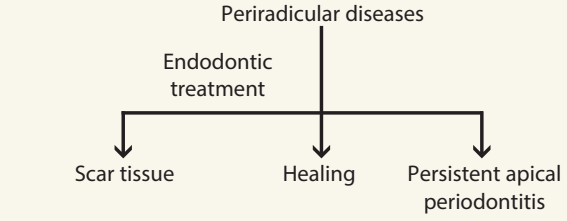


Figure 5.19 Photomicrograph of cholesterol crystals, implicated as one of the causes of persistent apical periodontitis. (*Courtesy: Bekir Karabucak, USA.*)

Box 5.3

Post-Treatment Sequelae of Periradicular Diseases



Bacteriology

Studies have shown the presence of yeasts and *Candida albicans* in post-treated cases. Gram-positive cocci, rods and filaments, and genera *Actinomyces*, *Enterococccus*, and *Propioniobacterium* have also been implicated. *E. faecalis* is the most consistently reported organism that can survive prolonged starvation and can grow as a monoinfection in endodontically treated teeth. *E. faecalis* is considered as a therapy-resistant microbe among the potential etiologic agents of post-treatment apical periodontitis.

The post-treatment sequelae of periradicular diseases are given in **Box 5.3**.

IV. EXTERNAL ROOT RESORPTION

Definition: *External resorption is a lytic process occurring in the cementum or cementum and dentin of the roots of teeth.*

Classification of Root Resorption

I. Internal root resorption
II. External root resorption
    1. External surface resorption (**Fig. 5.20**)
    2. External inflammatory root resorption (**Fig. 5.21**)
    3. External replacement resorption or ankylosis (**Fig. 5.22**)



Figure 5.20 External surface resorption (most likely on the facial surface) on the maxillary central incisor 3 years following trauma. The tooth is asymptomatic and stable. No treatment is indicated.



Figure 5.21 External inflammatory root resorption in a maxillary central incisor with a history of traumatic avulsion and replantation after 1 hour of extraoral dry time. (*Courtesy: James L. Gutmann, USA.*)

Causes

Although unknown, the suspected cause of external resorption is periradicular inflammation due to trauma, excessive forces, granuloma, cyst, central jaw tumors, replantation of teeth, bleaching of teeth, impaction of teeth, and systemic diseases. If no cause is evident, the disorder is called *idiopathic resorption*.

Histopathology

External resorption, regardless of cause, is the result of osteoclastic activity on the root surface of the involved tooth. Microscopically, it varies from small areas of cementum resorption replaced by connective tissue or repaired by new cementum to large areas of resorption replaced by osseous tissue, to "scooped-out" areas of resorption replaced by inflammatory or neoplastic tissues.

Symptoms

Throughout its development, external root resorption is asymptomatic. When the root is completely resorbed, the tooth may become mobile. If the external root resorption extends into the crown, it will give the appearance of *"pink tooth"* seen in internal resorption. Root resorption of the type called replacement resorption or ankylosis, in which the root is gradually replaced by bone (**Fig. 5.22**), renders the tooth immobile, in infraocclusion, and with a high metallic percussion sound.

Diagnosis

- Small areas of external surface resorption of cementum cannot be usually seen radiographically and can be detected histologically.
- External inflammatory root resorption is usually diagnosed by radiographs. Radiographically, external resorption appears as concave or ragged areas on the root surface or as blunting of the apex. Areas of inflammatory resorption caused by the pressure of a growing granuloma, cyst, or tumor have an area of root resorption adjacent to the area of radiolucency. Cysts, usually because of their slow growth, exert pressure on the roots of teeth and move the roots instead of causing resorption.
- Areas of replacement resorption or ankylosis have a resorbed root with no periodontal ligament space and with bone replacing the defects.

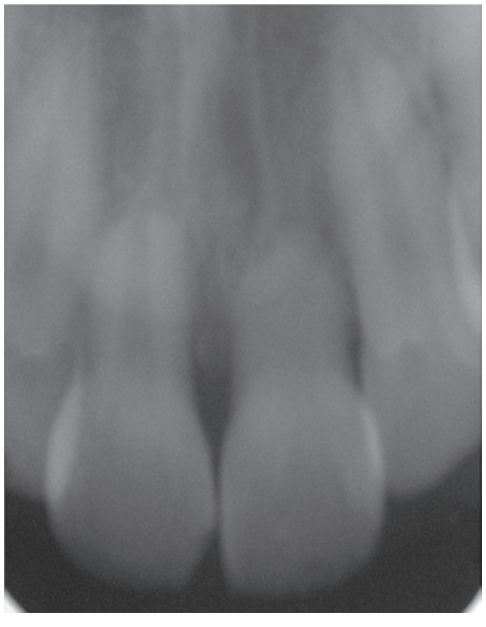
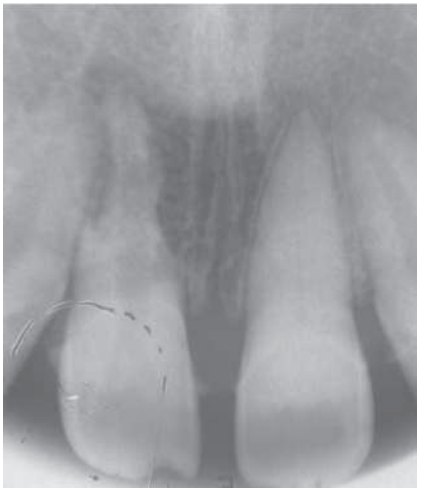


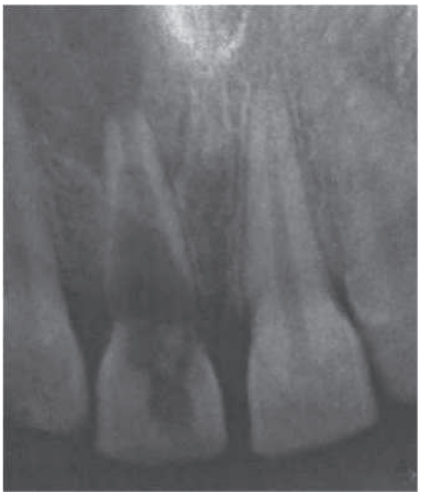
Figure 5.22 External replacement resorption (ankylosis) of the maxillary central incisor with a history of traumatic injury.

Differential Diagnosis

External resorption needs to be differentiated from internal resorption (**Fig. 5.23**). In external resorption, the radiograph shows a blunting of the apex, a ragged area, a *"scooped-out"* area on the side of the root, or if the area is superimposed on the root canal, the root canal clearly traverses the area of resorption. In internal resorption, one sees a root canal with a well-demarcated, enlarged *"ballooning"* area of resorption. It is sometimes difficult to determine whether the resorption is internal or external, i.e., whether internal resorption has perforated the root surface or external resorption has penetrated the pulpal cavity. Several radiographs taken at different



(a)



(b)

Figure 5.23 (a) Radiographic appearance of external root resorption. (b) Radiographic appearance of internal root resorption.

angles may help to resolve the question. When bone adjacent to the area of resorption is involved and the resorbed area is externally concave and when the root canal is intact, as seen in the radiograph, external resorption is present.

Treatment

Internal resorption ceases when the pulp is removed or becomes necrotic. Root canal therapy is the treatment of choice (**Fig. 5.24**). The treatment of external resorption varies with the etiologic factor. If external resorption is caused by extension of pulpal disease into the supporting tissues, root canal therapy will usually stop the resorptive process. External resorption produced by excessive forces from orthodontic appliances can be stopped by reducing those forces. In cases of external cervical root resorption, intervention in the form of surgical exposure of the defect and restoration with a suitable restorative material is the treatment of choice before the resorptive defect invades the pulp space (**Figs 5.25** and **5.26**).

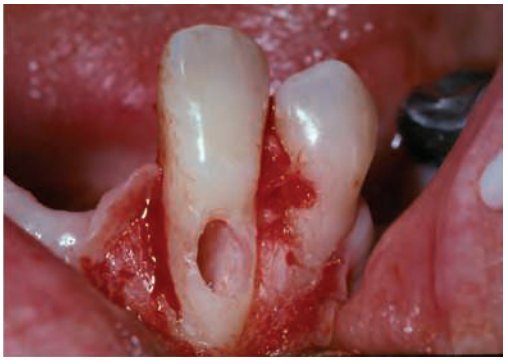


(a)



(b)

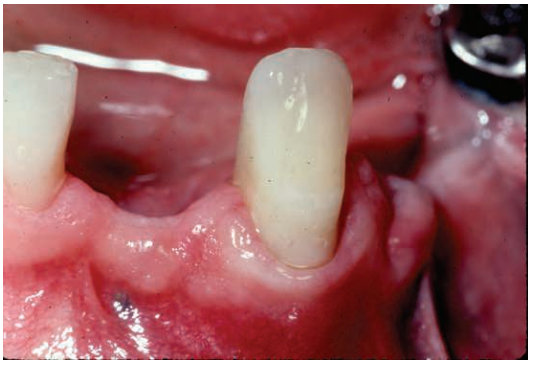
Figure 5.24 (a) Maxillary lateral incisor: pulp is necrotic and there is a perforating internal resorptive defect in the apical one-third of the root. (b) Re-examination 2 years later after root canal treatment shows healing of the resorptive defect. (*Courtesy: James L. Gutmann, USA.*)



(a)



(b)



(c)

Figure 5.25 External inflammatory cervical resorption: (a) Surgical isolation and preparation of an external cervical resorptive defect. (b) Placement of a bonded compomer. (c) One-month healing of the tissue around the restored defect. (*Courtesy: James L. Gutmann, USA.*)

Prognosis

The prognosis of a tooth with external resorption is *guarded*. If the etiologic factor is known and it is removed, the resorptive process will stop, but it may leave a weak tooth unable to sustain functional forces. In some cases, regardless of treatment, the tooth is lost. The differences between external and internal resorption are listed in **Table 5.2**.



Figure 5.26 External inflammatory cervical root resorption: (a) Maxillary central incisor with enlarged marginal gingiva and break in the facial cervical enamel margin. (b) Characteristic cervical radiolucency seen. (c) Wedges and matrix strip shown before placement of restorative material. (d) Labial view showing glass ionomer restoration of the defect. (e) Labial view at 2 months after composite resin placement over glass ionomer. (*Courtesy: Hemalatha Hiremath, India.*)

V. DISEASES OF THE PERIRADICULAR TISSUES OF NONENDODONTIC ORIGIN

Periradicular lesions not only arise as extensions of pulpal diseases but may also originate in the remnants of odontogenic epithelium. Such lesions may be manifestations of systemic diseases, such as multiple neurofibromatosis, or they may have other causes, such as periodontal diseases.

Some of these periradicular lesions, radiographically and clinically, resemble the sequelae of pulpal diseases in the periradicular area and should be differentiated from them to avoid errors in treatment.

Lesions of nonendodontic origin with vital pulps include:

- Periapical cemental dysplasia or cementoma
- Cementoblastoma (**Fig. 5.27**)

Table 5.2 Differences Between External and Internal Resorption

Features	External Root Resorption			Internal Root Resorption
Types	*1. External surface root resorption*	*2. External inflammatory root resorption*	*3. External replacement root resorption*	*Internal inflammatory root resorption*
Etiology	Luxation injuries to periodontal ligament. Traumatic occlusion, orthodontic treatment	Long-standing periradicular lesions, abnormal pressures (tumors, impactions, and orthodontic movement), and intrusive luxation cases	Intrusion and replantation of avulsed teeth	History of trauma, crown preparation, pulpotomy. The inflamed pulp is the tissue involved in resorbing the root structure
Clinical features	Initially asymptomatic, might cause mobility in short roots	Increased mobility, extruded occasionally, presence of sinus tract	Metallic sound on percussion	It is initially asymptomatic until the inflammatory process communicates with the external tooth surface
Radiographic features	Negative	Progressive cavitation involving the root and alveolar bone at 2–4 weeks	Root structure is replaced by bone	Outline of the root canal is distorted Root canal and radiolucent defect appear continuous Does not involve the bone
		Root canal outline is normal and "runs through" the radiolucent defect. Always accompanied by resorption of the bone		
Treatment	• Elimination of trauma/pressure • No endodontic treatment required	Endodontic treatment (pulpectomy) • *Mature teeth:* Shaping and cleaning and use of intracanal $CaOH_2$ medicament for 2–3 weeks followed by obturation • *Immature teeth:* Caution regarding the use of $CaOH_2$ for prolonged durations due to its weakening effect on the tooth • MTA/tricalcium silicate cement apexification is a valuable alternative		Endodontic treatment (pulpectomy)



Figure 5.27 Cementoblastoma in relation to the maxillary premolar.

- Odontogenic cysts
- Fissural cysts
- Central giant cell granuloma

Metastatic malignant tumors or *ameloblastomas* (**Fig. 5.28**) are aggressive lesions that produce excessive bone loss, mobility of teeth, extensive root resorption, and loss of pulp vitality. These lesions can be differentiated from endodontic lesions by their aggressiveness.

Clinical Note

One of the major diagnostic differences is that in lesions of endodontic origin, the pulp of the tooth is nonvital or is irreversibly diseased, whereas in most lesions of nonendodontic origin, the pulp is vital.

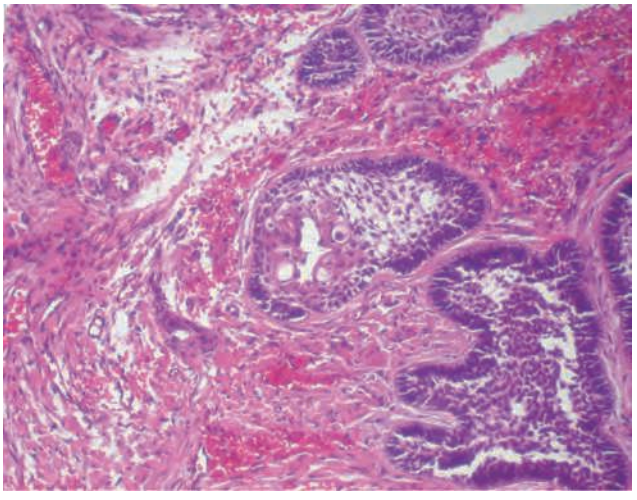
Another apical radiolucency may be confused with a lesion of endodontic origin. This lesion, the *apical scar*, may be differentiated from a lesion of pulpal origin by a thorough history. The tooth, which is completely asymptomatic, has undergone endodontic therapy or periradicular surgical procedures in the past. The radiograph shows a circumscribed radiolucency with an intact lamina dura and a well-obturated root canal (**Fig. 5.29**). Microscopic examination shows a lesion of dense collagen bundles or healing by fibrous tissue. No therapeutic intervention is necessary.



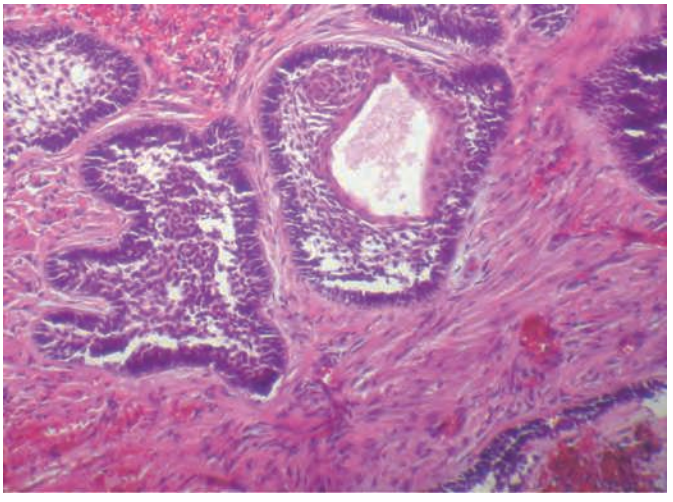
(a)



(b)



(c)



(d)



(e)



(f)



(g)

Figure 5.28 (a) Periapical radiograph showing radiolucent area well defined among periapical area of mandibular anterior teeth. (b) Endodontic treatment completed. (c and d) Microphotograph of ameloblastoma showing a basal layer; cuboidal cells with reverse polarity, resembling ameloblast-like cells; epithelial cells mimic the stellate reticulum of the enamel organ (H/E, 40). (e) Periapical radiograph after periapical surgery (enucleation of lesion and apicectomy of teeth). (f and g) Radiographs showing follow-up of 3 and 4 years, respectively. (*Courtesy: Prof. Carlos Estrela, Brazil.*)



Figure 5.29 Periapical radiolucent scar seen in asymptomatic endodontically treated mandibular molar.

HISTOPATHOLOGIC CLASSIFICATION OF PERIRADICULAR DISEASES

Histopathologically periradicular diseases can be classified as follows:

I. Apical granuloma
II. Apical abscess
III. Apical cyst

I. APICAL GRANULOMA

Apical granuloma is the most common histopathologic form of apical periodontitis. It is characterized by chronic inflammation and consists of elements of granulation tissue infiltrated by immune defense cells. Granulomatous tissue, which replaces the alveolar bone and periodontal ligament, may vary in diameter from a fraction of a millimeter to a centimeter or even larger. It consists of an outer fibrous capsule, which is continuous with the periodontal ligament, and an inner or central portion made up of loose connective tissue and blood vessels. It is composed of a rich vascular network, fibroblasts derived from the periodontal ligament, and a moderate infiltration of lymphocytes and plasma cells (**Fig. 5.30**).

Macrophages and foreign-body giant cells may also be present. Lying within the periodontal ligament near the cemental border may be clusters of epithelial cells called *cell rests of Malassez*. They are derived from Hertwig's sheath and represent the remains of the enamel organ.

II. APICAL ABSCESS

Please refer earlier sections on symptomatic (acute) apical abscess and asymptomatic (chronic) apical abscess.

III. APICAL CYST

Definition: *An apical cyst is* an inflammatory lesion of endodontic origin *with a closed cavity internally lined with epithelium, the center of which is filled with fluid or semisolid material.*

Cysts of the jaws are divided into odontogenic, nonodontogenic, and nonepithelial.

- *Odontogenic cysts* arise from odontogenic epithelium and are classified as follicular, arising from the enamel organ or follicle, and radicular, arising from the cell rests of Malassez.
- *Nonodontogenic cysts* are classified as either fissural, arising from epithelial remnants entrapped in the fusion of the facial processes, or nasopalatine, arising from the remnants of the nasopalatine duct.
- *Pseudocysts* or *nonepithelial cysts* are bony cavities that are not lined with epithelium and, therefore, are not truly

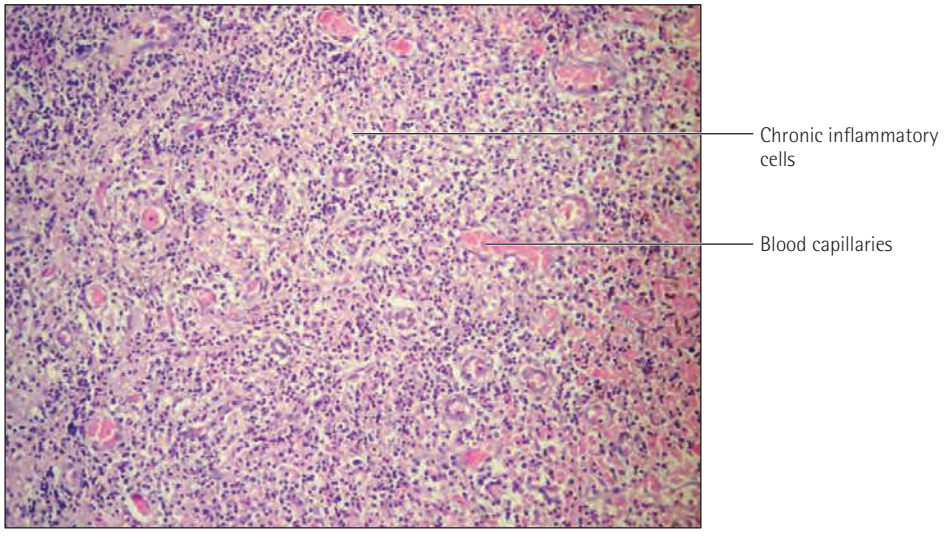
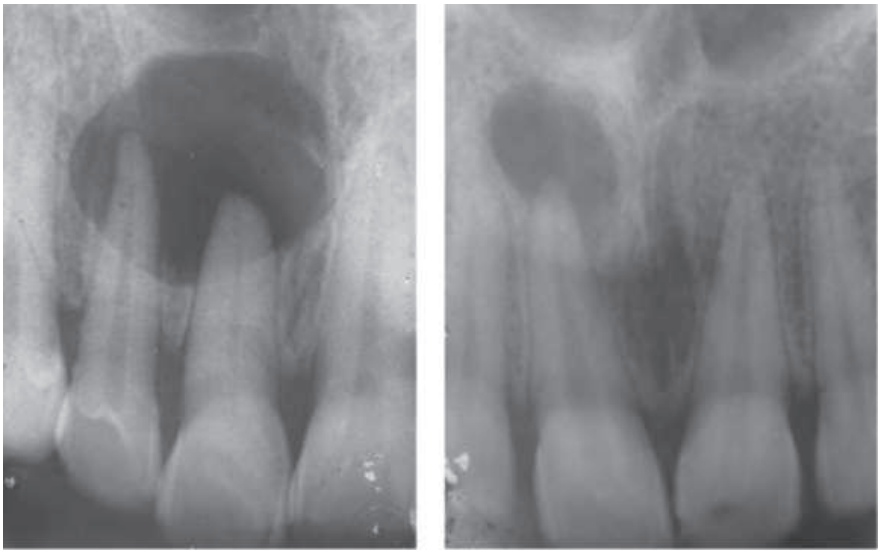


Figure 5.30 H/E-stained section of an apical granuloma, showing chronic inflammatory cell infiltrate predominantly of lymphocytes with areas of increased vascularity (10×). (*Courtesy: B. Sivapathasundharam and K. Manjunath, India.*)



(a) (b)

Figure 5.31 (a) Apical cyst in relation to the maxillary central and lateral incisors. (b) Apical cyst in relation to the maxillary central incisor.

cysts. They are divided into traumatic cysts, idiopathic bone cavities, and aneurysmal bone cysts. (*The reader is referred to textbooks of oral pathology for more detailed discussion.*)

An apical cyst is a slowly growing epithelial sac at the apex of a tooth that lines a pathologic cavity in the alveolar bone (**Fig. 5.31**). The lumen of the cyst is filled with a low concentration of proteinaceous fluid. The incidence of cysts reported by different authors depends on the criteria used for defining a cyst and on whether serial sections are examined. The incidence of cysts among apical periodontitis lesions varies from 6% to 55% and is shown in **Table 5.3**.

About 75% of all cysts occur in the maxilla, and about 25% occur in the mandible. The distribution in the maxilla is as follows: incisors, 62%; cuspids, 7%; premolars, 20%; and molars, 11%. In the mandible, the distribution is incisors, 16%; cuspids, 2%; premolars, 34%; and molars, 48%.

Table 5.3 Incidence of Periradicular Cysts and Granulomas

Authors	Cases	Cysts (%)	Granulomas (%)	Other Disorders (%)
Baumann and Rossman	121	26	74	–
Bhaskar	2400	42	48	10
Block et al.	230	6.1	93.9	–
Grossman and Ether	503	17	63	20
Lalonde and Luebke	800	43	45	12
Patterson et al.	510	14	84	2
Priebe et al.	101	54	46	–
Sommer and Kerr	170	7	84	9
Wais	50	26	64	10
Nair et al.	256	15	50	35
Simon	35	17	77	6
Stockdale and Chandler	1108	17	77	6
Nobuhara and Del Rio	150	22	59	19

Causes

A radicular cyst presupposes physical, chemical, or bacterial injury resulting in death of the pulp, followed by stimulation of the epithelial rests of Malassez, which are normally present in the periodontal ligament.

According to Nair, the periapical cyst develops from dormant epithelial cell rests that proliferate probably under the influence of inflammatory cytokines and growth factors released by various cells residing in the lesion. Thus, an epithelium-lined cavity comes into existence and the cyst grows, the exact mechanism of which is not clear. Four hypotheses are proposed for this growth:

1. *Nutritional deficient/breakdown theory*: This theory of cyst formation proposes that periradicular inflammatory changes cause the epithelium to proliferate. As the epithelium grows into a mass of cells, the center loses the source of nutrition from the peripheral tissues. These changes produce necrosis in the center; a cavity is formed and is lined by stratified squamous epithelium, and a cyst is created.

2. *Abscess theory:* Another theory of cyst formation is that an abscess cavity is formed in the connective tissue first, and then this abscess cavity gets surrounded with proliferating epithelial tissue, thereby producing a cyst.
3. *Immunologic theory:* This theory propounds that the cyst formation is mediated by an immune response against activated epithelial cell rest of Malassez.
4. *Fusion theory:* This theory states that the formation of the cyst is due to the fusion of proliferating epithelial strands in all direction that ultimately fuse to form an encapsulated mass. The tissue trapped in the epithelial mass would undergo degeneration to form the cystic cavity.

Stages of Apical Cyst Formation

Apical cyst formation can be divided into three distinct stages:

1. *Stage 1:* Chemical inflammatory mediators stimulate the dormant cell rests of Malassez to proliferate.
2. *Stage 2:* The cavity covered by epithelium is formed via one of the four mechanisms discussed above.
3. *Stage 3:* The cyst expands at the expense of bone.

Types of Apical Cysts

Two distinct categories of apical cysts were described by Nair:

1. *Apical pocket cyst*: The cyst contains an epithelial-lined cavity that is open toward the root canal of the affected tooth. It was originally designated as *bay cyst* and is now redesignated as the *periapical pocket cyst*.
   The periapical pocket cyst is probably initiated by accumulation of neutrophils around the apical foramen in response to microbial biofilm present in the apical portion of the root canal. This forms a microabscess that gets enclosed by the proliferating epithelium, forming a collar with epithelial attachment on contacting the root tip. The apical pouch seals off the infected root canals with the microabscess from the periapical tissue milieu (**Fig. 5.32**).
2. *Apical true cyst*: The cyst is characterized by cavities that are completely enclosed in epithelial lining and are totally independent of the root canal of the affected tooth (**Fig. 5.33**).

Symptoms

No symptoms are associated with the development of a cyst, except incidental to necrosis of the pulp.

The pressure of the cyst may be sufficient to cause movement of the affected teeth, owing to accumulation of cystic fluid. *Pain* might become evident in the later stages as the pressure starts to compress other anatomic structures. In such cases, the root apices of the involved teeth become spread apart, so the crowns are forced out of alignment. The teeth may also become mobile. If left untreated, a cyst may continue to grow at the expense of the maxilla or mandible.

Diagnosis

The pulp of a tooth with an apical cyst does not react to electrical or thermal stimuli, and results of other clinical tests are negative, except the radiograph. The patient may report a previous history of pain. Usually, on radiographic examination, one sees loss of continuity of the lamina dura with an area of rarefaction. The radiolucent area is generally round in outline, except where it approximates adjacent teeth, in which case it may be flattened and may have an oval shape. The radiolucent area may be larger than an asymptomatic (chronic) apical abscess and may include more than one tooth (**Fig. 5.34**).



Clinical Note

- Neither the size nor the shape of the rarefied area is a definite indication of a cyst.
- Radiographic examination alone is not sufficient for a diagnosis.

Differential Diagnosis

- The radiographic picture of a small apical cyst cannot be differentiated from that of an asymptomatic apical periodontitis. Although a positive differentiation between a cyst and an asymptomatic apical periodontitis cannot be made from radiographs alone, certain points may suggest the presence of a cyst.
- A cyst is usually larger than an *asymptomatic apical periodontal* lesion and may cause the roots of adjacent teeth to spread apart because of continuous pressure from accumulation of cystic fluid.
- One should differentiate an apical cyst from a normal bone cavity, such as the incisive foramen. A normal cavity appears dissociated from the root apex on radiographs taken at different angles, whereas a cyst remains attached to the root apex regardless of the angle at which the radiograph is taken.
- Other areas of periapical rarefaction that are not the result of pulp death may resemble an apical cyst radiographically. Some of these areas are globulomaxillary cysts, lateral periodontal cysts, incisive canal cysts, aneurysmal bone cysts, traumatic bone cysts, and fibrous dysplasia.
- A cystic apical periodontitis must also be differentiated from a *globulomaxillary cyst*, which is a fissural cyst that develops in the upper jaw between the roots of lateral and cuspid teeth. A globulomaxillary cyst is not the result of death of the pulp and may be marsupialized and later enucleated without involving pulp vitality of the adjacent teeth.
- A cystic apical periodontitis should also be differentiated from a *traumatic bone cyst*, also called a hemorrhagic or extravasation cyst, which is a hollow cavity lined not by epithelium, but by fibrous connective tissue. A method for treatment of a traumatic bone cyst is aspiration of fluid through a small surgical cavity in the bone, enlargement

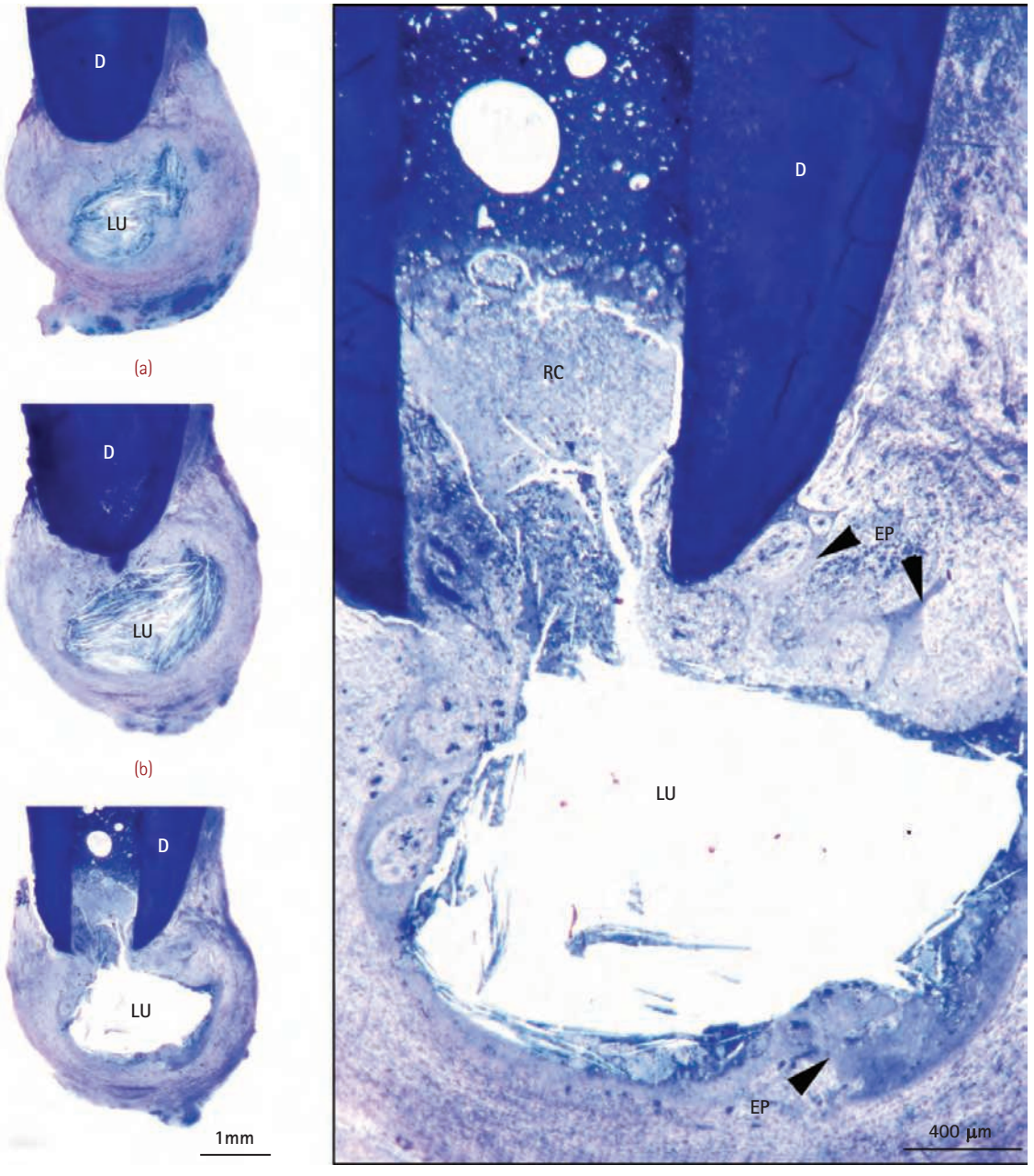


Figure 5.32 Structure of an apical pocket cyst: (a and b) Axial sections passing peripheral to the root canal give the false impression of a cystic lumen (LU) completely enclosed in epithelium. Sequential section (c) passing through the axial plane of the root canal clearly reveals the continuity of the cystic lumen (LU) with the root canal [RC in (d)]. The apical foramen and the cystic lumen (LU) of the section (c) are magnified in (d). Note the pouch-like lumen (LU) of the pocket cyst, with the epithelium (EP) forming a collar at the root apex. Dentin (D). Magnifications: (a–c) ×15; (d) ×50. (Adapted from Nair, P.N.R.: Non-microbial etiology: Periapical cysts sustain post-treatment apical periodontitis. *Endod. Topics*, **6**:94–113, 2003.)

of the opening for irrigation and aspiration until blood fills the wound, and closure of the mucoperiosteum with sutures.

- A *lateral periodontal cyst* can be identified by associated periodontal signs and symptoms (**Fig. 5.35**).

Bacteriology

A cyst may or may not be infected. Like asymptomatic apical periodontitis, a cyst represents a defensive reaction of the tissue to a mild irritant. *Actinomyces* organisms have been isolated from a periapical cyst.

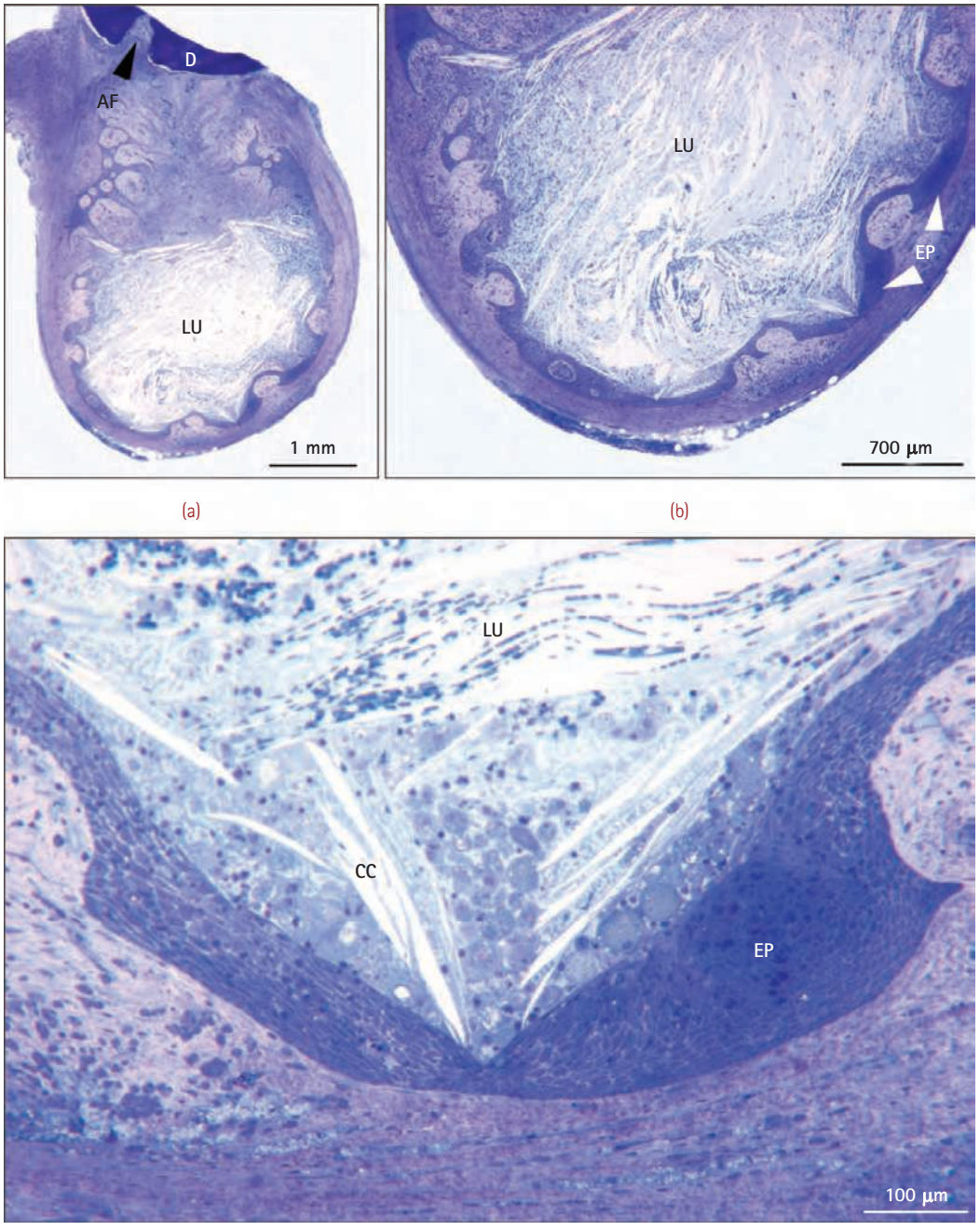


Figure 5.33 Structure of an apical true cyst: (a) Photomicrograph of an axial section passing through the apical foramen (AF). The lower half of the lesion and the epithelium [EP in (b)] are magnified in (b) and (c), respectively. Note the cystic lumen (LU) with cholesterol clefts (CC) completely enclosed in epithelium (EP), with no communication to the root canal. Magnifications: (a) ×15, (b) ×30, and (c) ×180. (Adapted from Nair, P.N.R.: Non-microbial etiology: Periapical cysts sustain post-treatment apical periodontitis. *Endod. Topics*, **6**:94–113, 2003.)

Histopathology

An apical cyst consists of a cavity lined with stratified squamous epithelium derived from epithelial cell rests of Malassez present in the periodontal ligament. Evidence supports a theory that the cavity formation and the destruction of the epithelial lining of radicular cysts are mediated by immunologic reactions. Immunologically competent cells are present in the epithelial lining, and immunoglobulins are present in the cyst fluid. The epithelial cell rests of Malassez can become recognized as antigen and may produce an immunologic reaction, which in turn causes lysis of the cystic wall.

Microscopically, because a cyst is derived from asymptomatic apical periodontitis with strands of epithelium, the



Figure 5.34 Apical cyst involving more than one tooth and with large periradicular radiolucency.



Figure 5.35 Lateral periodontal cyst in relation to the mandibular canine and premolar.

lesion is an asymptomatic apical periodontitis with a cavity lined with stratified squamous epithelium. The apical cyst is surrounded by connective tissue that is infiltrated by lymphocytes, plasma cells, and polymorphonuclear neutrophils. The cystic cavity contains debris and eosinophilic material. The connective tissue may have cholesterol clefts (**Fig. 5.36**), macrophages, and giant cells.

Treatment

Surgical enucleation of apical cysts is not necessary in all cases. Resolution of these areas of rarefaction occurs following root canal therapy in 80–98% of cases. A percentage of these healed areas may be cysts. The success and failure studies give ample evidence that some cystic apical periodontitis heal after nonsurgical endodontic treatment.

The mechanism of resolution is not known. Several hypotheses have been published:

1. The first suggests that the introduction of an endodontic instrument beyond the apex into the cystic area produces an acute inflammatory response that may destroy the epithelial lining of the cyst and may cause resolution. This hypothesis is rejected because healing usually occurs from the periphery to the center of the lesion.
2. The second hypothesis suggests that the introduction of the instrument into the cyst punctures the wall of the cyst and drains it. Drainage reduces the pressure of the cyst

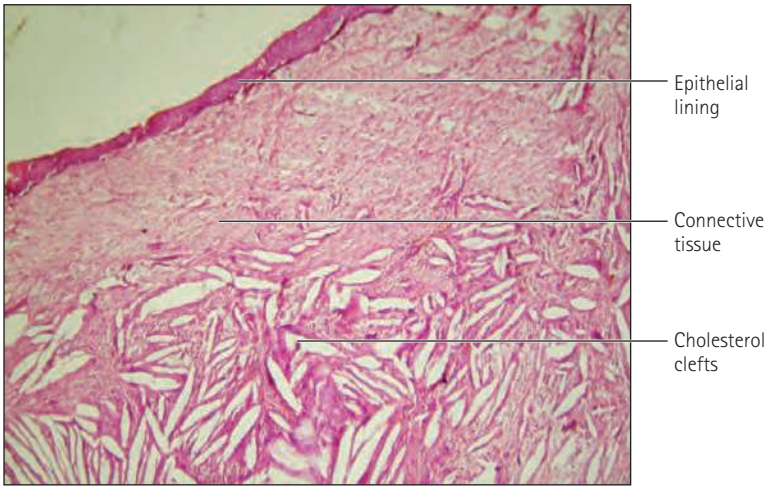


Figure 5.36 H/E-stained section of an apical cyst showing stratified squamous epithelial lining with fibrovascular connective tissue stroma with cholesterol clefts (10×). (*Courtesy: B. Sivapathasundharam and K. Manjunath, India.*)

on the walls of the osseous cavity and stimulates fibroplasia and repair from the periphery of the lesion.

The above-mentioned two hypotheses may explain the healing of an apical pocket cyst, lesions in which the cyst lumen communicates with the apical foramen. They do not explain the resolution of cysts that do not connect with the apical foramen (apical true cyst), however. The following hypotheses may explain the resolution of pathologic areas not connected with the apical foramen:

- When the inflammatory process has subsided, drainage is established and fibroplasia starts, producing collagen. The pressure of the proliferating collagen reduces the blood supply to the epithelium by compressing the vascular network of the granulomatous tissue. The collagen entraps the epithelial lining and causes it to degenerate. Macrophages remove the degenerating epithelial tissue.
- The current and most feasible hypothesis is that if periapical lesions are inflammatory responses to the antigen content of the root canal system, and the epithelial proliferation is a response to these irritating materials, then when the source of irritation is removed, the immune system gradually destroys and removes the proliferating epithelial cells.

The treatment of choice is *nonsurgical root canal therapy alone*, followed by periodic observation. Surgical treatment is indicated if a lesion fails to resolve or if symptoms develop.

Prognosis

The prognosis depends on the particular tooth, the extent of bone destroyed, and the accessibility for treatment.

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6 Clinical Diagnostic Methods

Listen to your patient ... The patient will give you the diagnosis.
—Sir William Osler

Correct treatment begins with a correct diagnosis. Arriving at a correct diagnosis requires knowledge, skill, and art—knowledge of the diseases and their symptoms, skill to apply proper test procedures, and the art of synthesizing impressions, facts, and experience into understanding.

Definition

- Diagnosis is the correct determination, discriminative estimation, and logical appraisal of conditions found during examination as evidenced by distinctive signs, marks, and symptoms.
- Diagnosis is also defined as the art of distinguishing one disease from another.

Diagnostic procedures should follow a consistent, logical order that includes comprehensive medical and dental history, radiographic examination, extraoral and intraoral clinical examination including histopathologic examination to arrive at the final diagnosis when required.

The process begins with the initial call requesting an appointment for some specific reason, usually a complaint of pain. Subjective information is supplied by the written history or questionnaire that each patient completes and signs.

Further information is obtained by the clinician, who reviews the questionnaire and asks specific questions regarding the patient's chief complaint, past medical history, past dental history, and present medical and dental status. The clinician should not hesitate to consult the patient's physician whenever the patient appears to be medically compromised or when the gained information is inadequate or unclear. More often than not, a patient's medical problem affects the course of treatment, especially concerning the use of anesthetics, antibiotics, and analgesics. Occasionally, the patient's medical status bears a direct relation to the clinical diagnosis. For example, diffuse pain in the mandibular left molars may be a referred pain caused by angina pectoris, or bizarre symptoms may be the result of psychogenic or neurologic disorders.

Diagnosis should be arrived only after assimilating all the objective and subjective findings. It should follow a proper diagnostic workflow as given in **Box 6.1**.

Box 6.1

Diagnostic Workflow

Diagnostic workflow

History taking—medical, dental, and presenting complaints

↓

Clinical examination

↓

Clinical tests

↓

Taking and interpretation of radiographs and/or other images

↓

Formulating the diagnosis

↓

Finalization of management option by discussing with patient

↓

Informed consent and proceeding with treatment plan

HISTORY AND RECORD

Definition: *Case history* is defined as the data concerning an individual and his or her family and environment, including the individual medical history that may be useful in analyzing and diagnosing his or her case or for instructional purposes.

As many diseases have similar symptoms, the clinician must be aware of the clinical manifestations of each disease to be able to determine the correct diagnosis. Differential diagnosis is the most common procedure. This technique distinguishes one disease from several other similar disorders by identifying their differences. Diagnosis by exclusion, on the other hand, eliminates all possible diseases under consideration until one remaining disease correctly explains the patient's symptoms.

To avoid irrelevant information and prevent errors of omission in clinical tests, the clinician must establish a routine for examination. The sequence of examination should be printed on the patient's chart and should act as a guide to proper diagnostic habits (**Fig. 6.1**).

The history of present illness indicates severity and urgency of the problem. The clinician is responsible for taking proper medical history for every patient. If the patient has a relevant medical condition that requires attention, he or she should

Endodontics Health Questionnaire

Name _____ _____

Address _____ Home phone _____

Pin code _____ Work phone _____

Age _____ Sex _____ Height _____ Weight _____

Occupation _____

Please answer each question	CIRCLE	
1. Are you in good health?	Yes	No
2. Name & address of your physician _____		
3. Have you been a patient in a hospital during the past 2 years?	Yes	No
4. Have you been under the care of a physician during the past 2 years?	Yes	No
5. Have you taken any kind of medicine or drugs during the past year?	Yes	No
6. Are you taking any medication now? if so, name them. _____		
7. Are you allergic to penicillin, local anesthetics, pain killers, or any drugs? If so, which drugs:		

Circle any of the following which you have had:

Heart trouble	High blood pressure	Sinus trouble	Other
- Angina/coronary	Abnormal bleeding	Asthma	
- Heart murmur	Anemia	Tuberculosis	
- Congenital heart lesions	Jaundice	Stroke	
- Rheumatic fever	Hepatitis/AIDS	Epilepsy	
Diabetes	Arthritis	Psychiatric treatment	

8. Do you have a pacemaker?	Yes	No
9. Are you pregnant now?	Yes	No

Date _____ **Signature of Patient** _____

Figure 6.1 Medical history form, to be completed and signed by the patient.

get clearance from the physician before endodontic treatment is begun. The endodontist must be aware of possible complications associated with medically compromised patients. He or she is also expected to be updated about the recommendations issued by the American Heart Association (*refer to* Chapter 8). One has to always obtain a written consent from the consulting physician or surgeon and record the same in the patient's file.

Questions concerning the patient's chief complaint, past medical history, and past dental history are reviewed. If more information is needed, further questions should be directed to the patient and should be recorded carefully (**Fig. 6.2**).

SYMPTOMS

Symptoms are the units of information sought in clinical diagnosis. They are defined as phenomena or signs of a departure from the normal state and are indicative of illness. Symptoms can be classified as follows:

- *Subjective symptoms:* Those experienced and reported to the clinician by the patient
- *Objective symptoms:* Those ascertained by the clinician through various tests

Understanding of both subjective and objective symptoms is essential for the correct identification of disease and thereby a diagnosis of the problem of the patient.

SUBJECTIVE SYMPTOMS

The completed medical form concerning the patient's past medical and dental history consists of subjective symptoms. Included in this category is the patient's reason for seeing the dentist or chief complaint. Generally, a chief complaint relates to pain, swelling, lack of function, or esthetics.

RECORD

Dr.
Mr./Ms.
PARENT OR GUARDIAN _____ PHONE: HOME _____
AGE AND SEX _____ OCCUPATION _____
REFERRED BY _____ PHYSICIAN _____

L	18	17	16	15	14	13	12	11	21	22	23	24	25	26	27	28	R
	48	47	46	45	44	43	42	41	31	32	33	34	35	36	37	38	

DATE	SERVICE RENDERED	CREDIT	BALANCE

DENTAL HISTORY:
Chief complaints (c.c): _____
History of involved tooth: _____

Subjective Symptoms:
PAIN
Present ☐ or Absent ☐; Sharp ☐ or Dull ☐; Localized ☐ or Diffuse ☐
Throbbing ☐, Intermittent ☐, or Continuous ☐;
Lasting seconds ☐, Minutes ☐, or Hours ☐;
Increased by Cold ☐, Heat ☐, Pressure ☐, Mastication ☐, Lying down ☐,
Sweet ☐, Sour ☐, or other _____

Objective Symptoms:
Extraoral swelling ☐; Intraoral swelling ☐; Sinus tract ☐
Lymph nodes involved: Submaxillary ☐; Submental ☐; Other ☐
Tooth discolored ☐; Painful on percussion ☐; Mobile ☐
Tissue tender on palpation ☐
Electric test: Control tooth respond at no. ☐ Test tooth respond at no. ☐
Thermal test: Normal ☐; Abnormal response to cold or heat ☐; No response ☐
Radiograph: Periradicular radiolucency present ☐ or Absent ☐
Thickened periodontal ligament ☐; Internal resorption ☐
External resorption ☐; Calcification ☐; Crown or root fracture ☐;
Periodontal disease ☐; Caries ☐; Atypical anatomy ☐

Clinical Diagnosis:
Pulpitis: Acute reversible (hyperemia) ☐;
Acute irreversible, responsive to heat ☐ or to cold ☐; Chronic irreversible ☐
Degenerative changes: Calcification ☐; Resorption ☐; Necrosis ☐
Periradicular lesion: Abscess
Intentional extirpation ☐; Retreatment ☐
Prognosis of tooth: Favorable ☐; Questionable ☐; Unfavorable ☐
Medical history:
Remarks:

Figure 6.2 Clinical record sheet.

The report of the chief complaint should include signs and symptoms, duration and intensity of pain, and relieving and exaggerating factors. It may be simply "something on the X-ray" which the patient has brought with him or her.

Clinical Note

Whatever the reason, the patient's chief complaint is the best starting point for a correct diagnosis.

I. Pain

The most common complaint that leads to dental treatment is pain. Judicious questioning about the pain can aid the diagnostician in developing a tentative diagnosis quickly. One should ask the patient about the kind of pain, its location, its duration, what causes it, what alleviates it, and whether or not it has been referred to another site.

A. Kind of Pain

Generally, pulpal pain is described by a patient in one of the following two ways:

(i) *Sharp, piercing, and lancinating:* This type of painful response is consistent with those usually associated with excitation of the "Aδ" nerve fibers in the pulp.

(ii) *Dull, boring, gnawing, and excruciating:* This kind of painful response is consistent with those resulting from excitation and slower rate of transmission of the "C" nerve fibers in the pulp. Determining the category of the pain is important in suggesting the next group of questions to be asked.

B. Location

The ability to localize the pain is obviously important.

(i) *Localized pain:* Pain is localized when the patient can point to a specific tooth or site with assurance and speed when asked to do so. Sharp, piercing, lancinating pain in a tooth usually responds promptly to cold and is easy to localize. Symptoms from such teeth are rarely referred to other sites.

(ii) *Diffuse pain:* When the pain is diffuse, however, the patient describes an area of discomfort rather than a specific site. When the patient is asked to point to the most painful spot, the patient's finger moves along the dental arch or between the maxilla and the mandible. This diffuseness is diagnostic because the inability to localize the pain frequently relates to dental pain that is dull, boring, and gnawing, from a tooth that responds abnormally to heat more than to cold and with symptoms that can be referred to other sites. The cause of diffuse pain is because of the fact that proprioceptive fibers are not located in the pulp.

C. Duration of Pain

The duration of the pain is also diagnostic.

(i) *Short and specific to stimuli:* At times, pulpal pain lasts only as long as an irritant is present. Acute reversible pulpitis (hyperemia) is characterized by pain of short duration, caused by a specific irritant, which disappears as soon as the irritant is removed. The pain is usually localized and is more responsive to cold than to heat. The pain may be either intermittent or constant. Clinical experience has shown that a tooth with fleeting pulpal pain that disappears on removal of the irritant has an excellent chance of recovery without the need for endodontic treatment.

(ii) *Persistent and lingering:* If the pain persists and if it lasts for minutes to hours after the removal of the stimuli, the pulpitis will usually be irreversible and the patient will require endodontic therapy.

Box 6.2

Types of Endodontic Pain

Pain

Kind of pain

Sharp, Piercing and Lancinating Pain
Due to excitation of A delta fibers

Relieved immediately on removal of stimuli

Indicative of reversible pulpitis

Dull, Boring or Gnawing Pain
Due to excitation of C fibers

Removal of stimuli does not give immediate relief

Indicative of irreversible pulpitis

Postural/Nocturnal Pain
Pain on changing position of head

Awakens patient from sleep

Indicative of irreversible pulpitis

Duration

Duration of Pain
Short and specific to stimuli

Pain lasting as long as the stimuli is present (More responsive to cold than heat)

Reversible pulpitis

Excellent chance of recovery without need of endodontic treatment if etiology is treated

Persistent and Lingering
Pain lasting for minutes to hours

Indictive of irreversible pulpitis

Spontaneous Pain
Pain occurs without cause

Indicative of irreversible pulpitis

(iii) *Spontaneous pain:* Spontaneous pain is one that occurs without any apparent cause and is usually a pain of long duration which is a symptom of irreversible pulpitis.
(iv) *Nocturnal pain:* Pain that occurs on changing the position of the head awakens the patient from sleep and usually is a symptom of irreversible pulpitis.

The various forms of pain are summarized in **Box 6.2**.

II. Dentinal Hypersensitivity

Definition: According to Holland et al., dentin hypersensitivity is characterized by short, sharp pain arising from exposed dentin in response to stimuli typically thermal, evaporative, tactile, osmotic, or chemical and which cannot be ascribed to any other form of dental defect or pathology (**Fig. 6.3**).

The proposed mechanism of dentinal hypersensitivity is given in **Box 6.3**, while **Box 6.4** provides the various etiologic and predisposing factors associated with dentinal hypersensitivity.



Figure 6.3 Cervical erosive lesions causing hypersensitive dentin. (*Courtesy: Gopikrishna: Sturdevant's Art and Science of Operative Dentistry, Second South Asian Edition, Elsevier.*)

Box 6.3

Brannstrom's Hydrodynamic Theory for Dentin Hypersensitivity

Stimulus
↓
Fluid flow in exposed open dentinal tubules
↓
Stimulation of Aδ nerve fibers
↓
Pain

Box 6.4

Etiologic and Predisposing Factors Associated with Dentin Hypersensitivity

- Loss of enamel
- Gingival recession
- Attrition
- Erosion (intrinsic and extrinsic)
- Tooth malposition
- Denudation of cementum
- Thinning, fenestration, absent buccal alveolar bone plate
- Abrasion
- Abfraction
- Periodontal disease and its treatment
- Periodontal surgery
- Patient habits

Courtesy: Gopikrishna: Sturdevant's Art and Science of Operative Dentistry, Second South Asian Edition, Elsevier.

Clinical Features

- Pain is the most common clinical feature associated with dentin hypersensitivity.
- The intensity of pain varies from mild discomfort to severe sensitivity.
- The pain is typically rapid in onset, sharp in character, and of short duration.
- External stimuli that can elicit the expression of this condition include:
  - Thermal stimuli
    - Hot/cold foods and beverages
    - Cold blast of air
  - Osmotic stimuli
    - Sweet food
  - Acidic stimuli
    - Citrus fruits
    - Acidic beverages
    - Medicines
  - Mechanical stimuli
    - Toothbrush
    - Dental instruments
- The most commonly involved teeth are as follows:
  - Buccal surfaces of premolars
  - Labial surfaces of incisors

Treatment Strategies

The various clinical methods of management of dentin hypersensitivity are given in **Box 6.5**.

A. Potassium Nitrate Desensitization

- Daily use of 5% potassium nitrate containing toothpaste for 4 weeks is an effective way to desensitize dentin.
- Potassium nitrate increases the extracellular potassium ion concentration and thus depolarizes the nerve. This prevents the transmission of pain signals to the brain.

B. Occluding the Dentinal Tubules

Occluding the distal terminal ends of exposed dentinal tubules is another method of managing dentin hypersensitivity.

- Fluorides decrease the dentinal permeability by precipitating calcium fluoride crystals inside the dentinal tubules. They are used in the form of *2% sodium fluoride* or *0.4% stannous fluoride*.
- *Potassium oxalate* has also been proved to reduce dentin hypersensitivity by forming calcium oxalate crystals inside the dentinal tubules.
- Casein is a milk protein, which has been used to develop *casein phosphopeptide (CPP)* that gets attached to *amorphous calcium phosphate (ACP)*. This **CPP–ACP** complex has been proved to enable early enamel remineralization in white spot lesions. It also has shown to have potential to prevent and treat dentin hypersensitivity.

Box 6.5

Treatment Strategies for Dentin Hypersensitivity

- Desensitizing the nerve
  - Potassium nitrate
- Occluding the dentinal tubules
  - Recent advances
    - Arginine
    - Calcium sodium phosphosilicate (CSPS)
  - Salts or ions
    - 0.4% stannous fluoride
    - 2% sodium fluoride
    - Potassium oxalate
    - Strontium chloride
    - Calcium carbonate
  - Protein precipitates
    - CPP–ACP
    - Silver nitrate
    - Glutaraldehyde
    - Zinc chloride
- Dentin adhesives
  - Dentin bonding agents
  - Composites
  - Glass ionomers
- Crown placement
- Periodontal grafting
- Lasers

Courtesy: Gopikrishna: Sturdevant's Art and Science of Operative Dentistry, Second South Asian Edition, Elsevier.

- *Arginine* is being incorporated in a number of recently developed toothpastes (Colgate Sensitive Pro-Relief, Colgate-Palmolive Company, New York). The combination of arginine with calcium carbonate and phosphate results in precipitate formation on the open dentinal tubules. In addition to toothpastes, it is available in several forms such as:
  - Arginine in-office paste (8%)
  - Arginine mouthwash (0.8%)
- *Calcium sodium phosphosilicate (CSPS): NovaMin* is the trade name for a CSPS bioactive glass. It acts by occlusion of dentinal tubules by precipitating calcium and phosphate. Calcium and phosphate ions react with oral fluids to form hydroxycarbonate apatite layer that is similar to natural tooth structure. It is available in the form of toothpaste (5% CSPS) and prophylaxis paste (15% CSPS), e.g., Sensodyne Repair and Protect.

C. Dentin Adhesives

The use of dentin adhesives to treat hypersensitive dentinal surfaces has gained popularity. Reductions in sensitivity can result from the formation of resin tags and a hybrid layer when a dentin adhesive is used.

OBJECTIVE SYMPTOMS

Objective symptoms are determined by tests and observations performed by the clinician. These tests are provided in **Box 6.6**.

Although it may not be necessary to perform all these tests at any one time, a combination of corroborating tests is desirable to ensure a correct diagnosis. One should not rely on the results of any single test.

I. Visual and Tactile Inspection

The simplest clinical test is visual examination. Too often, it is done casually during examination, and as a result, much essential information is lost inadvertently. A thorough visual and tactile examination of hard and soft tissue relies on checking the "three Cs": ***color***, ***contour***, *and* ***consistency***.

Box 6.6

Diagnostic Methods in Endodontics

1. Visual and tactile inspection
   (a) Hard tissues
   (b) Soft tissues
      (i) Gingiva
      (ii) Periodontium
2. Percussion
3. Palpation
4. Mobility and depressibility
5. Bite test
6. Radiography
   (a) Intraoral periapical radiographs
   (b) Bitewing radiographs
   (c) Digital radiography
   (d) Cone beam computed tomography (CBCT)
7. Assessment of pulp vitality
   (a) Neural sensibility tests
      (i) Thermal tests
      (ii) Heat testing
      (iii) Cold testing
      (iv) Electric pulp test (EPT)
      (v) Anesthetic test
      (vi) Test cavity
   (b) Pulp vascularity tests
      (i) Pulse oximetry
      (ii) Laser Doppler flowmetry
      (iii) Recent technologies
         - Dual-wavelength spectrophotometry
         - Thermography
         - Crown surface temperature
         - Transmitted light photoplethysmography

A. Hard Tissues

Teeth should be visually examined using the "three Cs." A normal-appearing crown has a life-like translucency and sparkle (**Fig. 6.4a**) that is missing in pulpless teeth (**Fig. 6.4b**). Teeth that are discolored, opaque, and less life-like in appearance should be carefully evaluated because the pulp may already be inflamed, degenerated, or necrotic. Not



(a) (b)

Figure 6.4 (a) Translucency and appearance of a normal vital tooth. (b) Loss of translucency and change of color in a nonvital tooth.



Figure 6.5 Tooth discoloration due to old amalgam filling.

all discolored teeth need endodontic treatment; staining may be caused by old amalgam restorations (**Fig. 6.5**), root canal filling materials and medicaments, or systemic medication, such as tetracycline staining. Many discolorations, however, are the result of diseases commonly associated with necrotic, gangrenous pulps, internal or external resorption, and carious exposure.

Crown contours should be examined. Because fractures, wear facets, and restorations change the crown's contour, the clinician should be prepared to evaluate the possible effects of such changes on the pulp.

Abou-Rass recommends endodontic treatment and crown restoration once a cracked tooth develops symptoms because tooth cracks can lead to tooth fractures (**Fig. 6.6**).

The consistency of the hard tissue relates to the presence of caries and internal or external resorption. Obviously, an exposed pulp will require some kind of treatment if the tooth is to be retained. Therefore, pulp exposure, initially recognized on the radiograph, should be confirmed by exploration and excavation.

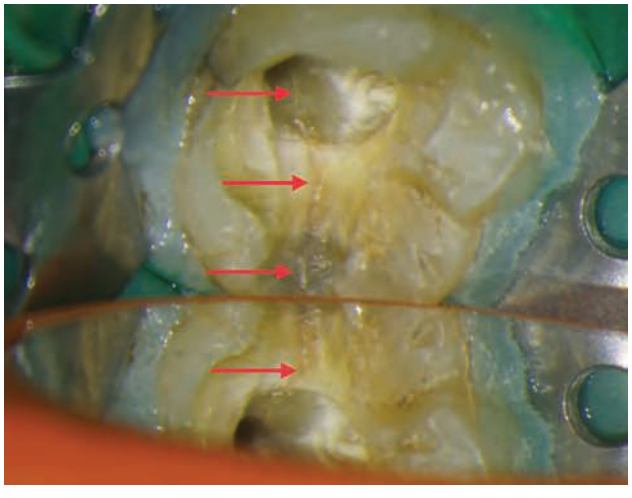


Figure 6.6 Crack developing on the marginal ridge and extending into the pulp chamber.

The technique of visual and tactile examination is simple. One uses one's eyes, fingers, an explorer, and the periodontal probe. Loss of translucency, slight color changes, and cracks may not be apparent in poor light. In fact, a transilluminator may aid in detecting enamel cracks or crown fractures.

B. Soft Tissues

i. Gingiva

In soft tissues, such as gingiva, deviation from the healthy pink *color* is readily recognized when inflammation is present (**Fig. 6.7**). A change in *contour* occurs with swelling, and the *consistency* of soft, fluctuant, or spongy tissue differs from that of normal, healthy, firm tissue and is indicative of a pathologic condition (**Fig. 6.8**).

ii. Periodontium

The patient's teeth and periodontium should be examined in good light under dry conditions. For example, a sinus tract (fistula) might escape detection if it is covered by saliva or an interproximal cavity may escape notice if it is filled with



Figure 6.7 Normal color, contour, and consistency of gingiva.



Figure 6.8 Change in tissue color, contour, or consistency signifying an underlying pathology.

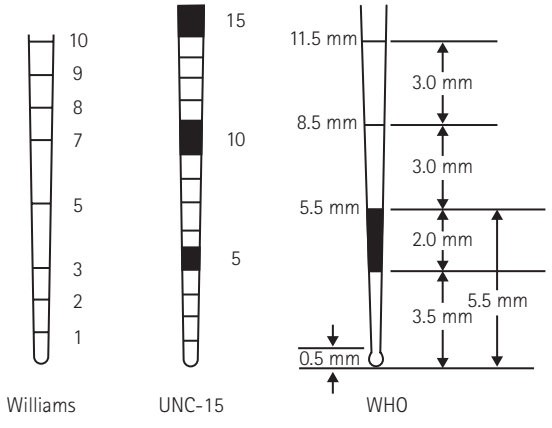
food. Visual examination should include the soft tissue adjacent to the involved tooth, for detection of swelling. The three common periodontal probes for assessment used clinically are as follows (**Fig. 6.9a**):

1. *William's periodontal probe:* This is characterized by a lack of marking at the 4th and 6th mm.
2. *University of North Carolina periodontal probe (UNC-15):* This is a probe with a color coding at the 5th, 10th, and 15th mm.
3. *World Health Organization (WHO) probe:* This probe has a 0.5-mm ball-ended probe tip with a color coding between the 3.5- and 5.5-mm markings.

The periodontal probe should be used routinely to determine the periodontal status of the suspected tooth and adjacent teeth (**Fig. 6.9b**).

Clinical Note

Sinus tracts opening into the gingival crevice or deep infrabony pockets may go undetected because of failure to use the periodontal probe.

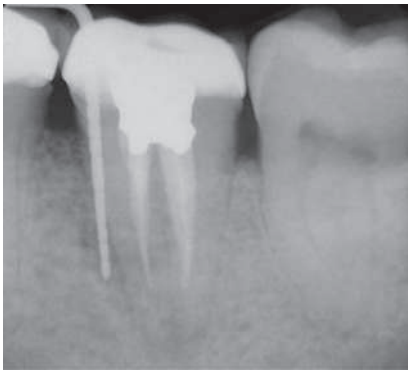


(a)



(b)

Figure 6.9 (a) Periodontal probes (William's probe, UNC-15 probe, and WHO probe). (b) Periodontal probing to ascertain the health of the periodontium.



(a)



(b)

Figure 6.10 (a) Deep periodontal probing on tooth #37 indicates that a vertical fracture is present. (b) A 45-year-old female patient presented with pain on mastication with the mandibular first molar. There was a history of root canal treatment and extensive restorative procedures. Radiographically, the patient has a J-shaped lesion on the mesial root. Probing confirmed the presence of a fracture. (*Courtesy: James L. Gutmann, USA.*)

Periodontal pocket probing depths must be measured and recorded. Bone loss in multirooted teeth can lead to a defect in the furcation region. A significant pocket in the absence of periodontal disease may indicate root fracture (**Fig. 6.10**). Poor periodontal prognosis may be a contraindication to root canal therapy. The classification of furcation defects is given in **Box 6.7**.

The crown of the tooth should be carefully evaluated to determine whether it can be restored properly after the completion of endodontic treatment. Finally, a rapid survey

Box 6.7

Glickman's Classification of Furcation Defects

- *Grade I:* Incipient lesion is present when the pocket is suprabony involving soft tissue and there is slight bone loss.
- *Grade II:* Bone is destroyed on one or more aspects of the furcation but probe can penetrate only partially into the furcation.
- *Grade III:* Intraradicular bone is completely absent but the tissue covers the furcation.
- *Grade IV:* Through-and-through furcation defect is present.

of the entire mouth should be made to ascertain whether the tooth requiring treatment is a strategic tooth.

II. Percussion

This test enables one to evaluate the status of the periodontium surrounding a tooth. The tooth is struck a quick, moderate blow, *initially with low intensity by the finger* and then with increasing intensity by using the handle of an instrument, to determine whether the tooth is tender. A sensitive response, differing from that of the adjacent teeth, usually indicates the presence of symptomatic apical periodontitis. Although percussion is a simple method of testing, it may be misleading if used alone. To eliminate bias on the part of the patient, one must change the sequence of the teeth percussed on successive tests. Moreover, one should change the direction of the blow from the vertical occlusal to the buccal or lingual surface of the crown and strike separate cusps in a differing order (**Fig. 6.11a** and **6.11b**).

Percussion is used in conjunction with other periodontal tests, namely, palpation, mobility, and depressibility. These tests help to corroborate the presence of periodontitis. The presence of this disorder is not a true indication of irreversible pulpitis or pulp necrosis, however. Although periodontitis may be a response to pulp necrosis, it can also occur around a tooth with a vital, clinically normal pulp, as in acute periodontal abscess. When periodontitis occurs unrelated to a periodontal cause, it is usually the result of, and a sequela to, pulpal necrosis. One infrequent exception occurs in the late stages of irreversible pulpitis when the tooth is abnormally responsive to heat. The pulp still has some vitality, but the tooth is sensitive to percussion.



(a)



(b)

Figure 6.11 (a) Vertical percussion using the handle of an operative instrument. (b) Horizontal percussion; before percussing a tooth with a metal handle, initially test the patient's response by lightly tapping the suspected tooth with your finger.

Clinical Note

- In patients reporting with acute pain, mild pressure with the clinician's thumb or finger is the most appropriate method for percussion testing.
- One must not percuss a sensitive tooth beyond the patient's tolerance. This problem can be avoided by lightly pressing several teeth prior to percussing them.
- While the clinician questions the patient about tenderness of a tooth, a more valid response can be obtained if at the same time, the patient's body movement, reflex pain reaction, or even an unspoken response is observed.

III. Palpation

This simple test is done with the fingertips, using light pressure to examine tissue consistency and pain response. Although simple, it is an important test. Its value lies in locating the swelling over an involved tooth and determining the following:

- Whether the tissue is fluctuant and enlarged sufficiently for incision and drainage
- Presence, intensity, and location of pain
- Presence and location of adenopathy
- Presence of bone crepitus

Diagnostically, when the posterior teeth are infected, the submandibular lymph nodes become involved (**Fig. 6.12**). Infection of the lower anterior teeth may cause swelling of the submental lymph nodes.

Clinical Note

When the infection/inflammation is confined to the pulp and has not progressed into the periodontium, palpation is not diagnostic.



Figure 6.12 Bimanual palpation of submandibular lymph nodes with the operator standing behind the patient.



Figure 6.13 Mobility is determined by moving a tooth laterally using the handles of two operative instruments.

Box 6.8

Miller's Tooth Mobility Index

- *First-degree mobility:* First distinguishable sign of movement greater than normal
- *Second-degree mobility:* Horizontal tooth movement within a range of 1 mm
- *Third-degree mobility:* Horizontal tooth movement greater than 1 mm or when the tooth can be depressed

IV. Mobility–Depressibility Testing

The mobility test is used to evaluate the integrity of the attachment apparatus surrounding the tooth. The test consists of moving a tooth laterally in its socket by using the fingers or, preferably, the handles of two operative instruments (**Fig. 6.13**). The objective of this test is to determine whether the tooth is firmly or loosely attached to its alveolus. The amount of movement is indicative of the condition of the periodontium; the greater the movement, the poorer the periodontal status.

Similarly, the test for depressibility consists of moving a tooth vertically in its socket. This test may be done with the fingers or with an instrument. When depressibility exists, the chance for retaining the tooth ranges from poor to hopeless. Miller's Tooth Mobility Index is given in **Box 6.8**.

Endodontic treatment should not be carried out on teeth with third-degree mobility unless mobility is reduced when pressure in the periodontium has been relieved.

Clinical Note

Palpation, percussion, mobility, and depressibility test the integrity of the attachment apparatus, i.e., periodontal ligament and bone, and are *not diagnostic* when the disease is confined within the pulp cavity of a tooth.

V. Bite Test

The bite test is useful in identifying a cracked tooth or fractured cusp (**Fig. 6.14**) when pressure is applied in a certain direction to one cusp or section of the tooth. It is also helpful in diagnosing cases wherein the pulpal pathosis has extended into the periradicular region causing apical periodontitis. The *Tooth Slooth* (**Fig. 6.15**) and the *Frac Finder* are the popular commercially available devices for the bite test.

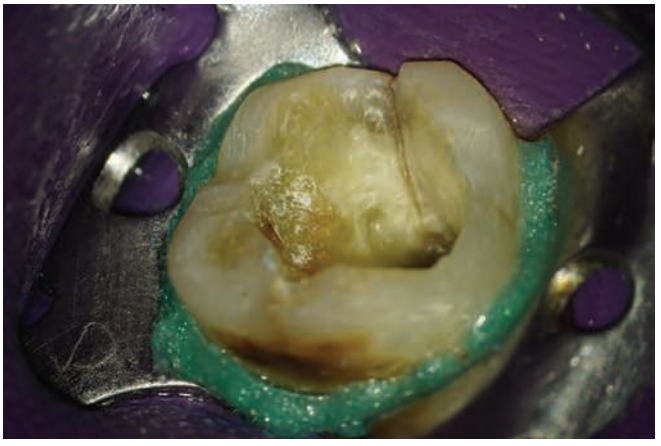


Figure 6.14 In this tooth, a fracture line is visible originating from the occlusal surface, indicating possible presence of crown originating fracture.



Figure 6.15 Use of a Tooth Slooth.

By defining the type of crack present, an assessment of the prognosis may be determined and treatment alternatives can be planned. Unfortunately, it is often extremely difficult to determine how extensive a crack is propagating into the tooth structure.

Cracks in teeth are divided into three basic categories:

1. Craze lines
2. Fractures (also referred to as crack)
3. Split tooth/roots

Another method to detect tooth fracture is transillumination.

Clinical Note

The clinician should note whether the discomfort or pain occurs during the act of biting or during the release of bite force:
- *Pain on biting:* Symptomatic apical periodontitis
- *Pain on release of biting force:* Cracked tooth

Radiographs are indispensable diagnostic and prognostic aids in endodontics and are one of the most reliable methods of monitoring endodontic treatment. They provide an important visual method of gaining clinical knowledge of teeth and periradicular tissues; therefore, they are essential to the practice of endodontics.

VI. Radiography

Radiographic Applications in Endodontics

According to Walton and Gomez, radiographs have the following applications:
- Help in the diagnosis of hard tissue alterations in the teeth and periapical structures
- Determine the number, location, shape, size, and direction of roots and root canals
- Assess anatomy, size, and alterations in the pulp chamber
- Detect procedural errors such as perforations, ledges, transportation, and instrument separation
- Locate root tips prior to surgery
- Estimate and confirm the length of canals
- Localize hard-to-find, or disclose unsuspected, pulp canals by examining the position of an instrument within the root
- Aid in locating a pulp space markedly calcified and/or receded
- Determine the relative position of structures in the facial–lingual dimension
- Confirm the position and adaptation of master cones
- Aid in the evaluation of obturation
- Facilitate the examination of soft tissues for tooth fragments and other foreign bodies following traumatic injuries
- Aid in localizing a hard-to-find apex during root-end surgery
- Confirm, following root-end surgery and before suturing, that all tooth fragments and excess filling material have been removed from the apical region and the surgical flap
- Evaluate, in follow-up films, the outcome of treatment

Radiographic Technical Requirements and Techniques

- The image of the tooth being evaluated or undergoing endodontic therapy should be in the center of the radiograph.
- Radiographs should show at least 5 mm of bone surrounding the apex of the tooth being evaluated or undergoing endodontic therapy.
- If a periradicular lesion is too large to fit in one periapical film, supplemental diagnostic radiographs must be made.
- A single radiograph taken from one direction only may not provide sufficient diagnostic information in multirooted teeth or in teeth with curved roots. Under these circumstances, at least two periapical radiographs should be taken to help gain a three-dimensional perspective. One radiograph should be taken at normal vertical and horizontal angulation, while the other should be taken at a 20° change in the horizontal angle from either the mesial or the distal direction (**Fig. 6.16**).
- If a sinus tract is present, a tracing radiograph should be taken. This procedure is accomplished by carefully threading a gutta-percha cone into the tract and by taking a radiograph to identify the origin of the tract. This technique is also useful for localization and depth marking of certain periodontal defects.
- Correct processing of the radiographic film is essential to evaluate the success or failure of the case at a later date.

In endodontics, the long-cone paralleling technique is preferred over the short-cone bisecting-angle technique because dimensional distortion is lesser, the image is sharper, and the same angulations are easily reproduced. The paralleling technique may be accomplished with the aid of the Rinn XCP instrument (**Figs 6.17** and **6.18**).

Radiographic Technique for Anterior Teeth

1. *Assembly of the endodontic film holder*
   (a) Select an appropriate film holder and anterior rod assembly (**Fig. 6.19**).
   (b) Slide the beam-alignment ring onto the rod and push it within 2 inches of the film-holding portion of the instrument (**Fig. 6.20**). Be sure that the film is centered in the ring and the long axis of the film is parallel to the anterior rod (**Fig. 6.21**).
2. *Taking the radiograph*
   (a) Remove the rubber dam frame.
   (b) Insert the assembled instrument and ensure that the tooth is in the center of the film and the film is parallel to the long axis of the tooth (**Fig. 6.22**). The edge of the film contacting the soft tissues should be about 1.5–2.5 cm palatal to the incisal edge of the tooth being radiographed. In the mandibular arch, this positions the edge of the film away from the muscle attachments and allows the floor of the mouth to flex to accommodate the depth of the film packet.
   (c) Slide the beam-alignment ring along the rod gently, until it lightly contacts the skin.
   (d) Align the X-ray tube with the rod and beam-alignment ring to obtain correct vertical and horizontal angulations (**Figs 6.23** and **6.24**).
   (e) Make the exposure.
   (f) Replace the rubber dam frame.

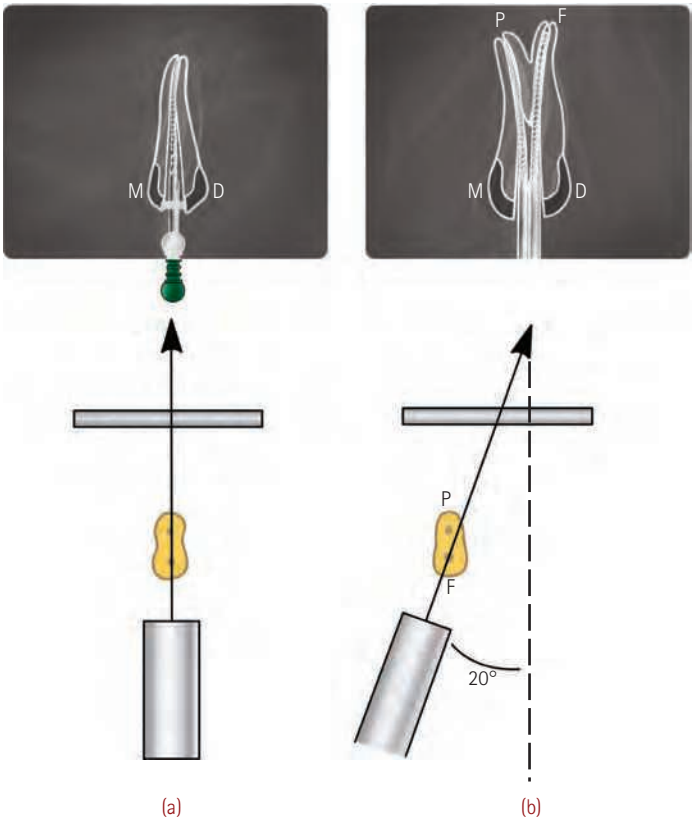


Figure 6.16 (a) Vertical and horizontal angulation for exposing a periapical radiograph of an upper first premolar. (b) Radiograph at a 20° horizontal angular change.

Radiographic Technique for Posterior Teeth

1. *Assembly of the endodontic film holder*
   (a) Select an appropriate film holder and posterior rod assembly.
   (b) Slide the beam-alignment ring onto the rod and push it within 2 inches of the film-holding portion of the instrument (**Fig. 6.25**). Be sure that the film is centered in the ring and the long axis of the film is parallel to the posterior rod (**Fig. 6.26**).
2. *Taking the radiograph*
   (a) Remove the rubber dam frame.
   (b) Insert the assembled instrument and make sure that the tooth is in the center of the film and the film is parallel to the long axis of the tooth (**Fig. 6.27**).
   (c) For mandibular radiographs, position the film between the teeth and the tongue and make sure that the lower edge of the film does not impinge on the muscle attachments in the floor of the mouth. Care should be taken that the patient does not displace the film by moving the tongue or swallowing when one is taking mandibular radiographs.
   (d) Slide the beam-alignment ring along the rod gently until it lightly contacts the skin.
   (e) Align the X-ray tube with the rod and beam-alignment ring to obtain correct vertical and horizontal angulations (**Fig. 6.28**).
   (f) Make the exposure.
   (g) Replace the rubber dam frame.
3. *Angulated radiographs*
   (a) Angulated radiographs can be obtained by *moving the cone 20° in a mesial or distal horizontal projection* (**Fig. 6.29**).
   (b) If a change in the vertical projection is needed, it can be accomplished by raising or lowering the cone by the desired number of degrees.

Intraoral Periapical Radiographs

Periapical views are used to record the crowns, roots, and surrounding bone. Film packs come in four sizes:

1. Size 0 for small children (22 × 35 mm)
2. Size 1 which is relatively narrow, used for views of anterior teeth (24 × 40 mm)
3. Size 2 standard film size used for posterior teeth in adults (31 × 41 mm)
4. Size 4 film used exclusively for the occlusal radiograph (57 × 76 mm)

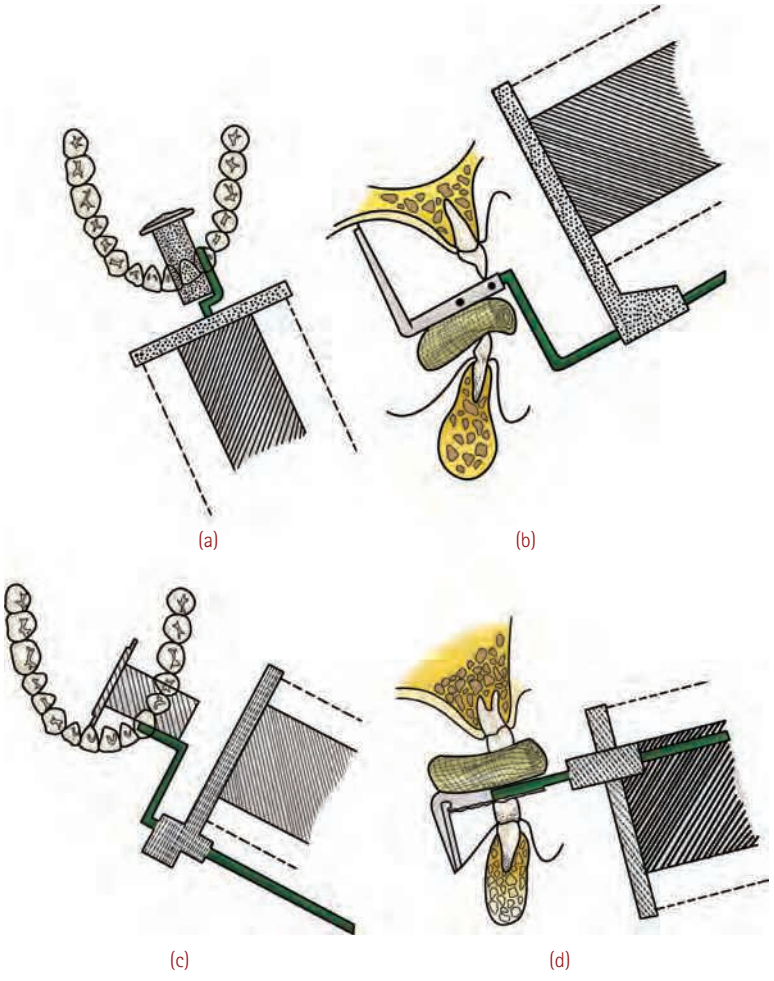


Figure 6.17 Paralleling radiographic technique. (See the text for details.) (a and b) XCP instrument positioned for exposing a radiograph of the maxillary lateral incisor. (c and d) XCP instrument positioned for exposing a radiograph of the mandibular premolars.

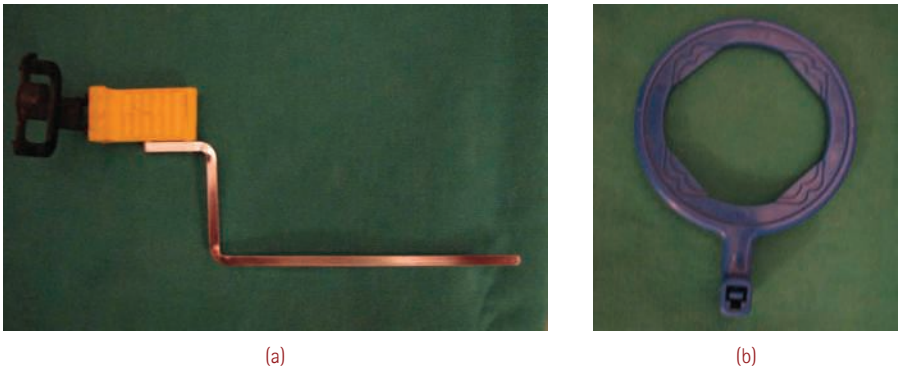


Figure 6.18 (a) Radiographic film-holding instrument. (b) XCP beam-positioning device. (See the text for details.)

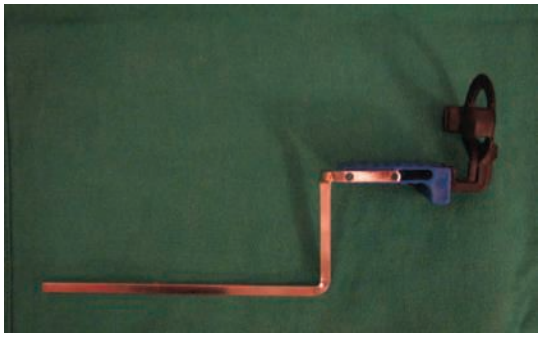


Figure 6.19 Correct method of assembling an endodontic film holder for anterior teeth. The assembly consists of an anterior rod inserted in a radiographic film holder.



Figure 6.20 Beam-alignment ring in place of an endodontic film holder.



Figure 6.21 Ensure that the film is centered in the beam-alignment ring. Note that the long axis of the film is parallel to the anterior rod.

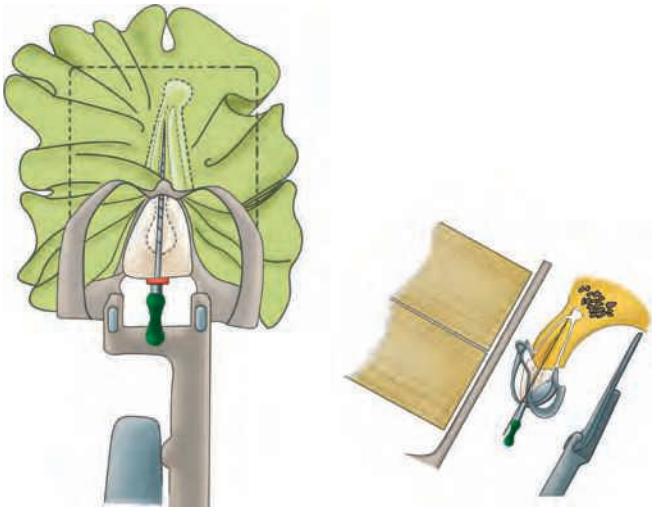


Figure 6.22 Radiographic technique for anterior teeth. (See the text for details.)



Figure 6.23 Alignment for correct radiographic angulation for maxillary incisors.



Figure 6.24 Alignment for correct radiographic angulation for mandibular incisors.

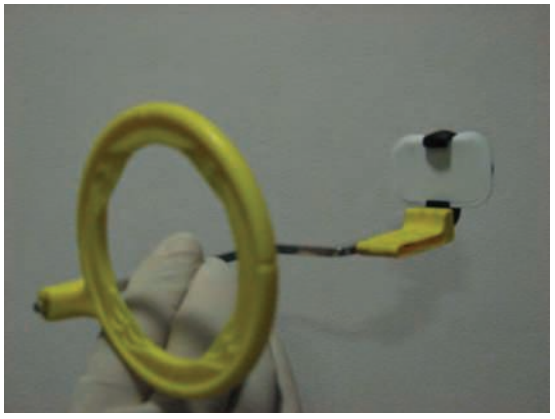


Figure 6.25 Beam-alignment ring in place for radiographs of posterior teeth.

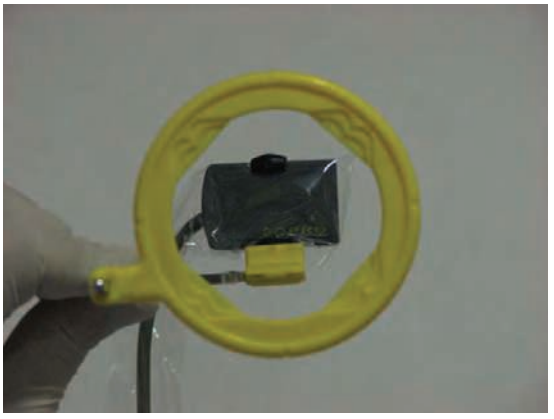


Figure 6.26 Ensure that the film is centered in the beam-alignment ring. The long axis of the film is parallel to the posterior rod. *Note:* The film positioning device can also accommodate a digital sensor.

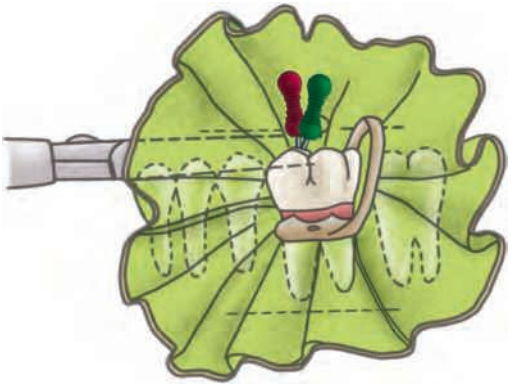
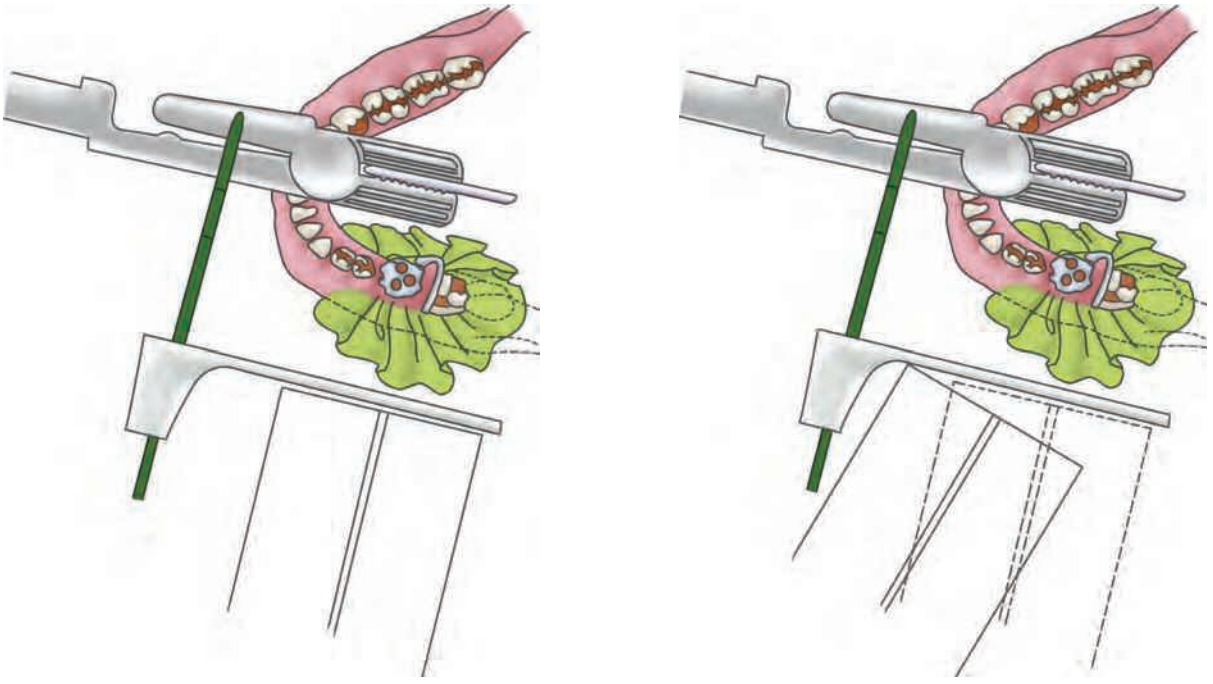


Figure 6.27 Radiographic technique for posterior teeth. (See the text for details.)



(a) (b)

Figure 6.28 (a) Radiographic alignment for mandibular posterior teeth. (b) Radiographic alignment for maxillary posterior teeth.



(a) (b)

Figure 6.29 Angulated radiographs. (See the text for details.)

To use radiographs properly, the clinician must have the knowledge and skill necessary to interpret them correctly. Required is a thorough understanding of the underlying normal anatomical structures (**Fig. 6.30a–6.30g**), anomalous anatomy, and the changes that can occur due to aging, trauma, disease, and healing. Only then will these two-dimensional black-and-white shadows on processed film have meaning.

Because the information contained within a radiograph is so essential to dental practice, it is important that radiographs be of excellent quality. An excellent radiograph may be difficult to interpret, but a poor radiograph is impossible to "*read*." To produce an excellent radiograph, one must master the necessary skills:

- Proper placement of the film in the patient's mouth
- Correct angulation of the cone in relation to the film and oral structures to prevent distortion of the anatomical images
- Correct exposure time, so that images are recorded with identifiable contrasts
- Proper developing technique to ensure a clear, permanent record that can be retained and stored for future use

Radiographs can contain information on the presence of caries that may involve or threaten to involve the pulp. They may show the number, course, shape, length, and width of root canals, the presence of calcified material in the pulp chamber or root canal, the resorption of dentin originating within the root canal (internal resorption) or from the root surface (external resorption), calcification or obliteration of the pulp cavity, thickening of the periodontal ligament, resorption of cementum, and nature and extent of periapical and alveolar bone destruction. Thus, radiographs provide pertinent information concerning diagnosis, prognosis, case selection, instrumentation, obturation, and repair of bone and cementum. They can be used to alert the clinician to impending difficulties caused by calcifications, periodontal problems, perforations, blockages, and fractures (**Fig. 6.31a–6.31l**).

Concomitantly, the presence of periradicular radiolucency on a tooth does not automatically indicate a diseased tooth. In many instances, an area of rarefaction that appears to be on the root apex of a tooth in a radiograph is actually a superimposition of an image on the root apex. This phenomenon may occur where the anatomy is normal, such as in the maxillary sinus, incisive foramen, mental foramen, and medullary spaces, or where a disorder is present but not pulpally related, such as an ameloblastoma, periodontal cyst, traumatic bone cyst, and malignant tumors.

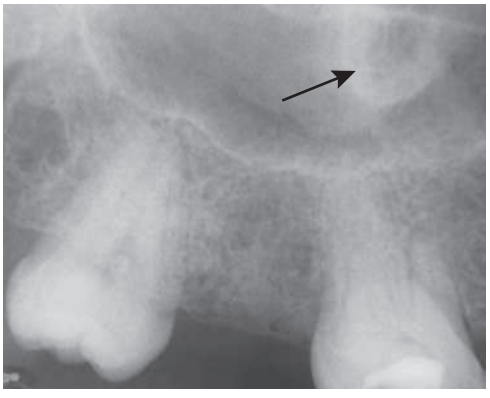
The conclusion of a study by Bender and Seltzer, confirmed in a later study by Schwartz and Foster, stated that a lesion in cancellous bone is not discernible on a radiograph until the cortical bone has been reached or penetrated. *Bender later reconfirmed that loss of cancellous bone is undetectable until at least 6.6% of the mineral content of the cortical bone in the direct path of the X-ray beam has been lost.* In other words, *a periradicular lesion is usually larger than its image on a radiograph.* A pathologic area can therefore be present, yet be obscured by a plate of cortical bone, and an acute abscess in a tooth can have a normal radiographic appearance with no apparent radiolucency.



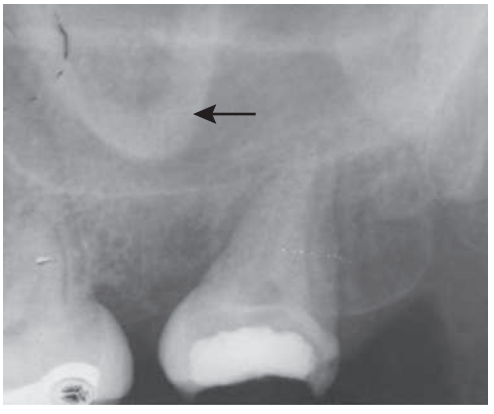
(a)



(b)



(c)



(d)



(e)

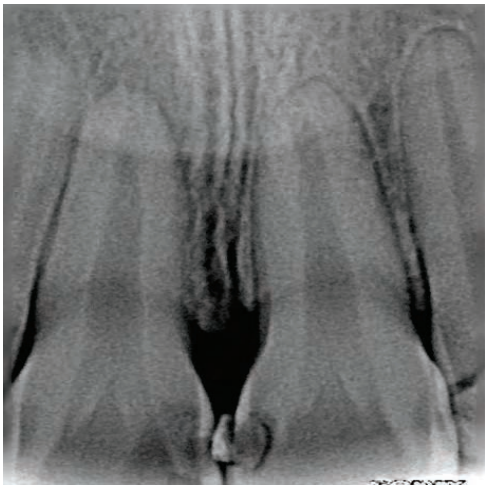


(f)

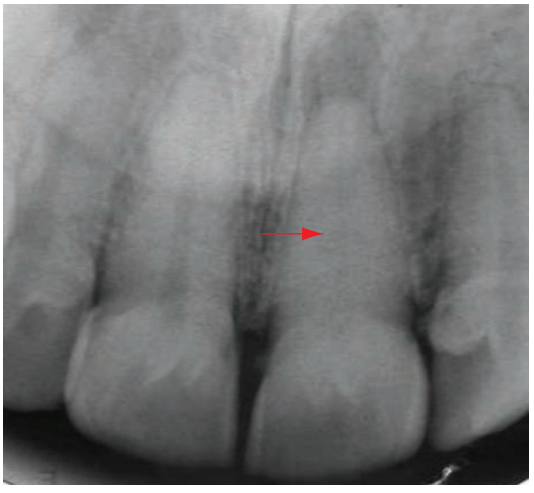


(g)

Figure 6.30 (a) IOPA radiograph of 36, 37, 38: anatomical structure seen is mylohyoid ridge as radiopaque line over the periapical region of 36 and 37. (b) IOPA radiograph of 36, 37, 38: anatomical structure seen is mandibular canal seen as a radiolucent tract of 2–3 mm width, with thin radiopaque border on sides well appreciated over the periapical area of 37 and 38. (c) IOPA radiograph of 16, 18 region: anatomical structures seen are pterygoid hamulus of medial pterygoid plate, maxillary sinus, U-shaped radiopacity of zygomatic bone, and coronoid process of mandible. (d) IOPA radiograph of 26, 28 region: anatomical structures seen are pterygoid hamulus of medial pterygoid plate, maxillary sinus, U-shaped radiopacity of zygomatic bone, and coronoid process of mandible. (e) IOPA radiograph of 23 region shows overlapping of the radiopaque border of nasal fossa and maxillary sinus in canine region resembling the alphabet "inverted Y," often referred to as inverted Y of Ennis. (f) IOPA radiograph of 45 region showing the mental foramen appearing like a periapical radiolucency at the root apex of 45. (g) IOPA radiograph of mixed dentition period in maxillary anterior region showing developing permanent teeth surrounded by the bone crypt. The radiolucent area surrounding the crown is called *dental follicle*. (*Courtesy: S. Karthiga Kannan, India.*)



(a)



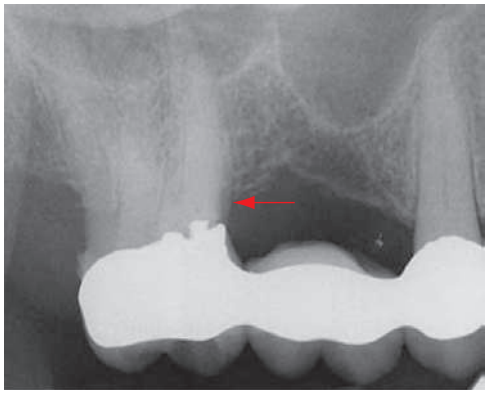
(b)



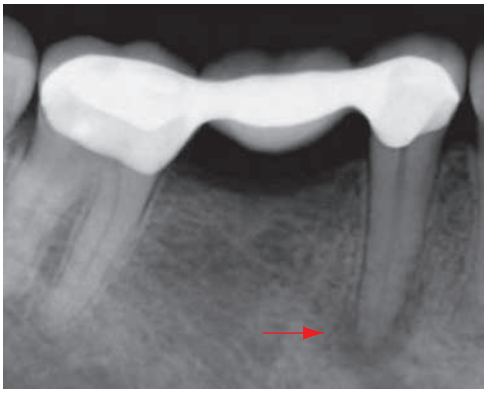
(c)



(d)



(e)



(f)

Figure 6.31 (a) Radiographic appearance of a normal vital permanent maxillary central incisor. (b) Calcific metamorphosis exhibiting canal calcification and obliteration in relation to the maxillary left central incisor. (c) Coronal radiolucency of mandibular second molar without pulpal involvement. (d) Distal coronal radiolucency in a mandibular second molar indicative of carious lesion involving the pulp. (e) Mesial marginal leakage from the terminal abutment of a three-unit bridge in relation to 15, 16, and 17. (f) Periradicular lesion in relation to a symptomatic mandibular premolar indicative of irreversible pulpal damage. *(continued)*



Figure 6.31 *(continued)* (g) Traumatic crown fracture with pulpal exposure in relation to the maxillary central incisor. (h) Oblique crown root fracture seen in a maxillary central incisor. (i) Radiograph of 11, 12 region showing a periapical radiolucency of 3 cm size with well-defined border and loss of lamina dura associated with the apex of 11. 11 also exhibits obliteration of pulp chamber and narrowing of root canal suggestive of nonvital tooth going for calcific metamorphosis. (j) Dentigerous cyst with a large periapical lesion in relation to a maxillary central incisor. (k) Internal resorption with intraosseous perforation of an endodontically treated upper left central incisor. (l) Separated instrument in the mesiobuccal canal of a mandibular first molar.

Box 6.9

Ørstavik's Periapical Index (PAI)

The PAI was developed to provide an ordinal scale of five scores denoting various stages of a disease. It is based on reference radiographs and has been designed for use in clinical trials and surveys. The purpose of the index is to integrate radiographic score with histologic characteristics of the disease and to provide standardization across studies.

- *Score 1:* Normal periapical structures
- *Score 2:* Small changes in bone structure
- *Score 3:* Changes in bone structure with some mineral loss
- *Score 4:* Periodontitis with well-defined radiolucent area
- *Score 5:* Severe periodontitis with exacerbating features

Radiographs have other limitations. Goldman and coworkers found that when five dentists examined the same endodontic radiographs, their interpretations concurred in only 67% of cases. Nevertheless, other tests must be used in conjunction with the radiograph to corroborate the interpretation.

Box 6.9 provides the periapical index for radiographic assessment of periapical changes.

Clinical Note

- Radiographs can be misleading and must be viewed with caution. The interpretation of radiographs is not an exact science. For example, a radiograph cannot be reliably used to differentiate a chronic abscess, a granuloma, or a cyst. To be accurate, such differentiation requires histopathologic evidence.
- The paradox of radiograph is that it does not always lend itself to correct interpretation, yet it has contributed more than any other diagnostic test toward the scientific practice of dentistry. Without it, we cannot properly diagnose dental pathologies with any reasonable degree of accuracy.

Bitewing Radiographs

Bitewing (interproximal) views (**Fig. 6.32**) are used to record the coronal portion of maxillary and mandibular teeth in one image. They are useful in detecting interproximal caries and evaluating the height of alveolar bone. Size 2 film is normally used in adults; smaller size 1 is preferred in children. In small children, size 0 may be used.

Advantages of using bitewing radiographs are as follow:

- Interproximal caries in early stage of development
- Reveal secondary caries below restorations
- Evaluating the periodontal condition
- Especially effective and useful for detecting calculus deposits in interproximal areas (because of its relatively low radiodensity, calculus is better visualized on radiographs made with reduced exposure)

Digital Radiography

Direct digital radiographic systems have three components:

1. *"Radio" component:* This consists of a high-resolution sensor plate with an active surface area. The dimensions of the sensor plate are similar to those of a radiographic film; however, the former is thicker, rigid, and smaller in dimension. The active surface of the sensor is protected from X-ray degradation by means of a fiberoptic film. This sensor is connected to the computer through a cable. Cordless sensors are also available (**Fig. 6.33**). The sensor is made of any of the following:
   (a) Charged couple device (CCD)
   (b) Complementary metal oxide semiconductor (CMOS)
   (c) Photostimulable phosphor detectors (PSP)
   When the sensor plate is exposed to X-rays, there is sensitization along the active surface area and the image is directly transmitted to the computer through radio

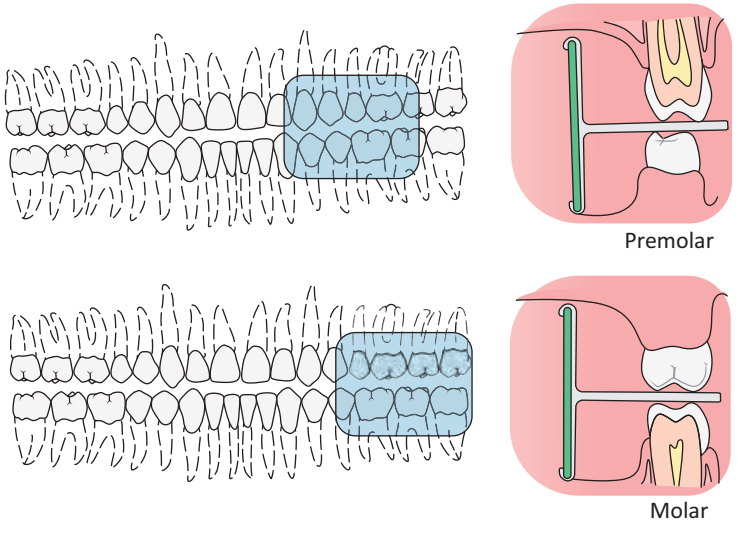


Figure 6.32 Bitewing view of a premolar and molar region.



(a)



(b)

Figure 6.33 Sensor plate used to capture the image: (a) Sensor with a wire. (b) Wireless sensor.

waves. This minimizes the time required to process a conventional film. Disposable plastic sleeves are available to prevent contamination of the sensor.

2. *"Visio" component:* This consists of a video monitor and a digital processing unit. The information obtained through the sensor plate is analyzed and given as an image. It can be manipulated in different dimensions with the help of software, which includes enhancement, contrast, magnification, colorizing, and reversing (**Fig. 6.34**). The image is stored in the computer for records.
3. *"Graphy" component:* This involves the production of a hard copy of the screen image using a high-resolution video printer.

Indirect digital radiography involves the digitalization of the conventional film. The radiographic image is scanned with a laser and transferred to a reusable film-like plate. The image on the plate is processed by the digital processing unit and obtained on the monitor.

Advantages

- Elimination of a conventional radiograph film and processing chemicals
- Reduction of radiation exposure by 80–90% when compared to a conventional D-speed film
- Maintaining electronic records of patients, which can be stored, assessed, and transferred
- Image manipulation to study details of the object and obtain maximum image optimization
- Reduced time to take a radiograph and reduced time to assess and retake another radiograph, if required
- Making measurements on the image such as measuring angle of curvature, linear measurements, and area measurements

Cone Beam Computed Tomography (CBCT)

Dental radiographs have been utilized as essential components of endodontic diagnosis and treatment planning. Limitations in conventional radiography such as providing two-dimensional representations of three-dimensional objects, image distortion, and superimposition of structures led to the development of three-dimensional imaging systems.

The introduction of CBCT or cone beam volumetric tomography (CBVT) imaging facilitated the transition from a 2D to a 3D approach in image acquisition and interpretation. The device utilizes a cone-shaped beam of ionizing radiation, which passes through the center of the region of interest. An X-ray detector attached to a rotating gantry captures the radiation on the opposite side. The resultant information is then generated digitally through a series of multiple planar projection images of the field of view (FOV). The image is captured as three-dimensional pixels termed *voxels* with a resolution ranging from 0.4 to 0.076 mm.

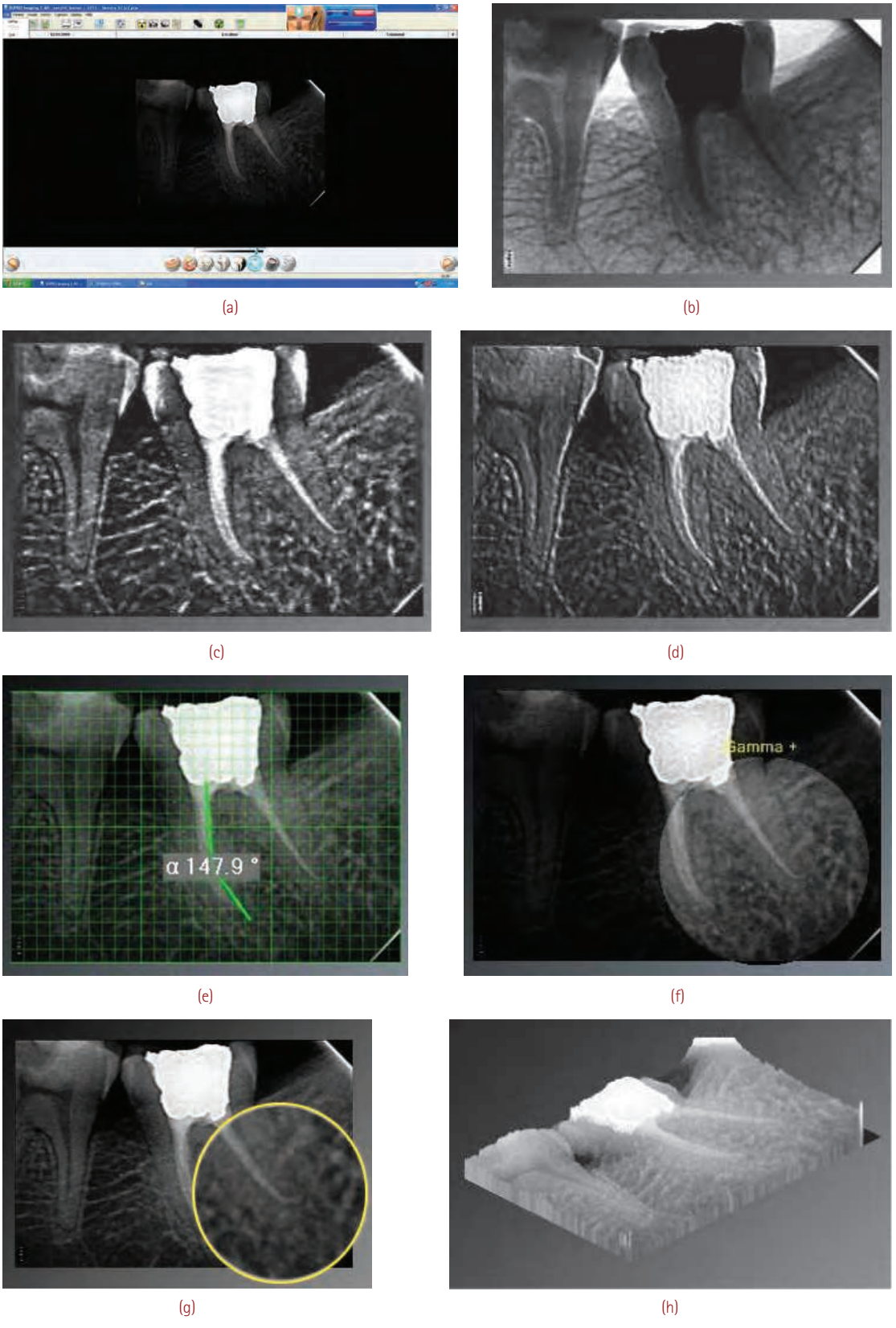
Steps in Processing

According to Scarfe et al., the following are the steps involved in CBCT image processing:

- Acquisition configuration
- Image detection
- Image reconstruction
- Image display

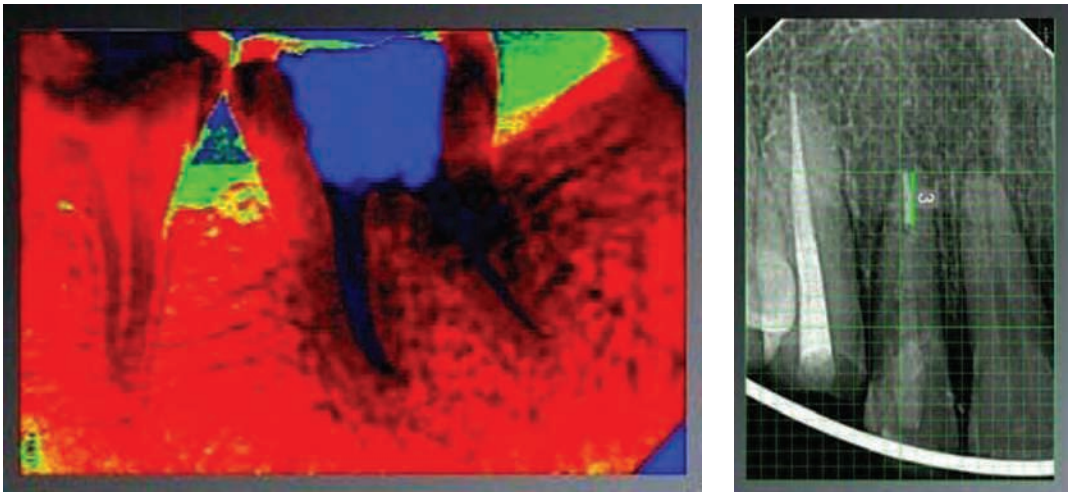
Applications in Endodontics

The applications of CBCT in endodontics (**Fig. 6.35**) include the diagnosis of periradicular lesions, canal visualization,



(a) (b) (c) (d) (e) (f) (g) (h)

Figure 6.34 Digital radiograph: (a) Digital radiograph of a molar tooth displayed on a computer screen. The image can be manipulated as follows: (b) Inversion. (c) Contrast. (d) Relief. (e) Measurement of the angle of root curvature. (f) Flashlight. (g) Magnification. (h) Three-dimensional view. *(continued)*



(i) (j)

Figure 6.34 *(continued)* (i) Pseudocolor. (j) Linear measurement.

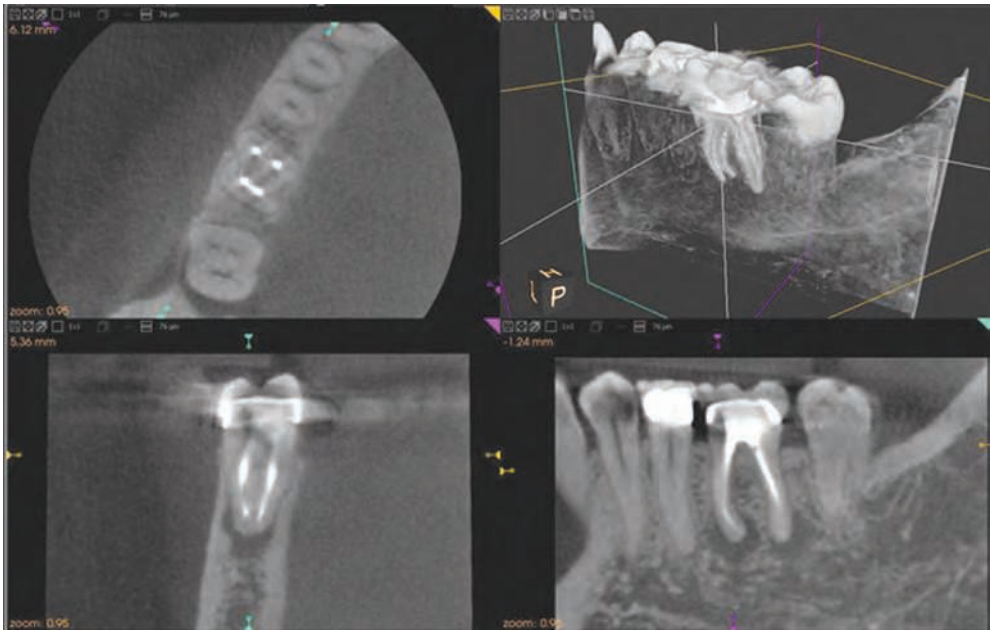


Figure 6.35 CBCT providing three-dimensional views in axial, coronal, and sagittal directions.

assessment of internal and external resorption, detection of root fractures and other dentoalveolar trauma, preparation for endodontic surgery, and detection of calcific metamorphosis.

Advantages

Rapid scan time, beam limitation, image accuracy, reduced patient radiation dose, interactive display modes applicable to maxillofacial imaging, multiplanar reformation, and three-dimensional volume rendering.

Limitations

Artifacts (X-ray beam related, patient related, cone beam related, and scanner related), image noise, and poor soft-tissue contrast.

VII. Assessment of Pulp Vitality

The accurate diagnosis of the true histologic status of the pulp is of significant importance for treatment planning. This is indirectly done by assessing the neural sensitivity of the pulp. The more accurate method would be to assess the

Box 6.10

Methods for Tooth Vitality Assessment

1. Neural sensibility tests
   (a) Thermal tests
      (i) Heat test
      (ii) Cold test
   (b) Electric pulp test (EPT)
   (c) Anesthetic test
   (d) Test cavity
2. Pulp vascularity tests
   (a) Pulse oximetry
   (b) Laser Doppler flowmetry
   (c) Others
      (i) Dual-wavelength spectrophotometry
      (ii) Thermography
      (iii) Crown surface temperature

vascularity of the pulp. However, *most common methods clinically employed assess neural sensitivity*, while the recent research and developments are trying to find a clinical method of vascularity assessment. **Box 6.10** provides the various methods of assessing pulpal vitality.

A. Neural Sensibility Tests

These are the tests that *indirectly* tell us about the vitality status of the pulp. They work on the principle of stimulating the neural fibers present in the pulp.

i. Thermal Tests

These tests involve the application of cold and heat to a tooth to determine its sensitivity to thermal changes.

The results of the thermal test should be correlated with the results of other tests to ensure validity.

Heat test

Materials used are as follows:

- Electrical heat carrier (**Fig. 6.36a**)
- Hot gutta-percha stick (>65.5°C)
- Others
  - Hot water under rubber dam isolation
  - Hot burnisher
  - Hot compound
  - Dry rubber polishing wheel

The heat test can be performed using different techniques that deliver different degrees of temperature. The area to be tested is isolated and dried, a suitable lubricant (Vaseline) is applied, heat is directed to the exposed surface of the tooth, and the patient's response is noted. A heat carrier instrument (**Fig. 6.36a**) that can deliver a controlled temperature to the tooth is preferable, or a hot gutta-percha stick can be employed. When using a solid substance, such as hot gutta-percha, the heat is applied to the occlusobuccal third of the exposed crown (**Fig. 6.36b**). If there is no response, the hot substance can be moved to the central portion of the crown or closer to the tooth cervical margin. When a response



(a)



(b)

Figure 6.36 (a) Tooth vitality scanner. (*Courtesy: SybronEndo, USA.*) (b) Heat test: applying heated gutta-percha stick to the tooth surface.

occurs, heat should be removed immediately. Care should be taken to avoid using excessive heat or prolonged application of heat to the tooth.

A different technique is required for the application of hot water. The tooth to be tested is isolated under a rubber dam. The tooth is then immersed in "coffee-hot" water delivered from a syringe, and the patient's reaction is noted. Because the hot water is contained in the rubber dam, the response is limited to the tooth tested. **Box 6.11** provides the mechanism of action of the heat test.

Cold Test

Materials used are as follows:

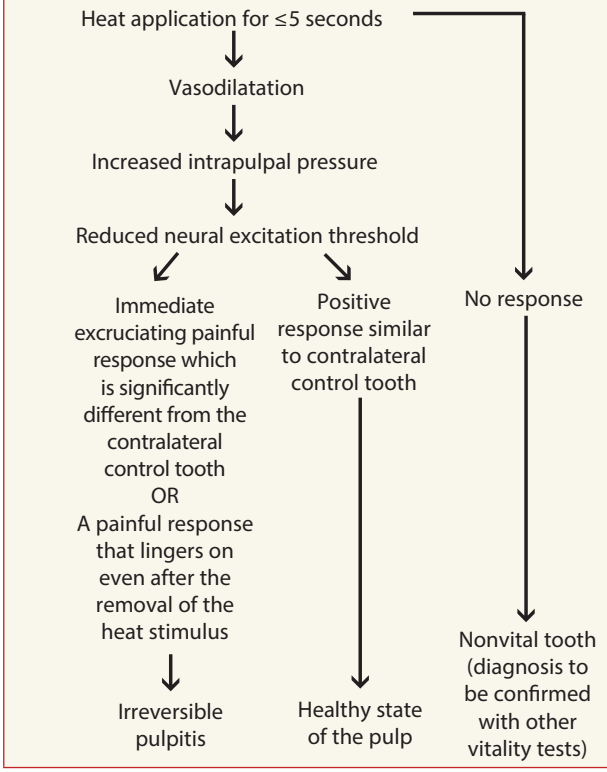
- Endo-Ice → 1,1,1,2-tetrafluoroethane
- CO_2 snow
- Pencil of ice
- Ice cold water under rubber dam isolation
- Ethyl chloride

Cold can be applied in several different ways (**Fig. 6.37a** and **6.37b**). **Box 6.12** provides the mechanism of action of the cold test. The most common method is to apply a cotton pellet saturated with 1,1,1,2-tetrafluoroethane to the tooth being tested.

Another simpler method of applying cold to a tooth is by following these steps: wrap a sliver of ice in wet gauze, place it against the facial surface of the tooth, and compare the reaction to a control tooth. Pencils of ice can be made by filling discarded anesthetic carpules with water and freezing them

Box 6.11

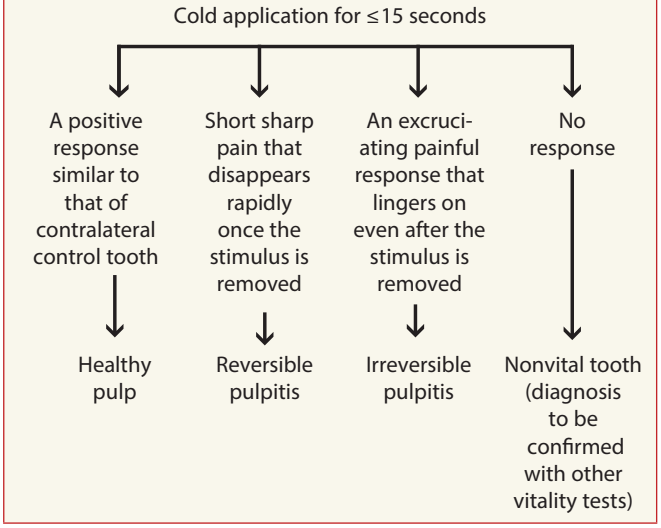
Mechanism of Heat Test (Van Hassel's Theory)



in an upright position in a refrigerator. The rubber stopper should be at the base of the carpule to enable one to force the ice out of the carpule and thereby obtain a pencil of ice. Dachi and associates recommended that a quarter-inch-diameter cone of ice be placed against a tooth for 5 seconds to quantify cold testing.

Box 6.12

Mechanism of Cold Test (Brannstrom's Theory)





(a)



(b)

Figure 6.37 (a) Hygenic Endo-Ice. (*Courtesy: Coltene/Whaledent, USA.*) (b) Cold testing: cotton pellet soaked with Endo-Ice being applied to a tooth.

Carbon dioxide (dry ice) snow has also been used for application of cold to teeth. The use of dry ice has been described by Ehrmann. Because the temperature of dry ice is –78°C, one is able to penetrate full-coverage restorations and elicit a reaction from the underlying tooth to the cold.

Clinical Note

- The diagnostic accuracy of cold test is 86%, the electric pulp test (EPT) is 81%, and heat test is 71%. Hence, clinically, a combination of cold test followed by EPT is recommended.
- Cold test can be used to differentiate between reversible and irreversible pulpitis.
- In irreversible pulpitis, patients complain of increased pain secondary to heat test, while in such a situation the application of cold would cause temporary relief of pain.
- Heat testing is recommended when the patient's chief complaint is pain in contact with any hot liquid or food.

ii. Electric Pulp Test (EPT)

The EPT is one of the tests used to determine pulp vitality. The electric pulp tester (**Fig. 6.38a**), when testing for pulp

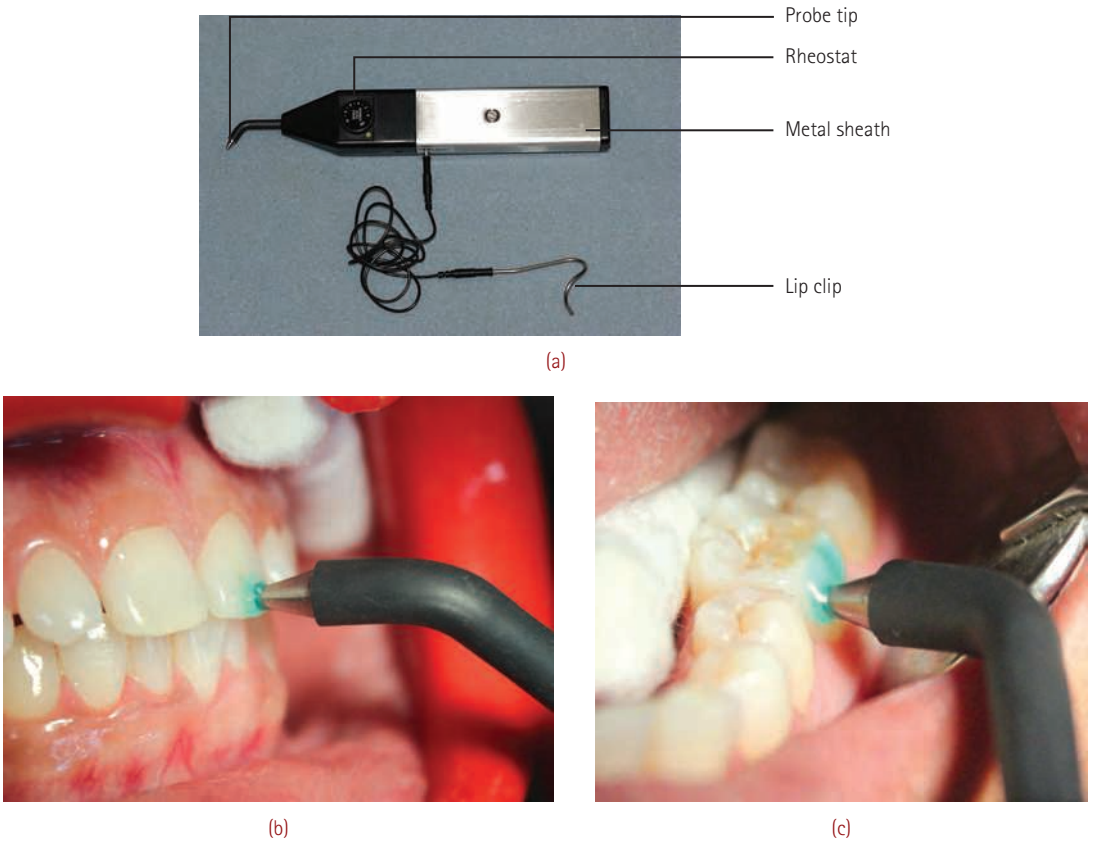


Figure 6.38 (a) Electric pulp tester. (*Courtesy: Parkell Inc., USA.*) (b and c) Electric pulp testing: (b) The electrode is placed against the incisal third enamel surface of the isolated and dried tooth crown using toothpaste as an electrolyte. (c) The electrode is placed against the mid-third surface of a posterior tooth.

vitality, uses nerve stimulation. The objective is to stimulate a pulpal response by subjecting the tooth to an increasing degree of electric current. A positive response is an indication of vitality and helps in determining the normality or abnormality of that pulp. No response to the electrical stimulus can be an indication of pulp necrosis.

The procedure for electrical pulp testing can be performed in the following simple steps:

- Describe the test to the patient in a way that will reduce anxiety and will eliminate a biased response.
- Isolate the area of the control tooth and the tooth to be tested with cotton rolls and a saliva ejector, and air-dry all the teeth.
- Check the electric pulp tester for function and determine that current is passing through the electrode.
- The test is always performed on a control tooth prior to testing the tooth in question.
- Apply an electrolyte (prophy paste or toothpaste) on the tooth electrode and place it against the dried enamel of the crown's occlusobuccal or incisolabial surface. It is important to avoid contacting any restorations in the tooth or the adjacent gingival tissue with the electrolyte or the electrode; this would cause a false and misleading response.
- Location of probe tip: The placement of the tester is critical to ensure accurate response from the tooth.
  - Anterior teeth → incisal third (**Fig. 6.38b**)
  - Posterior teeth → mid-third of the mesiobuccal cusp of molars and buccal cusp of premolars (**Fig. 6.38c**)
- Completion of the circuit: Retract the patient's cheek away from the tooth electrode and the electrical circuit is completed by either of the following:
  - A ground wire (lip clip) is placed over the patient's lip in contact with the oral mucosa.
  - The clinician instructs the patient to rest a finger on the metal sheath of the pulp tester.
- Turn the rheostat slowly to introduce minimal current into the tooth and increase the current slowly. Ask the patient to indicate when sensation occurs by using such words as "tingling" or "warmth." Record the result according to the numeric scale on the pulp tester.
- Repeat the foregoing for each tooth to be tested. The clinical interpretation of the pulpal response is given in **Box 6.13**.

As errors in technique or in response can occur easily, it is wise to recheck all results for accuracy whenever in doubt about the validity of the test. Testing the accuracy of the patient's response with the unit switched off or changing

Box 6.13

Clinical Interpretations of Pulpal Response to EPT

- *Normal response:* A positive response is a response that occurs at the same neural excitation threshold as the control tooth. For example, during the assessment of a maxillary left lateral incisor, the control tooth would be the maxillary right lateral incisor. The test tooth would be considered normal and vital if both the teeth exhibit a positive response at a similar numerical value of the EPT.
- *Negative response:* This denotes a nonvital tooth, which fails to respond even when the tester is set to the highest electrical excitation value.
- *Early response:* This denotes a diseased state of pulp as the tooth responds to a threshold which is less than that of the control tooth.
- *Delayed response:* This also denotes a diseased state of the pulp wherein the tooth responds at a significantly higher electrical excitation level compared to the control tooth.
- *False-positive response*
  - When gangrenous necrotic pulp is present in a root canal
  - Multirooted teeth in which the pulp is partially necrotic, with some nerve fibers still vital in one or more of the root canals
- *False-negative response*
  - Extensive calcification in the pulp tissue or dentin
  - In a tooth with increased reparative dentin and a diminishing pulp cavity
  - Fibrotic pulp
  - Teeth with extensive restorations and a pulp-protecting base
  - Recently traumatized teeth
  - Recently erupted teeth with incomplete root formation
  - Sedative medication taken by the patient
  - Patients with an unusually high pain threshold

the sequence of the teeth being tested prevents the accuracy of the results from being affected by the patient's reaction because of bias or anxiety. A radiograph of all teeth being tested should be visible for reference during the test. Finally, one should not rely on the results of any one test or reaction to any one tooth without similarly testing and comparing the response to a control tooth.

The EPT cannot be solely depended on for testing pulp vitality, and results should be corroborated with those of other tests, such as the cold test or test cavity.

Clinical Note

- The most ideal way of performing a pulp sensibility test is a ***combination of cold test and EPT***.
- The EPT is unreliable in testing immature permanent teeth.
- The EPT is not recommended for assessment of concussed teeth.
- Cold test is the most effective sensitivity test for immature permanent teeth.
- Electric pulp testing is not done on teeth with full-coverage restorations because an electrical stimulus cannot pass undistorted through acrylic, ceramic, or metallic portions of a crown. These teeth can be tested for vitality using a test cavity, but such a test should be done only under limited circumstances because it requires cavity preparation in the occlusal surface of the crown. Application of carbon dioxide snow (−78°C) is the test of choice under such circumstances.
- Following traumatic dental injuries, the reaction to the tests of pulp vitality may be negative for as long as 3 months in case of root fractures or trauma to supporting structures. Hence, *sensitivity tests may be negative initially and have to be monitored over a period of time*.

iii. Anesthetic Test

This test is restricted to patients who are in pain at the time of the test when the usual tests have failed to identify the tooth. The objective is to anesthetize one tooth at a time until the pain disappears and is localized to a specific tooth (**Fig. 6.39**).

The technique is as follows: using either infiltration or the intraligament injection, inject the most posterior tooth in the area suspected of being the cause of pain. If pain persists when the tooth has been fully anesthetized, anesthetize the next tooth mesial to it and continue to do so until the pain disappears. If the pain cannot be identified as from maxillary or mandibular origin, an inferior alveolar block (mandibular block) is given. Cessation of pain naturally indicates involvement of a mandibular tooth, and localization of the specific tooth is done by the intraligament injection when the anesthetic has spent itself.

Clinical Note

The anesthetic test is obviously a last resort test and has an advantage over the "test cavity," during which iatrogenic damage is possible.

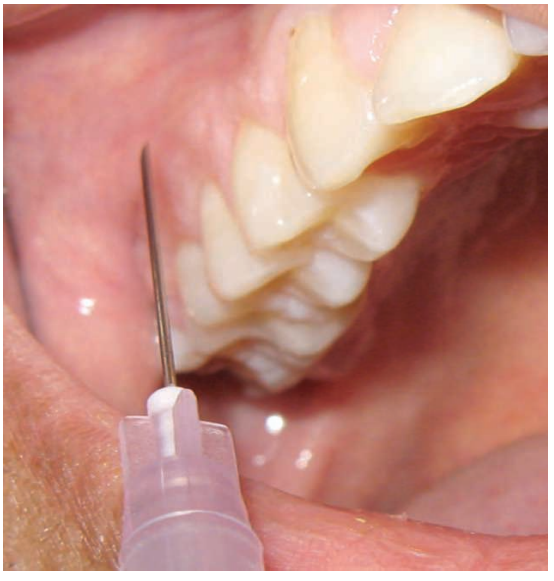


Figure 6.39 Anesthetic test: anesthetize a single tooth at a time until pain disappears.



Figure 6.40 Test cavity: when drilling through the dentinoenamel junction of an unanesthetized tooth, a painful sensation indicates some vitality present in the pulp.

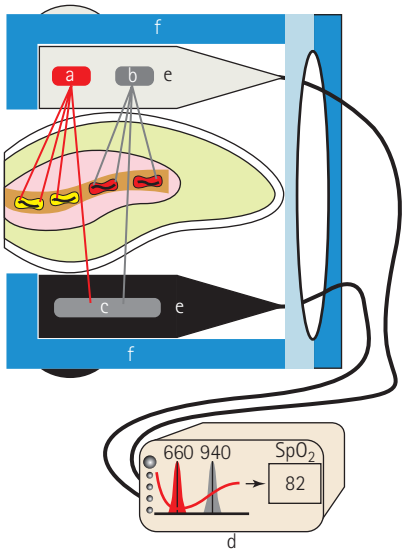


Figure 6.41 Mechanism of dental pulse oximeter: *a*, light-emitting diode emitting red light at 660 nm; *b*, light-emitting diode emitting infrared light at 940 nm; *c*, photodetector; *d*, pulse oximeter monitor; *e*, pulse oximeter sensor; *f*, custom-made pulse oximeter sensor holder.

iv. Test Cavity

This test allows one to determine pulp vitality (**Fig. 6.40**). It is performed when other methods of diagnosis have failed. The test cavity is made by drilling through the enamel–dentin junction of an *unanesthetized tooth*. The drilling should be done at *high speed and with a water coolant*. Sensitivity or pain felt by the patient is an indication of pulp vitality; no endodontic treatment is indicated. Sedative cement is then placed in the cavity, and the search for the source of pain continues. If no pain is felt, cavity preparation may be continued until the pulp chamber is reached. If the pulp is completely necrotic, endodontic treatment can be continued painlessly in many cases without anesthesia.

B. Pulp Vascularity Tests

The most common methods to assess pulp vitality are based on sensitivity assessment of the neural tissues of the pulp. These include thermal and EPTs. True vitality status can be ascertained only when we are able to assess the vascular or blood supply to the tooth. The two technologies which are being developed and which could potentially prove to be effective and objective vitality assessment tools are as follows.

i. Pulse Oximetry

Pulse oximetry is a noninvasive method to measure the oxygen saturation levels during the administration of anesthesia or other medications with the help of a finger, ear, or foot probes.
Principle: The pulse oximeter sensor (POS) consists of two light-emitting diodes, one to transmit red light (660 nm) and the other to transmit infrared light (940 nm), and a photodetector on the opposite side of the vascular bed. The light-emitting diode transmits red and infrared light through a vascular bed such as the finger or ear. Oxygenated hemoglobin and deoxygenated hemoglobin absorb different amounts of red and infrared light. The pulsatile change in the blood volume causes periodic changes in the amount of red and infrared light absorbed by the vascular bed before reaching the photodetector. The relationship between the pulsatile change in the absorption of red light and the pulsatile change in the absorption of infrared light is analyzed by the pulse oximeter to determine the saturation of arterial blood.

The pulse oximeter equipment (**Fig. 6.41**) consists of a *pulse oximeter monitor* (POM) which gives the digital display of oxygen saturation values. This POM is connected to a *POS* which is designed to anatomically conform to the area where oxygen saturation values have to be assessed, e.g., ear POS, finger sensor, and toe sensor. The POS is held in place with a *sensor holder* to ensure accurate adaptation of the sensor in the area being assessed.

This technology is still in developmental stage and has not been commercialized yet.

ii. Laser Doppler Flowmetry

Laser Doppler flowmetry (LDF) is a noninvasive method of assessing and accurately measuring the rate of blood flow in a tissue.

Principle: The laser light is transmitted through a fiberoptic source and placed onto the tooth surface. The light enters the tooth and gets absorbed by the red blood cells which leads to a shift in the frequency of the scattered light. This occurs due to the *Doppler principle*. This shift in frequency does not occur in light that is absorbed by stationary objects. The proportion of Doppler shifted light is detected with the help of a photodetector. This principle is used to ascertain the presence of blood movement within the pulp space. LDF can

thus be potentially used to differentiate a healthy, traumatized tooth with reduced blood supply from a nonvital tooth.

However, this is technique sensitive and requires splints to hold the sensors in place. Care has to be taken that there are no other motion artifacts during the procedure. Currently, this device has been developed for medical use and is expensive. It is probably for this reason that LDF has not been used as routine special investigation in dental practice.

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7 Endodontic Emergencies

"Deal with the fear first, then pain will be a minor problem."
– Peter Milgrom

Endodontic emergency is a condition associated with pain and/or swelling that requires immediate diagnosis and treatment. *Pulpal pathologies* and *traumatic injuries* are the two most common causes for these emergencies. Pain can originate from the pulp or the periradicular area. Pain in endodontic emergencies is mainly related to two factors, namely, *chemical mediators* and *pressure*. Chemical mediators cause pain directly by lowering the pain threshold of sensory nerve fibers or by increasing vascular permeability and producing edema. Increased fluid pressure resulting from edema also stimulates the pain receptors.

Definition: *An endodontic emergency is defined as pain and/or swelling caused by inflammation or infection of the pulp and/or periradicular tissues necessitating an emergency visit to the dentist for immediate treatment.*

CLASSIFICATION

Box 7.1 presents the classification of endodontic emergencies.

Box 7.1

Classification of Endodontic Emergencies

1. Before treatment
   - (a) Endodontic emergencies presenting with pain and/or swelling
     - (i) Crown-originating fracture (COF) (previously known as cracked tooth syndrome)
     - (ii) Symptomatic reversible pulpitis
     - (iii) Symptomatic irreversible pulpitis
     - (iv) Primary symptomatic apical periodontitis
     - (v) Secondary symptomatic apical periodontitis (acute exacerbation of asymptomatic apical periodontitis or phoenix abscess)
     - (vi) Symptomatic (acute) alveolar abscess
     - (vii) Cellulitis
   - (b) Traumatic injuries
     - (i) Crown/root fractures
     - (ii) Luxation injuries
     - (iii) Tooth avulsion
2. During treatment
   - (a) Hot tooth
   - (b) Endodontic flare-ups
3. After treatment
   - (a) Postobturation pain
   - (b) Vertical root fracture (VRF)

ENDODONTIC EMERGENCIES PRESENTING BEFORE TREATMENT

Table 7.1 presents the clinical management of endodontic emergencies arising before treatment.

The discussion of symptomatic reversible pulpitis, symptomatic irreversible pulpitis, primary symptomatic apical periodontitis, and secondary symptomatic apical periodontitis (acute exacerbation of asymptomatic apical periodontitis) has been done previously in Chapters 4 and 5, while traumatic injuries have been elaborated in Chapter 19.

CROWN-ORIGINATING FRACTURE (COF) (PREVIOUSLY KNOWN AS CRACKED TOOTH SYNDROME)

Definitions:

- ***Crown-originating fracture (COF)*** *denotes an incomplete fracture of a tooth with a vital pulp. The fracture involves enamel and dentin, often involving the dental pulp.*
  - ***Infraction*** is a very descriptive term that indicates an incomplete fracture without displacement of the fragments.
  - ***Craze lines*** are merely visible cracks in the enamel that do not extend into the dentin and either occur naturally or develop after trauma.

Prevalence

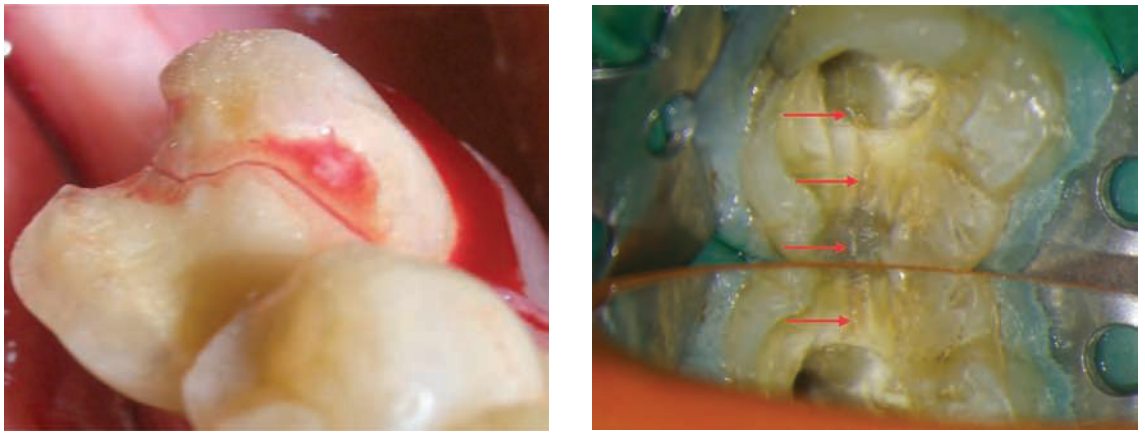
- Mandibular molars are most commonly affected (**Fig. 7.1a**), followed by maxillary molars and maxillary premolars.
- Molars of older individuals most frequently present with COF.
- Most cases occur in teeth with class I restorations (39%) or in those that are unrestored (25%), but with an opposing plunger cusp occluding centrically against a marginal ridge.

Symptoms

- The patient usually complains of *mild to excruciating pain at the initiation or release of biting pressure*. The pain is normally *not localized*, and the patient would show the region where the pain arises from. Such teeth may be sensitive for years because of an incomplete fracture of enamel and dentin that produces only mild pain.

Table 7.1 Clinical Management of Endodontic Emergencies Presenting with Pain and/or Swelling Before Treatment

Name	Clinical Characteristics	Treatment
Crown Originating Fracture (COF)	Incomplete vertical fractures, often involving the pulp	Reduction of occlusal contact, restoration/full occlusal coverage immobilizing the segments
Symptomatic reversible pulpitis	Mild-to-moderate pulpal inflammation caused by noxious stimuli; pulp capable of returning to normal once stimuli are removed	Removal of noxious stimuli and restoration, if required. Periodic vitality testing
Symptomatic irreversible pulpitis	Symptomatic pulpal inflammation; pulp incapable of healing	Pulpectomy and pharmacological management of pain
Primary symptomatic apical periodontitis	Painful periodontal inflammation due to trauma, irritation, or root canal infection; clinical symptoms include painful response to biting and percussion	Pharmacological management of pain and swelling along with one or more of the following: • Occlusal adjustment • Access opening of the root canal(s) • Incision and drainage • Needle aspiration • Antibiotics • Trephination and decompression
Secondary symptomatic apical periodontitis (acute exacerbation of asymptomatic apical periodontitis or Phoenix abscess)	Acute inflammatory reaction superimposed on an existing asymptomatic apical periodontitis	
Symptomatic (acute) alveolar abscess	Rapid inflammatory reaction to pulpal infection and necrosis; symptoms include spontaneous pain, tenderness of the tooth to pressure, pus formation, and eventual swelling of associated tissues	
Cellulitis	Symptomatic, edematous inflammatory process associated with invasive microorganisms that spread diffusely through connective tissues and fascial planes	



(a) (b)

Figure 7.1 (a) Mandibular molar showing Crown Originatiing Fracture (COF) with the crack extending mesiodistally along with clinical evidence of pulpal exposure. (b) Crack extending into the pulp chamber in a mandibular molar.

Eventually, this pain becomes severe when the fracture involves the pulp chamber also. The pulp in these teeth may become necrotic.

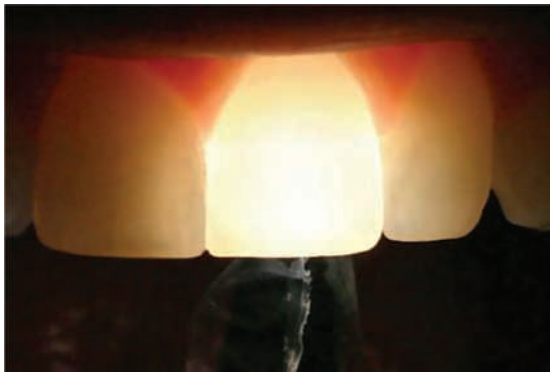
- The second most common symptom is pain on exposure to cold food and liquids.

Etiology

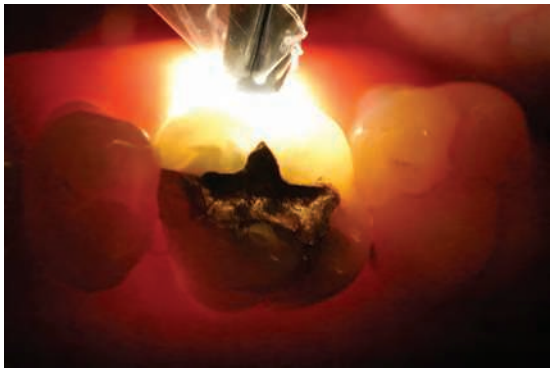
- Natural predisposing features:
  - Occlusal anatomy
  - Bruxism
- Iatrogenic causes:
  - Instrument used
  - Tooth preparations

Clinical Features

I. *Visual Examination*: Close examination of the crown of the tooth may disclose an enamel crack, that may be better visualized by using the following methods:
   - *Fiber optic light* (**Fig. 7.2a** and **7.2b**): This is used to transilluminate a fracture line. Most cracks run



(a)



(b)

Figure 7.2 (a) Transillumination test in a normal tooth. (b) Transillumination test for diagnosing crown-originating fracture (COF).

mesiodistally and are rarely detected radiographically when they are incomplete.

- *Dye*: Alternatively, staining the fracture with a dye, such as methylene blue, is a valuable aid to detect a fracture.

II. *Bite Test*: An important step in the clinical examinations is the application of a biting test. This can be done with the help of a moist cotton roll or by using a tooth slooth.

- *Tooth slooth* (**Fig. 7.3**): This is a small, pyramid-shaped plastic bite block, with a small concavity at the apex of the pyramid to accommodate the tooth cusp. This small indentation is placed over the cusp, and the patient is asked to bite down. Thus, the occlusal force is directed to one cusp at a time, exerting the desired pressure on the questionable cusp.



Figure 7.3 Tooth slooth.

Clinical Note

- *Pain upon release of pressure* is a strong indication of the presence of a crown-originating fracture (COF).
- The crack line in a COF extends in an *occluso-cervical direction* and is to be distinguished from a tooth with vertical root fracture wherein the crack extends from the tip of the root towards the cervical margin (**Fig. 7.1b**).

Diagnosis

- Bite test is an excellent way to facilitate diagnosis.
- Careful probing with an explorer and percussion of the teeth are secondary diagnostic tests to ascertain the presence of COF.

Management

- If the initial pulpal diagnosis is ***reversible pulpitis*** (based on no lingering pain to cold and no spontaneous, severe pain), a 2-week waiting period is recommended. The tooth is stabilized with an orthodontic band for these 2 weeks. Definite treatment of a cracked tooth attempts to preserve pulpal vitality by requiring *full occlusal coverage for cusp protection*. If the patient has an incomplete fracture of only the enamel and dentin, a full-crown restoration immobilizing the fragments may be successful. Cusp coverage as a treatment plan may seem as an invasive treatment, but a vertical crack that is left unprotected will migrate pulpally and apically.
- If the initial pulpal diagnosis is ***irreversible pulpitis,*** then this would necessitate the need for root canal treatment followed by *full occlusal coverage for cusp protection.*

ENDODONTIC EMERGENCIES DURING TREATMENT

HOT TOOTH

Definition: *A tooth that is difficult to anesthetize is known as a "hot tooth."*

This is most commonly encountered in a mandibular first molar tooth wherein after the anesthetic block, the patient may describe profound numbness of the ipsilateral lip and tongue but still may experience acute pain during the access opening procedure.

Mechanism

There is a special class of sodium channels on C-fibers, known as tetrodotoxin-resistant (TTXr) sodium channels. The expression shifts from TTX-sensitive to TTXr during neuroinflammatory reactions and the TTXr sodium channels play a role in sensitizing C-fibers and creating inflammatory hyperalgesia. One of the clinically significant characteristics of these sodium channels is that they are relatively resistant to lidocaine. These channels are five times more resistant to anesthetic than TTX-sensitive channels. Hot tooth may be

explained by the fact that the TTXr sodium channels have not been adequately blocked by the anesthetic.

Management

i. Supplementing an inferior alveolar nerve block (IANB) with **4% articaine with 1:100,000 epinephrine** buccal infiltration (0.9–1.2 mL) at the apex of the tooth to be treated is one of the most effective supplemental anesthetic techniques.

ii. *Buffering*: Buffering (e.g., alkalinizing) the dental local anesthetic solution immediately before its administration with a stabilized sodium bicarbonate solution has been found to make the onset of anesthesia much quicker in a hot tooth.

iii. *Supplemental intraligamentary injections* are also helpful to ensure profound local anesthesia. For intraligamentary injection, a volume of 0.2 mL of local anesthetic is deposited slowly using a 27-gauge short needle. The bevel of the needle is placed into the periodontal space on the mesial aspect of the first molar, either the mesiobuccal or mesiolingual; with the bevel facing the root of the tooth the needle is advanced into the periodontal ligament (PDL) space until firm resistance is encountered.

iv. *Intrapulpal injection:* This direct injection into the body of the exposed pulp can be done only if the exposure of the pulp is large enough to admit a hypodermic needle. However, this is a very painful injection. Pls refer chapter 10 for other supplementary anesthetic techniques.



Clinical Note

- The incidence of a hot tooth is most commonly encountered in *mandibular first molars.*
- The inferior alveolar nerve block (IANB) has the *highest failure rate* in achieving pulpal anesthesia.

ENDODONTIC FLARE-UPS

An endodontic flare-up is an acute exacerbation of an asymptomatic pulp or periapical pathosis after the initiation or continuation of root canal treatment.

The reported incidence of inter-appointment flare-ups ranges from 1.4 to 19%. Interappointment flare-ups form a true emergency that requires an unscheduled patient visit and immediate active treatment for pain relief.

Predisposing Factors

The predisposing factors that can contribute to an endodontic flare-up are listed in **Box 7.2**.

a. Preoperative history of pain

There is a highly significant correlation between preoperative pain and/or swelling and the incidence of inter-appointment flare-ups.

Box 7.2

Predisposing Factors for an Endodontic Flare-Up

(a) Preoperative history of pain
(b) Pulpoperiapical status
(c) Shaping errors
  (i) Overinstrumentation
  (ii) Incomplete or underinstrumentation
  (iii) Improper shaping technique
(d) Irrigant extrusion
(e) Retreatment cases

b. Pulpoperiapical status

- Teeth with acute alveolar abscesses have the highest incidence of flare-ups.
- Studies have indicated that teeth with vital pulps result in fewer flare-ups compared with those with necrotic pulps.

c. Shaping errors

- *Overinstrumentation:* This iatrogenic error results in forcing debris into the periradicular region resulting in an acute inflammatory response.
- *Incomplete or underinstrumentation:* This may provide pulpal remnants for the persistence of microorganisms. This leads to the production of virulence factors that may cause a previously asymptomatic infection to become symptomatic resulting in a flare-up.
- *Shaping technique:* Improper shaping protocol that might cause extrusion of debris is a significant cause of an endodontic flare-up. *The step-back shaping technique has a greater tendency to extrude debris into the periradicular region than the crown-down technique.*

d. Irrigant extrusion

The standard regimen of irrigation used routinely is 1.0 – 5.2% NaOCl with a final rinse of 17% EDTA. In endodontics, every procedure including irrigation of pulp space is passive in nature. Inadvertent extrusion of irrigant beyond the periapex, termed *sodium hypochlorite accident*, may be one of the serious causes of endodontic flare-ups.

Signs of hypochlorite accident

- The patient complains of severe and excruciating pain especially when he/she is not under local anesthesia.
- Even if the patient is under local anesthesia, he/she will complain of irritation at the periradicular area.
- There is a sudden flooding of the canal with blood and tissue fluids.
- There may be ballooning of the tissues in the area and swelling of soft tissues.

As sodium hypochlorite is hypertonic, if it enters the periradicular tissues, it would open up the capillaries and minute blood vessels. Flooding of the canal with blood is a physiological reaction to dilute the concentration of sodium hypochlorite.

Management

The patient has to be informed about the accident. If the patient is not under local anesthetic, block anesthesia should be given. Bleeding from the canal is continuously allowed to flow since this is a defense physiological mechanism. The canal is flooded with normal saline so that the accumulated blood comes out and the level of pain decreases.

Sodium hypochlorite can dissolve both normal and infected tissue. Post sodium hypochlorite accident, the periradicular area remains inflamed and the tissues are necrosed. It is preferred that the patient is immediately placed on parenteral antibiotic therapy and analgesics. Call the patient for a follow-up periodically to assess the rate of healing. In the event of an uncontrolled flare-up, some endodontists would prefer to consult a general surgeon or a physician and administer steroids in a planned manner. The patient may require backup vitamin therapy during the recovery phase.

Clinical Note

- Always use passive irrigation and never force the irrigant into the pulp space
- Sodium hypochlorite should be handled carefully as its inadvertent seepage under the rubber dam can result in multiple ulcers and leave the gingiva painfully inflamed
- The recommended endodontic irrigation needle is a 30-gauge side-vented, close-ended needle placed passively at:
  - 2–3 mm short of working length in posterior teeth
  - 1 mm short of working length in anterior teeth

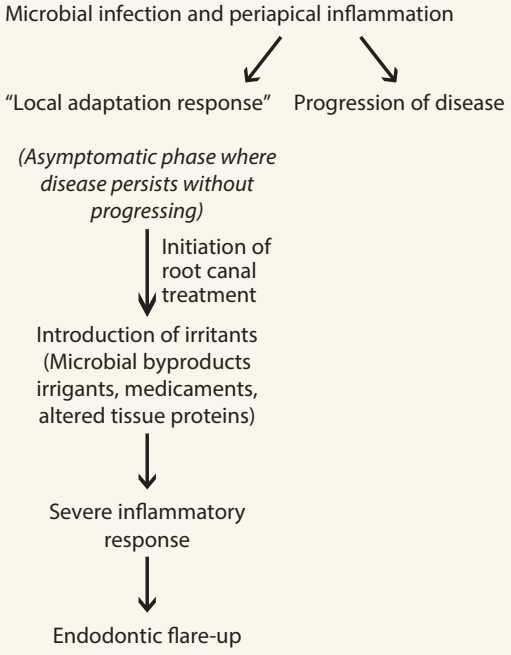
- In immature teeth with open apices, care should be exercised to ensure that the irrigant is not extruded into the periradicular space inadvertently.
- To avoid flushing of the canal beyond constriction, keep the *needle passively fitting in the canal* and do not wedge it against the root canal wall. There are several irrigating needles available with lateral (side vented) opening with the apical end closed. The use of such needles may be a safe way to irrigate the apical one-third area.
- Certain clinical situations require special irrigation precautions including *open apices*, particularly in young patients. Adopting a modified technique of using sodium hypochlorite more as a working solution will solve the problem. Sodium hypochlorite has to be passively placed into the pulp chamber during instrumentation rather than being employed as an active irrigant.
- Normal saline should be used to flush out the sodium hypochlorite.

e. Retreatment cases

- One of the highest incidences of flare-ups occur in *retreatment cases with symptomatic apical periodontitis in which the treatment is completed in a single visit*. Hence, this textbook would recommend all symptomatic retreatment cases to be completed in a two-visit protocol more elaborated in Chapter 21.
- These cases have a significantly higher incidence of flare-ups compared to primary endodontic cases as there is a greater tendency to push the necrotic debris apically during treatment.
- Another postulated cause is that the microbiota associated with such cases are usually therapy resistant.

Box 7.3

Mechanism of Endodontic Flare-Ups



Mechanism of Flare-Ups

The flowchart explaining the mechanism of endodontic flare-ups is given in **Box 7.3**.

Management of Endodontic Flare-Ups

- Pharmacologic measures
  - Non-steroidal anti-inflammatory drugs (NSAIDs) and acetaminophen
  - Long-acting local anesthesia
  - Antibiotics (if required)
- Anxiety reduction
- Occlusal high point reduction

ENDODONTIC EMERGENCIES AFTER TREATMENT

POSTOBTURATION PAIN

After completion of root canal treatment, patients usually complain of pain, especially on biting and chewing. More

postoperative discomfort is encountered in endodontic treatment of posterior teeth.

Etiology

- Overinstrumentation
- Persistent periapical inflammation
- Overfilling
- Missed canal
- Hyperocclusion
- Poor coronal seal
- Fracture of crown/root

Management

Generally, there is some discomfort following obturation that subsides in 2–5 days. Pain that persists beyond this period should make the operator reassess the treatment performed.

VERTICAL ROOT FRACTURE (VRF)

Vertical root fractures are longitudinal fractures that originate in the roots of teeth and with few exceptions, these fractures occur almost exclusively in endodontically treated teeth.

Etiology

- Root anatomy, amount of remaining sound tooth structure, loss of moisture in dentin, amount of bony support, pre-existing cracks, and biochemical properties of root dentin are predisposing etiological factors
- Traumatic occlusion
- Excessive load on an endodontically treated tooth (**Figs 7.4** and **7.5**)
- Bruxism

Clinical Note

Roots that are narrower in the *mesio-distal dimension* are more susceptible to VRFs, such as those in:
- Maxillary and mandibular premolars
- Mandibular molars
- Mandibular incisors
- Mesiobuccal roots of maxillary molars

Clinical Features

- The diagnosis is often difficult to establish by radiograph, percussion, or other means. In most cases, the patient complains of discomfort and may or may not be able to locate the affected tooth. In the early stage, when hairline fracture is present and before separation of the fragments is evident, no radiographic changes are visible either in the tooth or in the adjacent bone. At times, asking the patient to chew on a tooth slooth, cotton applicator, or rubber polishing wheel helps in identifying the tooth.
- The most important clinical signs that can help the clinician make an accurate diagnosis of a VRF are:
  - Deep and often narrow periodontal probing defect.
  - Sinus tract positioned more coronally in the attached gingiva (**Fig. 7.5a**).

Radiographic Features

- The most frequent radiographic presentation observed with VRFs, especially with maxillary premolars and the mesial roots of mandibular molars is the presence of a is a "halo" or "J-shaped" appearance of bone loss (**Fig. 7.6**).
  - Buccal bone dehiscence is also observed along the entire length of the fractured root in many cases
  - *Halo appearance* means a combined periapical and periradicular radiolucency on one or both sides of the involved root

Clinical Note

- Vertical root fractures (VRFs) are seen most commonly in endodontically treated teeth.
- The condition presents with a challenging diagnosis; however, exploratory surgery aids in a definitive diagnosis.

Management

When a longitudinal fracture of a root occurs, the prognosis for that root is usually hopeless. Endodontically treated teeth have to be extracted if they cannot be restored. Hence, *extraction of such teeth is the recommended treatment of choice.*

CLINICAL MANAGEMENT OF ENDODONTIC EMERGENCIES

ENDODONTIC EMERGENCIES PRESENTING WITH PAIN

Pain is one of the oldest universal medical and dental problems. The management of pain in endodontics is primarily achieved by a combination of endodontic therapy and pharmacotherapy. The two groups of analgesics that are commonly employed are elaborated in **Box 7.4**.

Clinical Note

- Preoperative NSAID given 1 hour before the administration of the local anesthetic can enhance the effect and depth of the local anesthetic.
- The first line of management is always restricted to the use of a non-narcotic analgesic.
- Opioid analgesics are more potent and effective in pain relief; however, they exhibit adverse side effects including nausea and drowsiness.
- In acute emergencies, a combination of NSAID and opioids is preferable.

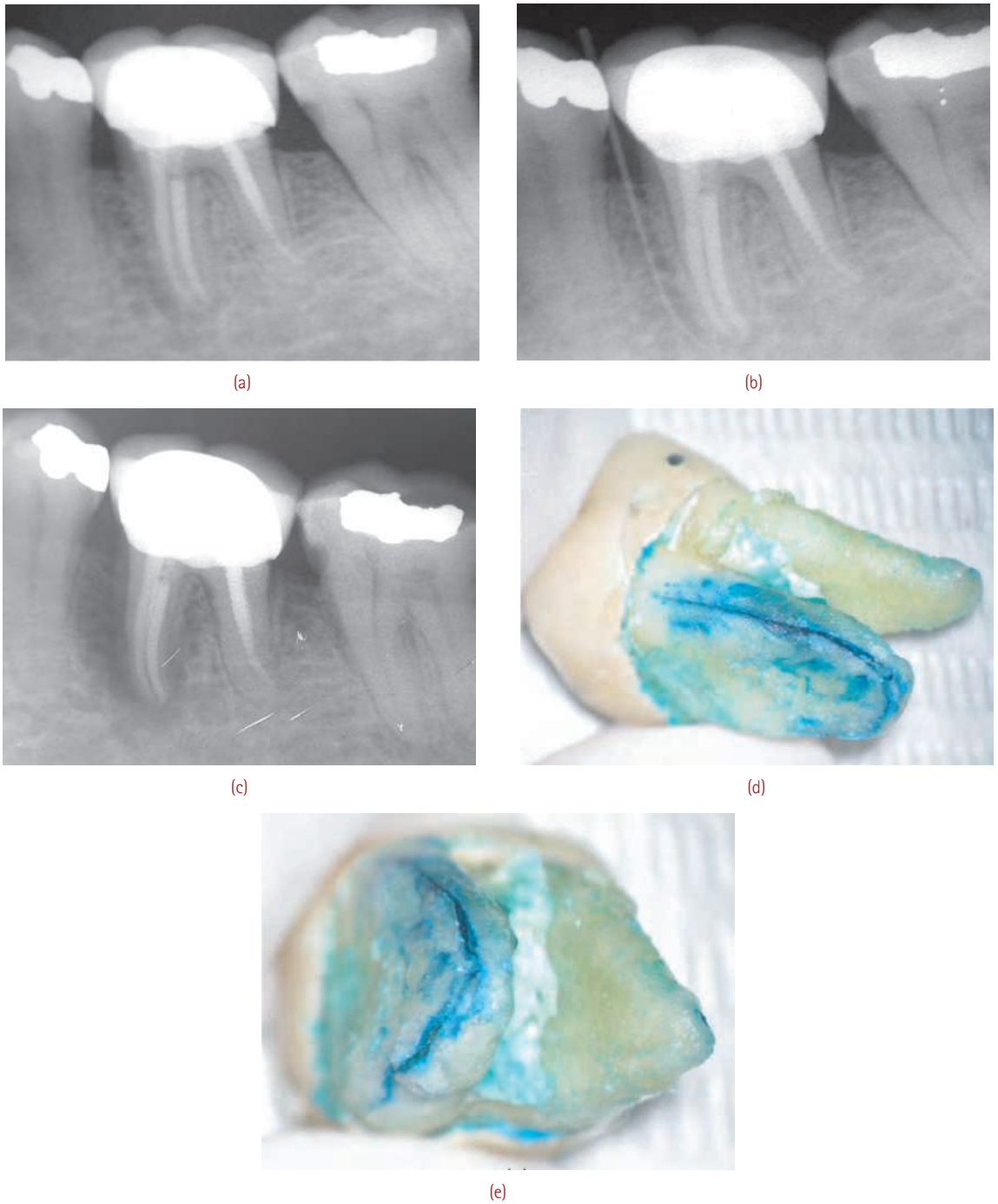
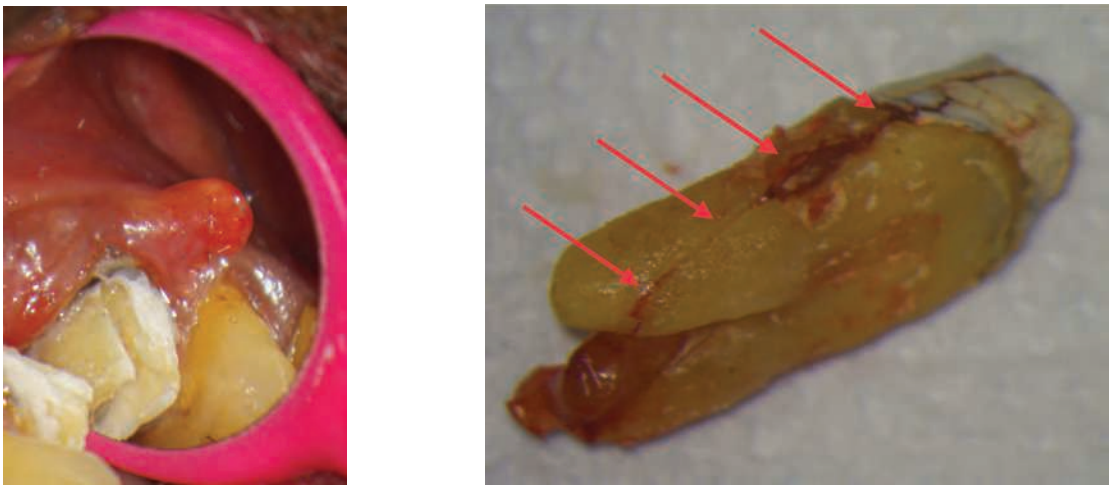


Figure 7.4 (a) Pain on palpation and sinus discharge in relation to an endodontically treated mandibular molar. (b) Gutta-percha tracing of the sinus leads to the mesial root of the molar. (c) Three months later, a characteristic J-shaped radiolucent lesion seen in this radiograph indicative of a vertical root fracture (VRF). (d) and (e) Tooth extracted and the VRF line can be clearly seen. (*Courtesy: Siju Jacob, India.*)

Antibiotics During Endodontic Emergencies

Penicillin was the first antibiotic to be discovered in 1928 by Alexander Fleming. *Antibiotics are substances that are produced in very low concentrations by microorganisms to suppress or to kill other microorganisms*. Antibiotics are drugs that attack cell structure and metabolic pathways of bacteria, but not human cells, and play a key role in controlling bacterial infections.

- Antibiotics are *not required for all endodontic cases.*
- It is a *common error to prescribe antibiotics for patients reporting with severe endodontic pain.*



(a) (b)

Figure 7.5 (a) Buccal sinus in relation to an endodontically treated maxillary premolar. (b) Vertical root fracture (VRF) evident in the same tooth after extraction.



Figure 7.6 J-shaped radiolucency indicative of a vertical root fracture (VRF) on the distal root of a mandibular molar

Box 7.4

Pharmacotherapy for Endodontic Pain Management

1. Non-narcotic analgesics
   (a) Acetaminophen 1000 mg every 6–8 hours
   (b) Non-steroidal anti-inflammatory drugs (NSAIDs)
      (i) Ibuprofen 600 mg every 6 hours
      (ii) Ketorolac Tromethamine 10 mg every 6 hours
      (iii) Piroxicam 20 mg every 12 hours
      (iv) Diclofenac (sodium/potassium) 50 mg every 8–12 hours
2. Opioid analgesics*
   (a) Codeine (60 mg) every 6 hours
   (b) Tramadol (50 mg) every 6 hours

* To be prescribed with caution as the second line of management if non-narcotic analgesics fail to provide relief.

- Antibiotics are **ONLY REQUIRED** in cases of endodontic infections with systemic signs and symptoms and **NOT REQUIRED** for most endodontic conditions (**Box 7.5**).

The common antibiotics used in endodontic emergencies are given in **Table 7.2**.

ENDODONTIC EMERGENCIES PRESENTING WITH SWELLING

This section elaborates the management of swellings associated with an acute alveolar abscess, cellulitis, or endodontic flare-ups. The emergency treatment of suppurative lesions involves establishing ***drainage***. This procedure releases the purulent exudate from the periapical tissues and aids in relieving pain and pressure.

We can achieve drainage and relieve the acute symptoms caused by a symptomatic (acute) alveolar abscess by following one of the following clinical protocols:

I. Achieving drainage through the root canals
II. Incision for drainage
III. Needle aspiration
IV. Cortical trephination and decompression

I. Achieving Drainage Through the Root Canals

Establishing drainage through the access opening has been recommended as a means of reducing pain following the treatment of necrotic teeth presenting with swellings.

Local Anesthesia Considerations

- As the pulp is necrotic, *local anesthesia is not needed routinely*. In fact, local anesthesia is frequently contraindicated in acutely inflamed tissue because its infiltration does not anesthetize the tissue. Acutely inflamed tissue has a localized pH that is acidic, in spite of the body's natural buffering action. Local anesthetics are effective in tissues

Box 7.5

Recommendations for Endodontic Cases that Would Either Require or not Require Antibiotics

Endodontic cases that REQUIRE antibiotics include infections with systemic signs and symptoms	Endodontic cases that do NOT REQUIRE antibiotics
• Localized swelling due to an abscess or cellulitis	• Endodontic pain without signs and symptoms of infection: – Symptomatic irreversible pulpitis – Symptomatic apical periodontitis
• Infections with associated systemic signs and symptoms like: – Fever >100°F – Lymphadenopathy – Malaise – Trismus	• Endodontically involved teeth with necrotic pulps with or without a radiolucency
	• Endodontically involved teeth with a sinus tract (asymptomatic apical abscess)

Table 7.2 Common Antibiotics Used in Endodontic Emergencies

Recommended Antibiotics in Endodontic Infections with Systemic Signs and Symptoms	Oral Dosage in Adults
I. Amoxicillin: This is a form of semi-synthetic penicillin that has a broader spectrum of antibacterial activity. *Amoxicillin is the antibiotic of choice for treating endodontic infections.*	1000 mg loading dosage followed by 500 mg every 8 hours for 5–7 days
II. Amoxicillin with clavulanate: Clavulanic acid is a beta-lactamase inhibitor that is often used as a combination drug along with amoxicillin in order to overcome bacterial drug resistance.	625 mg (500 mg amoxicillin with 125 mg clavulanate) every 12 hours for 5–7 days
III. Clindamycin: It is the drug of choice in patients with a history of drug allergy to penicillin group of antibiotics.	600 mg loading dose followed by 300 mg every 6 hours for 5–7 days
IV. Metronidazole: It is an antimicrobial that is effective against anaerobic bacteria. It is usually given in conjunction with amoxicillin in severe infections.	1000 mg loading dose followed by 500 mg every 6 hours for 5–7 days
V. Cephalosporins: Cephalexin is usually not indicated for the treatment of endodontic infections. However, they are considered safe to be prescribed during pregnancy.	500 mg every 12 hours for 5 days

with a more alkaline pH and, as a result, are ineffective when injected into an acutely inflamed tissue.
- Insinuating a needle and forcing anesthetic solution into an acutely infected and swollen area may increase pain and spread the infection into facial spaces.
- Conduction anesthesia may be administered to reduce the pain of acute alveolar abscess as long as the injection route is distant from the inflamed area.
- A mandibular block or an infraorbital block can be used effectively when needed for the few isolated cases in which some pulp vitality persists.

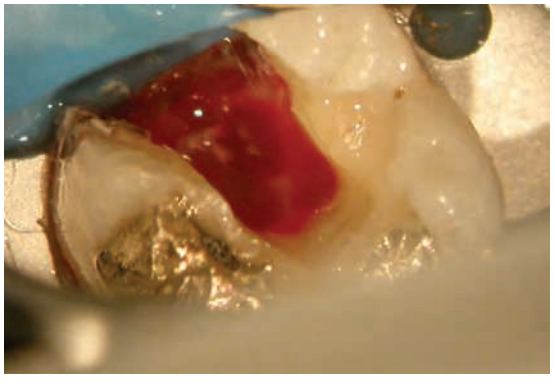
Clinical Protocol

To complete the emergency treatment, the following clinical protocol is recommended:
- The rubber dam is placed over the infected tooth.
- The access opening is completed painlessly by bracing the tooth with finger pressure.
- The pulp chamber is irrigated profusely and debrided, and forcing any solution or debris into the periradicular tissues should be avoided.
- The root canal orifices are located using a No. 8, 10, or 15 K file as an explorer and each root canal is instrumented within 1 mm of the root apex.
- Irrigation and debridement are continued while enlarging each root canal, but all instruments and irrigants are kept within the root canals.
- Frequently, a purulent exudate escapes into the chamber and indicates that the root canal is patent and draining; relief follows quickly.
- When periapical abscess does not drain through the root canal effectively, especially in curved roots in posterior teeth, the clinician should use a sterile precurved ISO No. 8 or 10 patency K-file and go 1 mm beyond the apical constriction to initiate drainage.

- If the abscess does not drain through the canal in spite of creating canal patency, the canals should be cleaned and shaped to facilitate the placement of a suitable intracanal medicament such as *calcium hydroxide*.
- If there is excessive drainage of blood and pus through the canals (**Fig. 7.7**), the clinician should patiently allow the drainage to take place and irrigate the canals copiously.
- In such cases, it is recommended to place a sterile cotton pack in the access-opened pulp chamber and make the patient wait in the hospital reception for some time to allow the drainage to take place. The pack can then be removed and the canals re-irrigated before placing calcium hydroxide medicament in the canals. The access is then sealed with a suitable temporary restoration such as IRM or Cavit.
- Prescribe suitable analgesics as the patient may have acute discomfort even after the initial treatment and antibiotics in cases where the patient has accompanying systemic symptoms.
- When symptoms have subsided, the root canals are opened and reassessed before completing the root canal therapy.



(a)



(b)

Figure 7.7 (a) and (b) Intracanal drainage of pus and blood on access opening in a mandibular molar with acute alveolar abscess.

Clinical Note

- Current evidence suggests that leaving teeth open between appointments **(*open dressing*) is *not clinically recommended*** as it impairs the prognosis. Leaving the tooth open for drainage causes salivary and bacteriological contamination and increases the risk of adverse reaction when the tooth is resealed. In addition, the bacterial contamination prolongs the treatment time needed to overcome the resulting infection.
- Most of the pain that occurs during access-cavity preparation is caused by tooth movement resulting from vibration of the high-speed bur. Hence, one should *stabilize the tooth with finger pressure*, so that penetration into the pulp chamber will be painless.
- *Test cavity* is very significant in treating teeth with acute alveolar abscess. The test cavity initiates therapy quickly as painless penetration into pulp is possible. It also identifies any remaining vital pulp that may require anesthesia.

II. Incision for Drainage

The pain in a tooth with acute abscess, whether of periradicular or periodontal origin, is frequently accompanied by swelling. When the buildup of exudate (pus) is confined to the hard tissues, a dull, boring, excruciating pressure pain develops. As the exudate penetrates the cortical plate, swelling occurs and pain diminishes only when:

- Swelling creates enough pressure and bone lysis to create a sinus drainage through the bone. This is the phase where the symptomatic acute alveolar abscess becomes an asymptomatic chronic alveolar abscess

(OR)

- The operator surgically creates an incision in the dependent part of the swelling to facilitate drainage.

If the swelling is slight and localized, it will disappear in 24–48 hours after drainage has been established. Routinely, hot saline holds and rinses should be prescribed to assist drainage. If the swelling is extensive, soft, and fluctuant, an incision through the soft tissue to the bone may be necessary.

- *Fluctuant swellings:* When the swelling "points," i.e., it localizes into a soft, fluctuant, palpable mass, it should be incised and drained, a procedure that dramatically reduces the swelling and pain.
- *Indurated swellings:* If the swelling remains hard or indurated, then the swollen tissue should be bathed in warm saline rinses for 5 minutes every hour until it becomes soft, fluctuant, and ready for incision. Some clinicians advocate incising even hard tissue whenever pain is present; they suggest that the tissues will drain eventually and the pain will disappear sooner.

Clinical Protocol

- The clinician should first dry the mucosa over the affected area and then spray the tissue with a refrigerant topical anesthetic.
- Some clinicians prefer to anesthetize the area with conduction anesthesia (mandibular or infraorbital block),

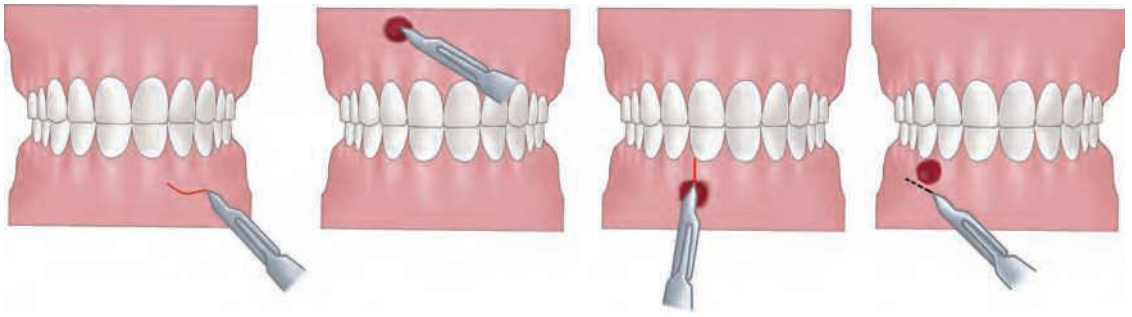


Figure 7.8 (a) Correct incision at the most dependent portion of swelling. (b)–(d) Incorrect incisions. (b) Incision at the midportion of swelling. (c) A vertical incision would leave an unsightly "V"-shaped break in the gingiva. (d) Incision not made in the most dependent portion of the swelling.

or peripheral infiltration around but not in the swollen tissues, prior to incision.

- Although a topical anesthetic is minimally effective, it usually suffices for the quick, sharp stab incision through the periosteum with the help of a No. 11 scalpel through the center of the soft, fluctuant mass down to the solid cortical bone plate. *The incision should be made at the most dependent site of the swelling.*
- A hemostat or a periosteal elevator is then used to dissect the incision site to facilitate ease of drainage.
- Soft tissue compression over the site of the swelling is then performed allowing the abscess to drain through the incised site.
- Antibiotics and analgesics can be prescribed as needed.
- Finally, the tooth should be disoccluded slightly if it is extruded from its socket. This procedure eliminates pain caused by contact with teeth in the opposing arch. **Figure 7.8** depicts the technique of performing incision for drainage.

III. Needle Aspiration

Needle aspiration has been defined as the use of suction to remove fluids from a cavity or space. The procedure provides information regarding the presence, type, and volume of exudate, cystic fluid, or blood present in the lesion. The samples obtained can be utilized for microbial identification by culture or molecular techniques.

Clinical Protocol

- According to Simon, the technique involves the administration of local anesthetic solution,
- Then a *syringe with an 18-gauge needle* is used to aspirate the cystic contents of a swelling.
- The advantages of this technique are reduced scarring, evaluation of volume and character of aspirate, and lack of postoperative drain removal. **Figure 7.9** demonstrates the technique of needle aspiration of serous exudate from an extraradicular infection.

IV. Cortical Trephination and Decompression

Definition: Cortical trephination is the surgical perforation of the alveolar cortical plate to create a channel for the release of the accumulated tissue exudate.

Clinical Protocol for Cortical Trephination

Cortical trephination involves:

- The area must be adequately anesthetized whenever trephination is contemplated.
- The cortical bone is exposed after placing the surgical incision (a closed small hemostat may be inserted and then opened to enlarge the surgical site)
- Creating an opening in the cortical bone to facilitate drainage:
  - In cancellous bone, this can be achieved with a sharp surgical explorer
  - In harder bone regions, use of a surgical high-speed round bur would be recommended.
- A rubber dam "T" drain may be inserted for several days to prevent closure of the incision, but it is frequently unnecessary and omitted.

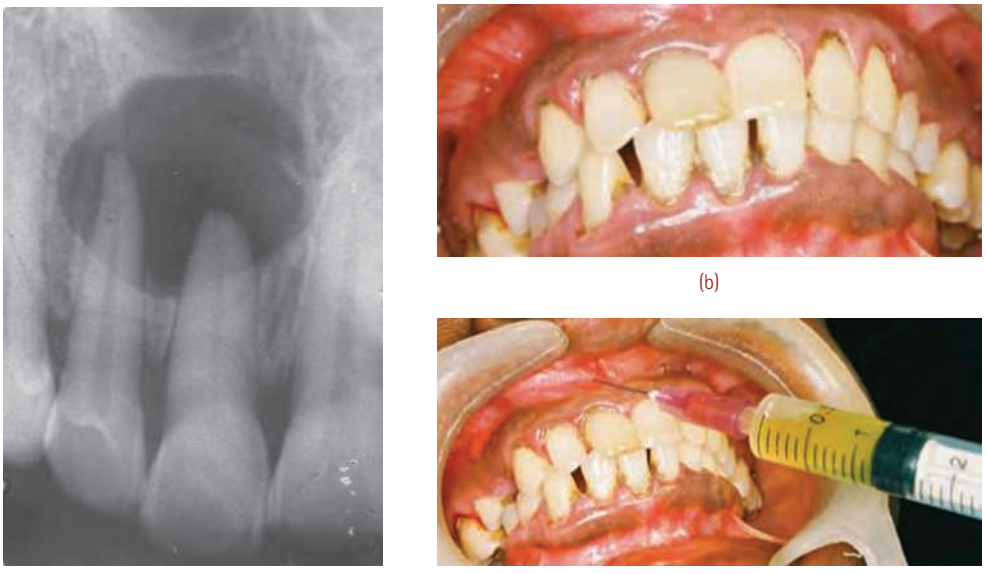
Clinical Note

This is not a frequently recommended procedure and is only indicated in patients with severe periradicular pain of endodontic origin without any swelling and performed when no other treatment options are relieving the pain.

Definition: Decompression involves trephination followed by the placement of a drain tube for facilitating exudate drainage as well as for allowing irrigation of the cyst cavity.

Clinical Protocol for Decompression

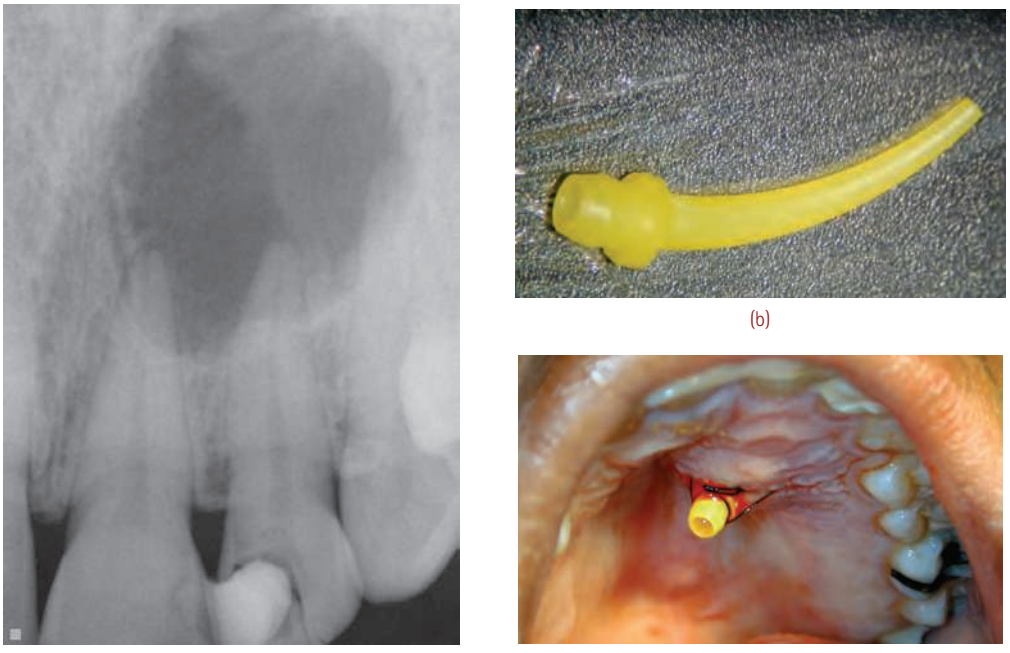
- In large cysts with swelling, a decompression procedure is advocated wherein a drain tube is inserted into the trephined cyst cavity for several weeks to enable communication between the cyst cavity and the oral cavity.



(a) (b) (c)

Figure 7.9 (a) Radiographic appearance, (b) clinical view, and (c) aspiration of serous exudate from an extraradicular infection.

- If the swelling is hard, it can be converted to a soft, fluctuant swelling by rinsing with hot saline solution 3–5 minutes every hour. This decompression technique enables the gradual resolution of the cyst wall. **Figure 7.10** demonstrates the management of a large lesion in a maxillary lateral incisor using trephination and decompression.



(a) (b) (c)

Figure 7.10 (a) Large lesion with palatal swelling associated with a maxillary central incisor with necrotic pulp. Access was made and drainage obtained through the canal. Calcium hydroxide was placed as intracanal medicament. (b) and (c) Needle tip used in an impression material gun was modified and sutured into place as a drain in the palatal tissue. The patient was instructed to irrigate with chlorhexidine through the drain. *(continued)*

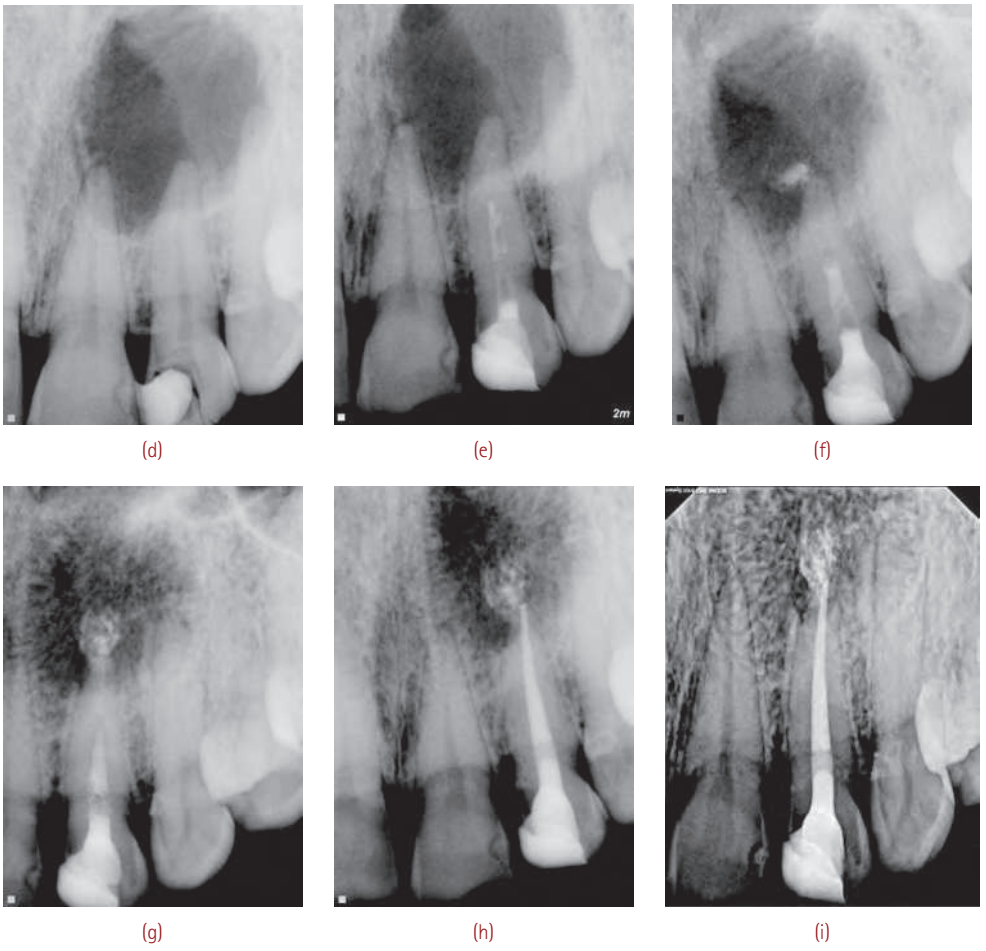


Figure 7.10 *(continued)* (d) Drain kept in place for 2 weeks. (e) and (f) The patient was reviewed every 3 months and if the $Ca(OH)_2$ had washed out, it was replaced. (g) and (h) Once the canal was found dry, root canal obturation was performed. (i) One-year recall shows excellent healing. (*Courtesy: Sashi Nallapati, Jamaica.*)

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8 Selection of Cases for Treatment

Education is a progressive discovery of our own ignorance.
—Will Durant

Proper selection of cases avoids pitfalls during endodontic treatment and helps to ensure success. Not every tooth is suitable for endodontic treatment. Errors in case selection, some of which could have been avoided, constituted 22% of failures reported in a study by Ingle and Beveridge.

Many more root canals are treated today than before because of a greater interest in endodontics by the practitioner not only to save endodontically involved teeth but also to use them as abutments for bridges or partial dentures. Unfortunately, a general practitioner's best effort may not be good enough because of a mistaken diagnosis, such as a curved canal not capable of being instrumented to the apex, with a resulting persistence of the area of rarefaction. On the other hand, certain cases formerly contraindicated for endodontic treatment, such as a sinus tract discharging into the gingival sulcus, are treated successfully today because of advances in both endodontic and periodontal therapies. To depend on root canal treatment alone for all endodontic cases is bound to meet with a certain degree of failure. However, if such treatment is combined with other endodontic procedures, such as apexification with mineral trioxide aggregate (MTA) to induce the formation of a calcific barrier in root canals with open apex or the use of periapical microsurgery to remove the periradicular pathologic tissues, the possibilities of it being successful are high. On the other hand, microsurgery is not indicated simply because an area of rarefaction is present.

The selection of cases for endodontic treatment has been discussed by a number of authors, including Bender, Grossman and associates, and Strindberg. However, before selecting a case for endodontic therapy, the clinician should consider the following factors that influence the outcome of the treatment:

- Health and systemic status of the patient
- Anatomy of the root canal system
- Extent of previous tooth restoration
- Presence or absence of periradicular pathosis
- Radiographic interpretation
- Degree of difficulty in locating, shaping, cleaning, and obturating the complete root canal system
- Periodontal status of the tooth
- Presence of crown or root fractures
- Presence of root resorption
- Patient's desire, motivation, cooperation, and pain threshold
- Clinical skill and expertise of the operator

Clinical Note

Advances in the understanding of endodontics, better techniques, and principles of canal preparation and obturation have led to significantly increased and predictable healing rates for endodontic treatment—95% and higher under ideal conditions according to current literature.

ASSESSMENT OF THE PATIENT'S SYSTEMIC STATUS

A concise medical history, including careful questioning, should be obtained whenever possible. The questions should be designed to throw light on the existence of a suspected systemic disease. Under certain circumstances, the patient's physician should be consulted. The identification of medical conditions that may complicate endodontic treatment helps the dentist avoid potential medical emergencies during treatment. In addition, consideration of complicating patient factors such as anxiety, limited opening, or gag reflex allows the dentist to avoid situations that may compromise treatment outcomes.

The American Heart Association (AHA) has revised its guidelines on antibiotic prophylaxis (**Box 8.1**).

According to the American Association of Endodontists (AAE), the practitioner and the patient should consider possible clinical circumstances that may suggest the presence of a significant medical risk in providing dental care without antibiotic prophylaxis. These considerations include, but are not limited to:

- Patients with a previous late artificial joint infection
- Increased morbidity associated with joint surgery (wound drainage/hematoma)
- Patients undergoing treatment of severe and spreading oral infections (cellulitis)
- Patients with increased susceptibility for systemic infection
- Congenital or acquired immunodeficiency
- Patients on immunosuppressive medications
- Diabetics with poor glycemic control

Box 8.1

Recommendations Regarding Prophylaxis for Bacterial Endocarditis

Endocarditis prophylaxis recommended

Preventive antibiotics prior to a dental procedure are advised for patients with:

- Prosthetic cardiac valves
- History of infective endocarditis
- Certain specific, serious congenital (present from birth) heart diseases (CHD), including unrepaired or incompletely repaired cyanotic congenital heart disease as well as those with palliative shunts and conduits
- Completely repaired congenital heart defect with prosthetic material or device, whether placed by surgery or by catheter intervention, during the first 6 months after the procedure
- Repaired congenital heart defect with residual defect at the site or adjacent to the site of a prosthetic patch or a prosthetic device (which inhibits endothelialization)
- Cardiac transplantation recipients who develop cardiac valvulopathy

Endocarditis prophylaxis not recommended

Patients who have taken prophylactic antibiotics routinely in the past but *no longer need them* include people with:

- Mitral valve prolapse
- Rheumatic heart disease
- Bicuspid valve disease
- Calcified aortic stenosis
- Congenital heart conditions, such as
  - Ventricular septal defect
  - Atrial septal defect
  - Hypertrophic cardiomyopathy

- Patients with systemic immunocompromising disorders (e.g., rheumatoid arthritis, lupus erythematosus)
- Patients in whom extensive and invasive procedures are planned
- Prior to surgical procedures in patients at a significant risk for medication-related osteonecrosis of the jaw

Clinical Note

The current practice of giving antibiotics to patients prior to a dental procedure is no longer recommended, *except* for patients with the highest risk of adverse outcomes resulting from bacterial endocarditis.

The current AHA recommendation for antibiotics for dental procedures requiring prophylaxis is summarized in **Table 8.1**.

In most instances, case selection is dictated by what we see in the radiograph. What cannot be seen on the radiograph is often encountered during operation in the root canal. An examination of the radiograph may disclose the following problems:

- Extent of carious lesion involvement in the tooth (**Fig. 8.1a–8.1d**)
- Periradicular lesions (**Figs 8.2a–8.2d** and **8.3a–8.3d**)
- Internal or external resorption (**Fig. 8.4a–8.4e**)
- Fracture of a tooth or root (**Fig. 8.5a–8.5c**)
- Periodontal status of the tooth (**Fig. 8.6**)
- Complex anatomy of the root canal
- Fusion (**Fig. 8.7**)
- Supernumerary root or root canal (**Fig. 8.8**)
- Dilacerated or curved root canal (**Fig. 8.8**)
- Pathologically resorbed root tip
- Wide open apex in a young tooth
- Iatrogenic errors such as ledging and separated instruments (**Fig. 8.9**)
- Taurodontism (**Fig. 8.10**)
- Partial or completely calcified root canal
- Any obstruction in the canal

Table 8.1 AHA-Recommended Antibiotic Prophylaxis Regimens to be Taken 1 Hour Prior to the Dental Procedure

Situation	Agent	Adults	Children
Oral	Amoxicillin	2 g	50 mg/kg
Unable to take oral medication	Ampicillin Or Cefazolin or ceftriaxone	2 g IM or IV 1 g IM or IV	50 mg/kg IM or IV 50 mg/kg IM or IV
Allergic to penicillin or ampicillin—oral	Cephalexin*,† Or Clindamycin Or Azithromycin or clarithromycin	2 g 600 mg 500 mg	50 mg/kg 20 mg/kg 15 mg/kg
Allergic to penicillin or ampicillin and unable to take oral medication	Cefazolin Or Ceftriaxone† Or Clindamycin	1 g IM or IV 600 mg IM or IV	50 mg/kg IM or IV 20 mg/kg IM or IV

IM, intramuscular; IV, intravenous.
*Or other first- or second-generation in equivalent adult or pediatric dosage.
†Cephalosporins should not be used in an individual with a history of anaphylaxis, angioderma, or urticaria with penicillins or ampicillin.

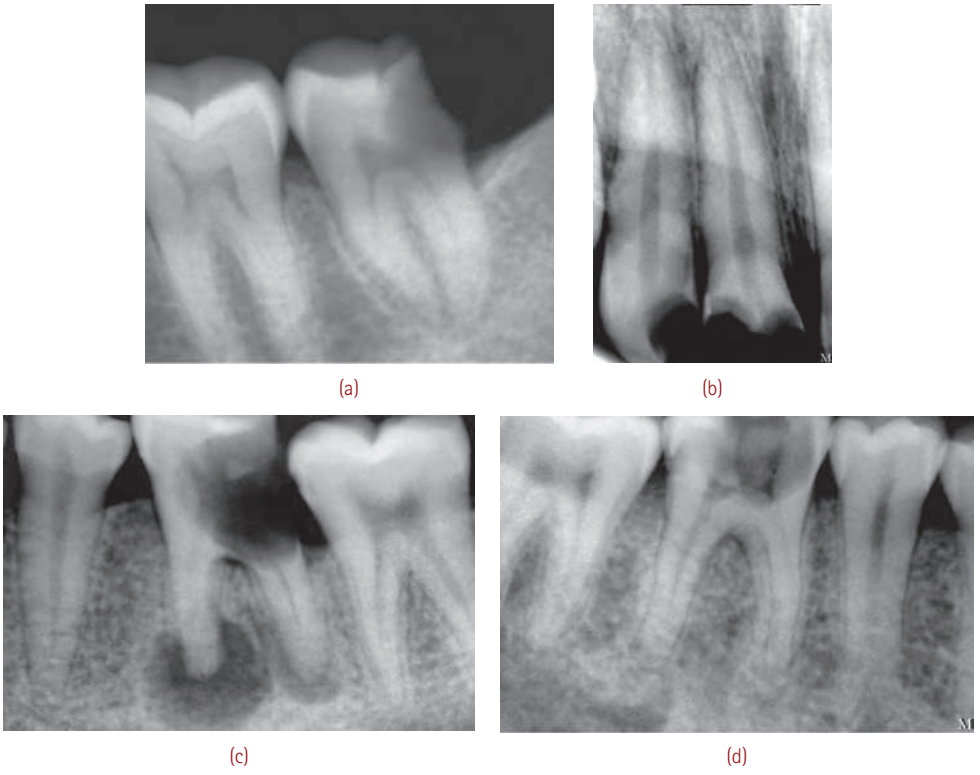


Figure 8.1 (a) Distal carious lesion involving the pulp with periradicular changes. (b) Extensive loss of coronal tooth structure due to rapidly advancing caries lesion. (c) Extensive carious destruction of tooth with large periradicular lesion. (d) Carious involvement of the lower molar with progressive calcification of pulp chamber and canals.

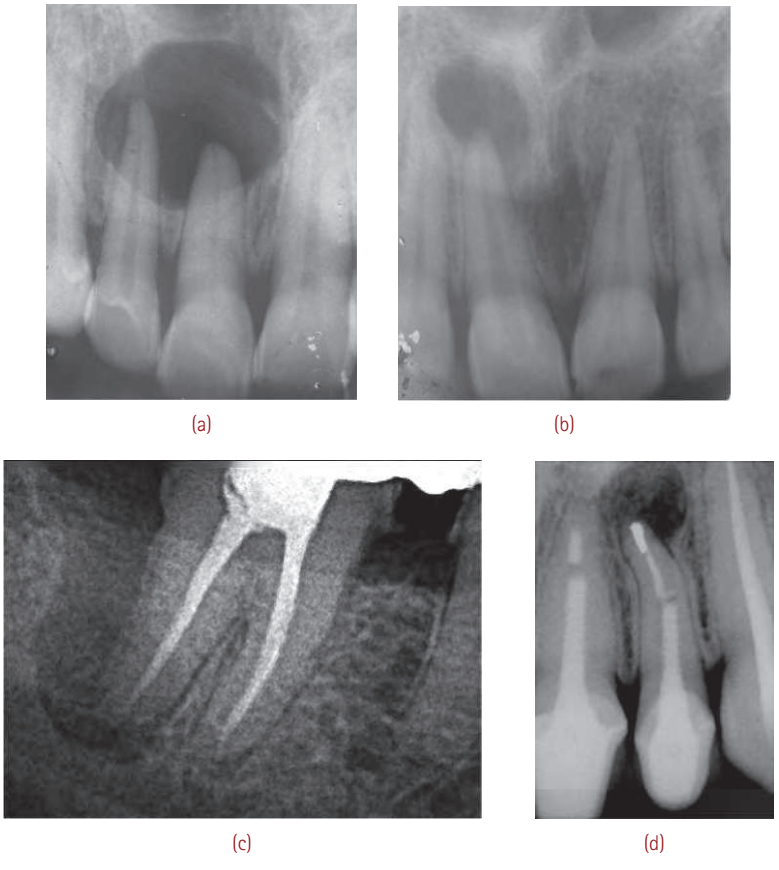
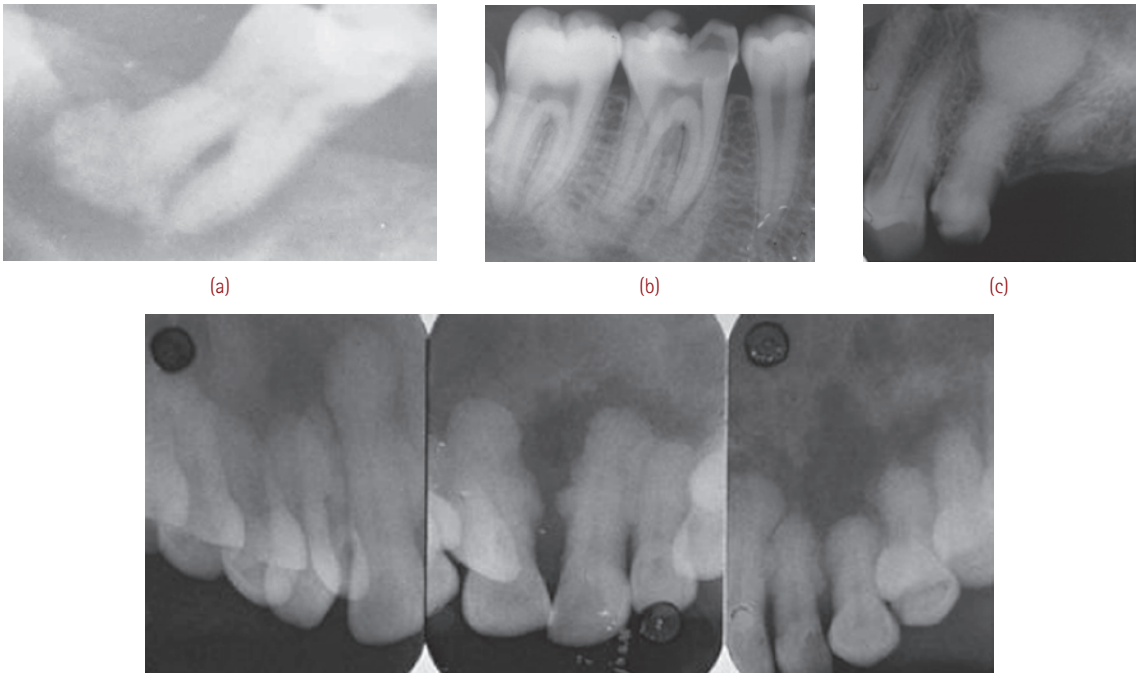


Figure 8.2 (a) Intraoral periapical (IOPA) radiograph of 11, 12 region showing a periradicular radiolucency of 3 cm size with well-defined border and loss of lamina dura associated with the apex of 11, suggestive of cystic lesion. 11 also exhibits obliteration of pulp chamber and narrowing of root canal, suggestive of nonvital tooth going for calcific metamorphosis. (b) IOPA of 11, 21 region showing well-defined radiolucency of 7 mm size with loss of lamina dura at the root apex of 11, suggestive of asymptomatic apical periodontitis. (c) J-shaped radiolucent lesion in the distal root of mandibular molar indicating vertical fracture of the root. (d) Persistent periradicular lesion in endodontically treated tooth with a periapical retrofilling.



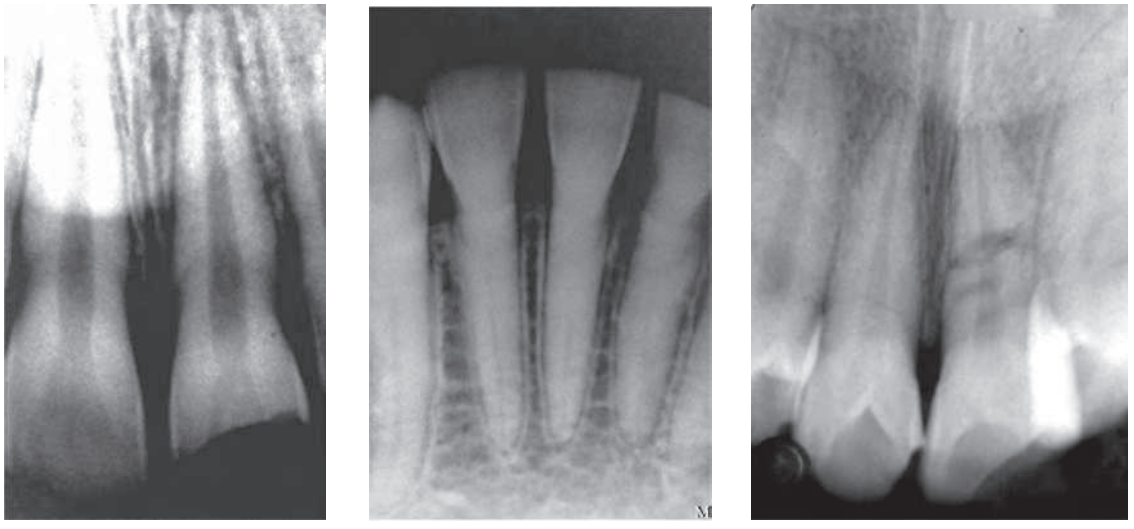
(a) (b) (c) (d)

Figure 8.3 (a) Cementoblastoma: a cropped image from part of the panoramic radiograph showing radiopaque mass of 1.5 cm attached to the distal root apex of 47 surrounded by a radiolucent rim. The outline of the distal root apex is not visible, suggesting that the radiopaque mass is fused with the root. (b) Condensing osteitis: IOPA of 36 showing coronal radiolucency involving pulp chamber, periapical region showing loss of lamina dura, ill-defined radiolucency of 1 mm surrounded by an area of diffuse radiopacity with lack of trabecular pattern. (c) Ossifying fibroma. (d) Hypercementosis in Paget's disease. Intraoral radiographs showing club-shaped root apex affecting all the teeth. Note the associated irregular radiolucent lesion in the periapical bone suggesting the early lytic stage of the Paget's disease of bone. (*Courtesy: S. Karthiga Kannan, India.*)



(a) (b) (c) (d) (e)

Figure 8.4 (a) External root resorption: moth-eaten radiolucent root resorption in traumatized 11. Note the traumatized 21 exhibiting calcific metamorphosis. (b) 11 with extensive internal resorption, the periapical area showing a well-defined radiolucency with sclerotic border of size of around 1.5 cm, suggestive of periapical cyst. (c) Mandibular first molar showing root resorption. (d) Endodontically treated tooth with signs of apical root resorption. (e) Endodontically treated tooth with evidence of external cervical resorption in relation to maxillary central incisor.



(a) (b) (c)

Figure 8.5 (a) Trauma causing oblique fracture of the crown with pulpal involvement. (b) Trauma from occlusion causing obliteration of the coronal and middle third of the root canal in lower anterior teeth. (c) Midroot fracture of a maxillary central incisor.



Figure 8.6 Periodontal lesion in the distal root of the mandibular first molar causing endodontic involvement.



Figure 8.7 Fusion: a case of bilateral fusion of 31, 32 and 41, 42. Radiographically, the teeth showed bifid crown and a single root with one root canal. (*Courtesy: S. Karthiga Kannan, India.*)



Figure 8.8 Supernumerary roots: extracted specimens of maxillary third molars demonstrating extra root with marked dilacerations.



Figure 8.9 Mesial root of maxillary first molar showing a separated instrument and ledging of the canal along with short of working length obturation.

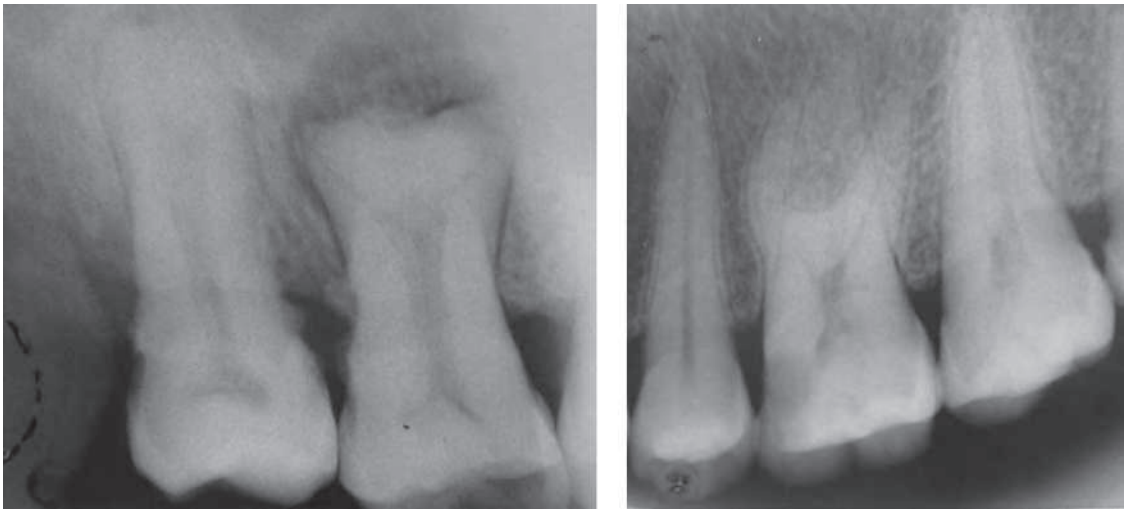


Figure 8.10 Taurodontism: enlargement of the body and pulp chamber of 16 with apical displacement of the pulpal floor and trifurcation of the roots resulting in increased apico-occlusal height of the pulp chamber.

- Pulp stone occupying almost the entire pulp chamber and root canal
- Subgingival decay of a crown
- Dens invaginatus (**Fig. 8.11**)
- Gemination (**Fig. 8.12**)
- Extent of root canal obturation in an endodontically treated tooth

CASE DIFFICULTY ASSESSMENT FORM

The AAE has developed a practical tool that makes case selection more efficient, more consistent, and easier to document. The *Endodontic Case Difficulty Assessment Form* (**Fig. 8.13**) is intended to assist practitioners with endodontic treatment planning, but can also be used to help with referral decisions and record keeping. The assessment form identifies three categories of considerations which may affect treatment complexity:

1. Patient considerations
   a. Medical history
   b. Anesthesia
   c. Patient disposition
   d. Mouth opening
   e. Gag reflex
   f. Emergency condition
2. Diagnostic and treatment considerations
   a. Diagnosis
   b. Radiographic difficulties
   c. Position in the arch

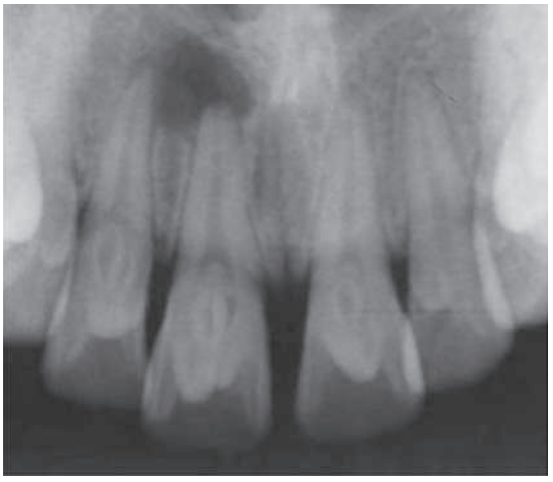


Figure 8.11 Dens invaginatus: anterior maxillary occlusal view showing double invaginations extending into the root, involving multiple maxillary anterior teeth. 11 shows a well-defined periapical radiolucency of 0.5 cm size with loss of lamina dura, suggestive of periapical granuloma.



Figure 8.12 Gemination: 12 shows a bifid crown clinically. Radiographically, the crown blends into one enlarged root with a large single canal.

   d. Tooth isolation
   e. Morphologic aberrations of the crown
   f. Canal and root morphology
   g. Radiographic appearance of the canal(s)
   h. Resorption
3. Additional considerations
   a. History of trauma
   b. History of endodontic treatment
   c. Periodontal–endodontic condition

Within each category, levels of difficulty are assigned on the basis of potential risk factors. The levels of difficulty are sets of conditions that may not be controllable by the dentist. Each of the risk factors can influence the practitioner's ability to provide care at a consistently predictable level. This may impact the appropriate provision of care and quality assurance. For each level of difficulty, guidelines are given to aid the dentist in determining whether the complexity of the case is appropriate for his or her experience or comfort level.

GUIDELINES FOR USING THE AAE ENDODONTIC CASE DIFFICULTY ASSESSMENT FORM

The AAE designed the Endodontic Case Difficulty Assessment Form for use in endodontic curricula. Conditions listed in this form should be considered potential risk factors that may complicate the treatment and adversely affect the outcome. Levels of difficulty are sets of conditions that may not be controllable by the dentist. Risk factors can influence the ability to provide care at a consistently predictable level and impact the appropriate provision of care and quality assurance. The Assessment Form enables a practitioner to assign a level of difficulty to a particular case.

Criteria and Subcriteria	Minimal Difficulty	Moderate Difficulty	High Difficulty
	A. PATIENT CONSIDERATIONS		
Medical history	☐ No medical problem (ASA Class 1*)	☐ One or more medical problems (ASA Class 2*)	☐ Complex medical history/serious illness/disability (ASA Classes 3–5*)
Anesthesia	☐ No history of anesthesia problems	☐ Vasoconstrictor intolerance	☐ Difficulty achieving anesthesia
Patient disposition	☐ Cooperative and compliant	☐ Anxious but cooperative	☐ Uncooperative
Ability to open mouth	☐ No limitation	☐ Slight limitation in opening	☐ Significant limitation in opening
Gag reflex	☐ None	☐ Gags occasionally with radiographs/treatment	☐ Extreme gag reflex which has compromised past dental care
Emergency condition	☐ Minimum pain or swelling	☐ Moderate pain or swelling	☐ Severe pain or swelling
	B. DIAGNOSTIC AND TREATMENT CONSIDERATIONS		
Diagnosis	☐ Signs and symptoms consistent with recognized pulpal and periapical conditions	☐ Extensive differential diagnosis of usual signs and symptoms required	☐ Confusing and complex sings and symptoms: difficult diagnosis ☐ History of chronic oral/facial pain
Radiographic difficulties	☐ Minimal difficulty obtaining/interpreting radiographs	☐ Moderate difficulty obtaining/interpreting radiographs (*e.g.*, high floor of mouth, narrow or low palatal vault, presence of tori)	☐ Extreme difficulty obtaining/interpreting radiographs (*e.g.*, superimposed anatomical structures)
Position in the arch	☐ Anterior/premolar ☐ Slight inclination (<10°) ☐ Slight rotation (<10°)	☐ 1st molar ☐ Moderate inclination (10–30°) ☐ Moderate rotation (10–30°)	☐ 2nd or 3rd molar ☐ Extreme inclination (>30°) ☐ Extreme rotation (>30°)
Tooth isolation	☐ Routine rubber dam placement	☐ Simple pretreatment modification required for rubber dam isolation	☐ Extensive pretreatment modification required for rubber dam isolation
Morphologic aberrations of crown	☐ Normal original crown morphology	☐ Full coverage restoration ☐ Porcelain restoration ☐ Bridge abutment ☐ Moderate deviation from normal tooth/root form (*e.g.*, taurodontism, microdens) ☐ Teeth with extensive coronal destruction	☐ Restoration does not reflect original anatomy/alignment ☐ Significant deviation from normal tooth/root form (*e.g.*, fusion, dens in dente)
Canal and root morphology	☐ Slight or no curvature (<10°) ☐ Closed apex (<1 mm in diameter)	☐ Moderate curvature (10-30°) ☐ Crown axis differs moderately from root axis. Apical opening 1-1.5 mm in diameter	☐ Extreme curvature (>30°) or S-shaped curve ☐ Mandibular premolar or anterior with 2 roots ☐ Maxillary premolar with 3 roots ☐ Canal divides in the middle or apical third ☐ Very long tooth (>25 mm) ☐ Open apex (>1.5 mm in diameter)
Radiographic appearance of canal(s)	☐ Canal(s) visible and not reduced in size	☐ Canal(s) and chamber visible but reduced in size ☐ Pulp stones	☐ Indistinct canal path ☐ Canal(s) not visible
Resorption	☐ No resorption evident	☐ Minimal apical resorption	☐ Extensive apical resorption ☐ Internal resorption ☐ External resorption
	C. ADDITIONAL CONSIDERATIONS		
Trauma history	☐ Uncomplicated crown fracture of mature or immature teeth	☐ Complicated crown fracture of mature teeth ☐ Subluxation	☐ Complicated crown fracture of immature teeth ☐ Horizontal root fracture ☐ Alveolar fracture ☐ Intrusive, extrusive or lateral luxation ☐ Avulsion
Endodontic treatment history	☐ No previous treatment	☐ Previous access without complications	☐ Previous access with complications (*e.g.*, perforation, non-negotiated canal, ledge, separated instrument) ☐ Previous surgical or nonsurgical endodontic treatment completed
Periodontal–endodontic condition	☐ None or mild periodontal disease	☐ Concurrent moderate periodontal disease	☐ Concurrent severe periodontal disease ☐ Cracked teeth with periodontal complications ☐ Combined endodontic/periodontic lesion ☐ Root amputation prior to endodontic treatment

*American Society of Anesthesiologists (ASA) Classification System

Class 1: No systemic illness. Patient healthy.
Class 1: Patient with mild degree of systemic illness, but without functional restrictions, ***e.g.,*** well-controlled hypertension.
Class 3: Patient with severe degree of systemic illness which limits activities, but does not immobilize the patient.
Class 4: Patient with severe systemic illness that immobilizes and is sometimes life threatening.
Class 5: Patient will not survive more than 24 hours whether or not surgical intervention takes place.
www.asahq.orgiclinical/physicalstatus.htm

Figure 8.13 AAE Endodontic Case Difficulty Assessment Form. (Reprinted with permission from the American Association of Endodontists.)

Levels of Difficulty

Minimal Difficulty

Preoperative condition indicates routine complexity (uncomplicated). These types of cases would exhibit only those factors that are listed in the Minimal Difficulty category. A predictable treatment outcome should be attainable by a competent practitioner with limited experience.

Moderate Difficulty

Preoperative condition is complicated, exhibiting one or more patient or treatment factors listed in the Moderate

Difficulty category. A predictable treatment outcome is challenging for a competent, experienced practitioner.

High Difficulty

Preoperative condition is exceptionally complicated, exhibiting several factors listed in the Moderate Difficulty category or at least one in the High Difficulty category. A predictable treatment outcome is challenging for even the most experienced practitioner with an extensive history of favorable outcomes.

Use of Endodontic Case Difficulty Assessment form

In order to make the *Case Difficulty Assessment Form* a more objective exercise, it is recommended that a point score be assigned to each item within each difficulty category. This point system is offered for educational purposes only and is not recommended for clinical practice.

- Items listed in the Minimal Difficulty category are assigned a point value of 1.
- Items listed in the Moderate Difficulty category are assigned a point value of 2.
- Items listed in the High Difficulty category are assigned a point value of 5.

The following score ranges are recommended in making the decision whether to treat or refer:

- *Less than 20 points:* Dental student may treat; the level of faculty supervision should be tailored to the student's level of experience.
- *20–40 points:* An experienced and skilled dental student may treat with very close supervision by an endodontist, or the case referred to a graduate student or endodontist.
- *Above 40 points:* The case should not be treated by a predoctoral dental student. The patient should be referred to a graduate student or endodontist.

The assignment of an objective "point score" will hopefully assist the dental student in critically evaluating the difficulty associated with treating each patient, assist him or her in making a treatment decision that is in the patient's best interests, as well as enhance the student's educational experience.

ENDODONTIC TREATMENT OUTCOMES

According to Friedman, the assessment of treatment outcomes in endodontics should be classified as follows:

- *Healed:* This denotes complete clinical and radiographic normalcy (no signs, symptoms, residual radiolucency). This category also includes the typical appearance of a scar after apical surgery.
- *Healing:* This denotes a decrease in the size of radiolucency and clinical normalcy after a follow-up period shorter than 4 years.
- *Disease (refractory/recurrent/emerged apical periodontitis):* This indicates the presence of radiolucency (new, increased, unchanged, or reduced after observation exceeding 4 years) regardless of clinical presentation or the presence of symptoms regardless of radiographic appearance.



Clinical Note

- Dynamics of healing: The potential of teeth to remain free of apical periodontitis after nonsurgical endodontic treatment is 93–98%.
- The signs of healing are evident within the first year after treatment in nearly 90% of the cases.

The various factors influencing healing after endodontic treatment can be classified as follows:

- Pretreatment variables
- Pertreatment variables
- Post-treatment variables

I. PRETREATMENT VARIABLES

- *Presence of periradicular radiolucency:* The presence of pretreatment periradicular radiolucency has a strong negative influence on the healing potential following nonsurgical endodontic treatment. Majority of studies have shown a poorer outcome in teeth affected by apical periodontitis.
- *Size of periradicular radiolucency:* Earlier studies had demonstrated that teeth with periradicular lesions (5 mm in diameter) exhibited better healing potential than those larger than 5 mm. However, recent studies have shown that the size of radiolucency does not influence the healing potential.
- *Systemic health:* Compromised nonspecific immune system impairs the outcome of nonsurgical treatment in teeth with apical periodontitis.
- *In apical third root fractures with periradicular changes:* Root fracture alone is not a reason for endodontic treatment, and resection is contraindicated if the pulp is vital and the tooth can be stabilized. When the fracture is in the apical third and the pulp has died, endodontic treatment should be carried out. In cases where the clinician is unable to negotiate the apical fragment through the main canal, the untreated apical root tip and the treated root segment are monitored radiographically. If an area of rarefaction develops, the apical root fragment should be managed surgically.
- *Combined periodontal–endodontic lesion in which an acutely infected pulpless tooth communicates with the gingival sulcus through a sinus tract that cannot be eliminated:* Although it is possible to eliminate infection in the root canal in such cases by simultaneous periodontal treatment, and although the gingival sulcus area heals once the endodontic treatment is completed, consideration should be given to the extent of the periodontal lesion prior to endodontic treatment. If destruction of the periodontal

attachment is considerable, repair of the periodontal fibers may not occur even after the endodontic treatment.

- *When alveolar resorption is extensive, involving at least half the root surface:* When the periodontal involvement is severe and the tooth is mobile, or when the crown–root ratio is unfavorable, an effort should be made to improve the periodontal status in conjunction with endodontic therapy. If class III mobility is present, extraction of the tooth is preferable to root canal treatment because the prognosis from a periodontal standpoint is poor even though the endodontic treatment may be successful. In some cases, however, the tooth may be firm despite radiographic evidence of considerable bone resorption. In such cases, endodontic treatment is not contraindicated.
- *Damage to the crown is so extensive that endodontic treatment cannot be carried out under aseptic conditions:* If the crown of the tooth can be restored, and if a rubber dam can be applied, routine endodontic treatment should be done. A stainless steel band has to be applied in some cases, and in others, gingivectomy should be done. Root canal treatment should not be attempted unless the crown can be restored properly.

Clinical Note

- The pulpal status does not affect the healing potential of endodontics; hence vital and nonvital teeth heal similarly in teeth without apical periodontitis.
- Presence or absence of clinical symptoms does not influence the healing potential.

II. PERTREATMENT VARIABLES

- *Influence of working length determination:* There is a significantly better prognosis in teeth instrumented to within 0–2 mm from the working length than in teeth that have been shaped and cleaned more than 2 mm short of the working length.
- *Cleaning and shaping of the apical third of the canal:* The root canal of a pulpless tooth with a radiolucent area can be obstructed by a curved root, a tortuous canal, secondary dentin, a pulp stone that cannot be removed or bypassed, a calcified or partially calcified canal, a malformed tooth, or a broken instrument. In such cases, when it is impossible to instrument the root canal or to fill it apically for at least 3–4 mm, the prognosis is poor. Instrumentation, disinfection, and obturation of the coronal and middle thirds of the canal are less important, provided the apical third of the root is properly cleaned, disinfected, and obturated. *The apical third of the root canal is critical and must therefore be disinfected and obturated so that microorganisms can no longer reach the periradicular tissues.* If this procedure cannot be done because of blockage of the apical portion of the canal, repair of the diseased periradicular tissues is not likely to occur.

Clinical Note

- Copious irrigation with irrigants such as sodium hypochlorite plays a crucial role in intracanal disinfection.
- Shaping of the canal to an appropriate size that would facilitate the placement of a small-gauge irrigation needle in the critical apical third of a root canal has a significant role in achieving clinical success.

- *Midtreatment complications:* Perforation of the root surface may occur accidentally by misdirection of the bur while attempting to reach the pulp chamber or by a hand-operated or engine-driven instrument. It may also be the result of internal or external resorption. In cases of resorption, an effort should be made to induce repair by means of calcium hydroxide or MTA, or the perforated area must be walled off by MTA; otherwise, hemorrhage will continue into the root canal, and it will not be possible to disinfect and fill the canal properly. An external surgical approach is necessary to wall off the perforation in some cases.

Clinical Note

Canals that exhibit serous drainage should not be obturated in a single sitting and an intracanal medicament such as calcium hydroxide should be employed. Persistent drainage in spite of multiple applications of the intracanal medicament warrants a reassessment of the case and sometimes a surgical intervention.

III. POST-TREATMENT VARIABLES

- *Coronal seal:* The coronal seal provided by the final postendodontic restoration is an important factor to prevent infection and failure.
- *In cases of retreatment:* After retreatment, a foreign body, such as a fragment of gutta-percha or of root canal filling material, may lie in the periradicular tissues of the tooth in question. The presence of a foreign body increases the difficulty of eliminating infection by intracanal treatment alone. Root-end surgery should be done in addition to canal filling to clear the periradicular structures off the foreign body.
- *When persistent and repeated acute infections occur in a previously treated and filled pulpless tooth:* The first line of treatment in persistent episodes of acute infections in a root canal–treated tooth is to advocate nonsurgical retreatment. Surgical intervention should be considered in cases where nonsurgical retreatment is not feasible or is failing.

SUCCESS AND FAILURE IN ENDODONTICS

When root canal treatment is unsuccessful, we are apt to blame the technique, the intracanal medicament, the filling material, the radiographic interpretation, the tooth, or even the patient. In fact, we blame everyone and everything except ourselves. As often as not, no one is to blame but *ourselves* for poor judgment in accepting the tooth for treatment, for careless cleaning protocol of the canal, for inadequate instrumental shaping of the canal, for the slips that occur in the chain of asepsis, for failure to determine whether the canal was clean before obturation, for an inadequately filled root canal, and for lack of judgment in determining whether endodontic treatment should have been followed by root resection. Treatment of pulpless teeth with areas of rarefaction is not always successful, although a successful result may be expected in more than 90% of cases if the endodontic procedure has been properly performed.

The percentage of successfully treated cases naturally varies with judgment in selection of cases for treatment, with the method of therapy, with the skill of the operator, with the technical difficulties, and with other factors. Nevertheless, some idea of the probability of success can be gained from published reports, as listed in **Table 8.2**.

In a "blind" study, Goldman et al. have shown that a high percentage of error can occur in interpreting postoperative radiographs of endodontically treated teeth. In examining and evaluating check-up films, five of six examiners agreed only 67% of the time. Some of the possible causes of failure are given in **Box 8.2**.

Box 8.2

Possible Causes of Endodontic Failures

- Lack of judgment in accepting a tooth for treatment because of either operative difficulties or poor health of the patient
- Missed root canal
- Lack of adequate disinfection and debridement during canal preparation
- Failure to disinfect the root canal due to poor clinical protocol
- Infection in accessory canals with failure to disinfect them (this comprises a small percentage of cases)
- Imperfect root canal obturation failing to seal off the apical foramen
- Foreign body reaction of an overfilled canal
- Extraradicular microbial infections such as actinomycosis
- True apical cystic lesions
- Vertical root fracture
- Poor periodontal health leading to mobility of tooth
- Poor coronal seal leading to reinfection of the root canal space
- Traumatic injury leading to tooth/root fracture

A poorly functioning tooth, i.e., the one out of occlusion or in traumatic occlusion, may also contribute to slow healing of the periradicular tissues. In addition, a general systemic condition may contribute to poor healing of the periapical tissues, such as failure to lay down collagen by the fibroblasts because of vitamin C deficiency, hormonal imbalance, uncontrolled diabetes, nephritis, and long-term corticosteroid intake.

Table 8.2 Incidence of Successes and Failures in Endodontic Treatment

	Number of Teeth or Roots	Percentage of Success	Percentage of Doubtful Cases	Percentage of Failure	Follow-Up (Years)
Auerbach	299 (t)	83	–	17	3–5
Barbakow et al.	335 (t)	87	6	7	1+
Castagnola and Orlay	1000 (t)	78	9	13	2+
Fechter	8886 (r)	65	–	–	1.25
Grahnen and Hansson	763 (t)	83	5	12	4–5
Grossman et al.	432 (t)	90	1	9	1–5
Ingle and Beveridge	162 (t)	94	–	6	2
Jokinen et al.	1304 (r)	53	13	34	2–7
Kerekes and Tronstad	501 (r)	91	4	5	3–5
Morse et al.	220 (t)	94	–	–	1–3
Selden	355 (t)	93	–	7	1.5
Strindberg	529 (t)	83	3	14	6
Swartz et al.	1007 (t)	89	–	–	1–10
Tamse and Heling	122 (t)	85	–	15	1–6

r, roots; t, teeth.

Clinical Note

Three-dimensional disinfection and obturation of the pulp space is essential to ensure long-term clinical success. The key prognostic factors that have been found to influence the success rate of nonsurgical endodontic cases include the following:

- Canals obturated to within 2 mm of the working length exhibited a success rate of 87% compared to a 77% success rate in canals that were obturated more than 2 mm short of the working length.
- Flared preparations obturated using the vertical compaction technique showed success rates of 90% when compared to the traditional step-back preparations obturated using lateral condensation technique.
- One of the key prognostic factors which influenced and reduced success rates was the presence of a *pre-existing periradicular radiolucency*.

In all cases, an effort should be made to determine whether the tooth is strategic. This determination is especially important if the patient is already wearing a partial denture, or if an implant or a fixed partial denture is planned for the patient, particularly if an area of rarefaction is present or if the crown is in poor condition. Extraction of the tooth in such cases may make for a better design of denture, may save time, and may be not only more economical but also more satisfactory in the long run. On the other hand, salvaging a tooth by endodontic treatment may mean the difference between an implant, a bridge, and a partial or full denture.

When more than one focus of infection are present in the oral cavity, each focus should be considered as an individual unit of the same problem and treated coordinately. Examples are as follows:

- When two adjacent untreated pulpless teeth are present
- When periradicular rarefaction and periodontal disease of the same tooth are coexistent
- When periradicular rarefaction of the maxillary posterior teeth and sinus involvement are coexistent (unless coordinate treatment of the foregoing conditions is carried out, the prognosis for endodontic treatment is less favorable)

CONSIDERATIONS WARRANTING REMOVAL OF TOOTH

- Symptomatic teeth in which canals are non-negotiable due to calcifications or iatrogenic errors and whose surgical management is not feasible
- Endodontically treated teeth exhibiting failure, which is not amenable to either nonsurgical or surgical retreatment
- Irreparable fracture of the tooth
- Extensive periodontal disease with loss of bone support, causing irreversible mobility of the tooth

ENDODONTICS AND PROSTHODONTIC TREATMENT

Many dentists believe that pulpless teeth may be used satisfactorily for bridge abutments. From an analysis of many case histories, Tylman found that pulpless teeth are satisfactory bridge abutments, and in an in vitro study, Trabert and associates found no difference in impact fractures between untreated and endodontically treated teeth.

Pulpless posterior teeth that are to be used as abutments for bridges or for partial dentures should have *complete occlusal coverage*. When the crown of a tooth is weak and is undermined by the presence of mesial or distal fillings, the fracture resistance of such teeth can be improved by employing glass fiber posts instead of metal posts.

The following types of teeth may be retained and used for fixed-bridge abutments or as abutments for removable bridges or dentures:

- Any vital tooth requiring pulp extirpation
- Any pulpless tooth without an area of rarefaction
- Any pulpless tooth with an area of rarefaction requiring root resection, provided sufficient alveolar support remains
- Any pulpless tooth with an area of rarefaction considered to be of strategic importance to the retention of the denture, and in which the potential for repair is good
- Any previously treated pulpless tooth with no clinical and radiographic signs of disease progression

When the root canal filling is inadequate, however, the canal should be retreated and refilled.

Before deciding to remove a salvageable pulpless tooth, one should consider the relation of the tooth to other teeth in the arch. One must be careful not to create an orthodontic problem or a difficult prosthetic problem by heedless removal of a tooth. Removed, but not replaced, first molars are often the cause of disturbed occlusion in the young and of "bite collapse" in the adult. Certain teeth are considered strategic teeth in the dental arch from a prosthetic standpoint. For example, any terminal second molar is difficult to replace by itself. In most cases, replacement is not done because of inherent technical difficulties. In addition, if the first molar is missing and the second molar requires endodontic treatment, the second molar may be considered a strategic tooth because its removal presents difficulties in replacement if no other tooth is missing in the arch. The problem is similar when a second molar is already missing and the first molar is in need of endodontic treatment. Other difficult prosthetic problems are conceivable. For example, if the lateral incisor and both premolars are missing on one side and the cuspid on the same side is in need of endodontic treatment, extraction of the cuspid presents a problem from the standpoint of both fixed and removable bridgework. The replacement of a single anterior tooth, particularly mandibular, by any type of removable appliance or fixed bridgework is not usually satisfactory.

Clinical Note

Under no circumstances should endodontic treatment be dictated only by the strategic need for the tooth.

ENDODONTICS AND ORTHODONTIC TREATMENT

Will pulpless tooth respond to orthodontic treatment as well as a vital tooth? This question has been answered by Huettner and Young on the basis of experimental work in monkeys and by clinical observation in humans. Whether a vital or a pulpless tooth was stimulated to movement by the orthodontic appliance, the histologic picture was the same. Clinical observation in many cases compels one to conclude that no difference exists in the degree of tooth movement regardless of whether the tooth moved is vital or pulpless. In fact, Peskin and Graber surgically repositioned teeth for orthodontic reasons and found that the pulps remained vital if the apices of the teeth were luxated minimally.

It is advisable to relieve or remove any strain on the tooth by an orthodontic appliance while the tooth is under endodontic treatment to avoid confusion as to whether the discomfort is from the appliance or from endodontic treatment. Appliances should not be placed for 1 or 2 weeks after endodontic treatment, to allow sufficient time for recovery because the periodontal ligament is sometimes irritated during endodontic treatment and may need a rest for recovery.

ENDODONTICS AND SINGLE-TOOTH IMPLANTS

In deciding whether to retain or to extract a pulpless tooth, the following points should be remembered:

- Pulpless teeth generally are not the cause or contributing cause of systemic disease.
- In patients with severe systemic disease, such as uncontrolled diabetes, HIV infection, tuberculosis, and a severe anemia, infected pulpless teeth with areas of rarefaction may not respond as readily to treatment; repair of periradicular tissues may be delayed or may not occur as the potential for repair is reduced.
- In certain cases, extraction is contraindicated because of an existing systemic condition of the patient, such as leukemia or radiation necrosis.
  - Bender and colleagues are of the opinion that "in the presence of blood dyscrasias, hemophilia, hyperthyroidism, Paget's disease, and many other systemic disorders patients would fare best if endodontic procedures were performed rather than exodontic procedures."
  - In patients with acute or chronic leukemia, hemophilia, purpura hemorrhagica, rheumatic heart disease, radiation necrosis, or other severe illness, endodontic treatment is preferable to extraction.

According to Torabinejad and Goodacre, the decision to retain or remove teeth should be based on a thorough assessment of the risk factors affecting the long-term prognosis of endodontic and dental implant treatment.

The clinician should consider several factors when determining to save a tooth through endodontic therapy or extract it and place an implant. These factors include the following:

- *Patient-related factors:* Systemic and oral health, as well as patients' comfort and perceptions about treatment
- *Tooth- and periodontium-related factors:* Pulpal and periodontal conditions, biological environmental considerations, color characteristics of the teeth, quantity and quality of bone, and soft-tissue anatomy
- *Treatment-related factors:* An assessment of potential procedural complications, required adjunctive procedures, and treatment outcomes data

A detailed history of the case is recorded, and the required diagnostic test is conducted, including radiographs. The clinician arrives at a provisional diagnosis and treatment planning. The endodontist should present to the patient and/or the patient's relative a comprehensive treatment plan including financial considerations and the time taken, also including a mention on prognosis. An informed consent is always obtained prior to starting any dental treatment.

INFORMED CONSENT

Adhering to highest standard of care in a given procedure alone will not prevent the endodontist from being subjected to a claim by the patient for an untoward result. Failure to inform the patient of the risk of an untoward result prior to the performance of that procedure will just as likely result in a claim by the patient for failing to obtain his or her consent.

Informed consent is obtained after the endodontist has discussed with his or her patient all relevant information so as to assist the patient in making an informed decision with respect to undergoing that proposed procedure.

GENERAL GUIDELINES (Fig. 8.14)

- Disclose the following information in an understandable lay language:
  - Diagnosis of the existing problem
  - Nature of the proposed treatment or procedure
  - Inherent risks associated with the proposed treatment or procedure
  - Prognosis
  - Feasible alternatives to the proposed treatment or procedure
  - Inherent risks associated with the alternative treatments or procedures
  - Prognosis of alternative treatments or procedures
- Provide an opportunity to question the doctor about any of the above.

SAMPLE STATEMENT OF CONSENT FOR ENDODONTIC TREATMENT

1. I hereby authorize Dr._____ and any other agents or employees of _____ and such assistants as may be selected by any of them to treat the condition(s) described below:

   _____

   _____

2. The procedure(s) necessary to treat the condition(s) have been explained to me, and I understand the nature of the procedure(s) to be:_____

   _____

3. The prognosis for this(these) procedure(s) was described as:_____

   _____

4. I have been informed of possible alternative methods of treatment including no treatment at all.

5. The doctor has explained to me that there are certain inherent and potential risks in any treatment plan or procedure. I understand that the following may be inherent or potential risks for the treatment I will receive:
   swelling; sensitivity; bleeding; pain; infection; numbness and/or tingling sensation in the lip, tongue, chin, gums, cheeks, and teeth, which is transient but on infrequent occasions may be permanent; reactions to injections; changes in occlusion (biting); jaw muscle cramps and spasm; temporomandibular joint difficulty; loosening of teeth, crowns or bridges; referred pain to ear, neck and head; delayed healing; sinus perforations; treatment failure; complications resulting from the use of dental instruments (broken instruments–perforation of tooth, root, sinus), medications, anesthetics and injections; discoloration of the face; reactions to medications causing drowsiness and lack of coordination; and antibiotics may inhibit the effectiveness of birth control pills.

6. It has been explained to me and I understand that a perfect result is not guaranteed or warranted and cannot be guaranteed or warranted.

7. I have been given the opportunity to question the doctor concerning the nature of treatment, the inherent risks of the treatment, and the alternatives to this treatment.

8. This consent form does not encompass the entire discussion I had with the doctor regarding the proposed treatment.

Patient's Signature _____ Date/Time_____

Doctor's Signature _____ Date/Time_____

Witness' Signature _____ Date/Time_____

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Figure 8.14 Sample of informed consent form.

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9 Magnification in Endodontics

The only thing worse than being blind is having sight but no vision.
—Helen Keller

Endodontic procedures inside the pulp chamber and root canal system require high levels of precision. Performing endodontic therapy is like working inside a blind space wherein procedures are traditionally done by tactile sensation and with the help of radiographs. The greatest challenge a clinician faces while trying to achieve clinical perfection is in trying to visualize the operating site with clarity. This is not possible beyond a point due to the inherent limitation of the human visual spectrum.

The advent of magnification aids has greatly revolutionized dentistry and especially endodontics. Either using a dental loupe (**Fig. 9.1**) or preferably employing a dental operating microscope (DOM) (**Fig. 9.2**) can achieve enhanced visualization in clinical dentistry. The introduction of DOMs has revolutionized a new era in endodontics.



Figure 9.1 (a) Customized Galilean *through the lens* (TTL) dental loupe. (*Courtesy: Orangedental GmbH & Co.*). (b) Prismatic dental loupe. (*Courtesy: Zeiss.*)

DENTAL LOUPES

Loupes can be classified by the optical method in which they produce magnification and also based on how the lenses are mounted on to the frame.

I. Based on the *kind of lenses* being employed, there are three types of binocular magnifying loupes:
   1. Diopter, flat-plane, single-lens loupes
      - Their only advantage is that they are the most economical of all the options available.
      - However, as the operator needs to be close to the viewed operating site, these loupes are associated with compromised posture and musculoskeletal stresses and fatigue.
   2. Surgical telescopes with a Galilean system (two-lens system)
      - They are the most recommended in dentistry and are available in a magnification range of 2× to 4.5× (**Fig. 9.1a**).
      - They are relatively compact and lighter in weight.
   3. Surgical telescopes with a Keplerian system
      - They employ refractive prisms and are heavier (**Fig. 9.1b**).
      - They can provide magnification up to 6× and are sometimes used with a head band.

II. Loupes can also be classified based on *how the lens are mounted* to the frame:
   1. Flip-up loupes
   2. Through the lens (TTL) loupes

Comparative assessment of features between these two types of loupes is given in **Box 9.1**.

DENTAL OPERATING MICROSCOPE

The introduction and acceptance of DOM has been one of the most important dental innovations in the past three decades. Currently, every endodontist is expected to learn and use a DOM in order to improve clinical proficiency and deliver better treatment outcomes for the patient.

HISTORY

- *Apotheker (1981)*: Introduction of DOM



(a) (b) (c)

Figure 9.2 (a) Leica M320 dental operating microscope. (*Courtesy: Leica Microsystems.*) (b) Global A6 dental operating microscope. (*Courtesy: Global Surgical Corporation.*) (c) Zeiss Opmi pico dental operating microscope. (*Courtesy: Zeiss.*)

Box 9.1

Features of Flip-Up Loupes Versus TTL Loupes

Feature	Flip-Up Loupes	Through the Lens (TTL) Loupes
Mobility of the lens	As the name indicates, can be flipped up when operator does not need them	They are fixed to the frame of the lens
Adjustment of the optics	Interpupillary distance and declination angle can be altered by the operator	The interpupillary distance and declination angle are fixed (custom-made for a single operator) and cannot be altered
Ability to share between operators	Possible	Custom-made for a single operator
Cost	Relatively economical	Relatively expensive
Weight	Heavier	Lighter

- *Gary Carr (1991)*: Introduction of ergonomic DOM with Galilean optics (this enables the light input to be sent as parallel beams of light to each eye, thus permitting operators to work for long hours without creating any eye fatigue)

PARTS OF THE BODY OF A MICROSCOPE

The body of the microscope has four main parts (**Fig. 9.2**).

1. Eyepiece Lens

- The operator views the field through the eyepiece lens. Both the eyepiece and the objective lens have convex lenses.
- Eyepieces are generally available in powers of 10×, 12.5×, 16×, and 20×. The most commonly used are 10× and 12.5×.
- Eyepieces have adjustable diopter setting to adjust for accommodation (ability to focus the lens of the eyes).

2. Binoculars

- The function of binoculars is to hold the eyepieces.
- They need to be adjusted according to the interpupillary distance of the operator. As in a typical pair of field binoculars, adjusting the distance between the binocular tubes sets the interpupillary distance.
- This is done with the help of a small knob or manually until the operator is able to visualize the area of interest with a single focus from both the eyepieces.
- *Inclinable tube microscopes* are recommended in dentistry as they allow the clinician to adjust the angle of the binocular according to the clinical situation. They can often provide the operator with additional postural comfort during long procedures.

Clinical Note

The *diopter settings* and *interpupillary distance settings* would vary from one operator to the other and need to be changed whenever a new operator wants to work on a microscope.

3. Magnification Changer

- Magnification changers are located within the head of the microscope. The magnification is increased or decreased by rotating a dial.
- A magnification of 2–2.5× would enable the dental operator to see multiple quadrant areas in focus. This is the magnification normally used in general dental practice and is recommended for new users. At magnifications of 3.5×, the field becomes restricted to a single quadrant, while at a magnification beyond 3.5×, the view becomes increasingly restricted until only a single tooth is seen.

4. Objective Lens

- The objective lens is the first optical component that the image information crosses on its path from the object to the eye. The lenses vary in their focal distance (focal length).
- The focal length influences the working distance (i.e., the distance between the object in the treatment field and the surface of the lens), the magnification, and the resolution.
- The most common working distances are 200, 250, and 300 mm.
- Unlike an objective lens with fixed focal length, you can also have a variable focal length objective lens. Therefore, it can be set to a range of working distances to meet different application and ergonomic requirements. The focal range of such a variable focal length objective lens can be varied from 200 to 300 mm (**Fig. 9.3**).



Figure 9.3 The multifocal objective lens enables an operator to adjust the working distance from 200 to 300 mm with the help of a knob. (*Courtesy: Leica Microsystems.*)

Clinical Note

- Depth of field refers to the ability of the magnifying system to focus on objects that are both near and far without having to change the lens position.
  - Magnification increases → Smaller field of view → Depth of field decreases.
  - Magnification decreases → Larger field of view → Depth of field increases.
- The use of magnification causes a restriction in the depth of field and, as the magnification increases, the depth of field decreases to the point that only a small object is sharply in focus and everything around is out of focus.

HOW THE DENTAL OPERATING MICROSCOPE WORKS

To appreciate what a surgical operating microscope can do, it is essential to understand the various aspects of its working that includes:

I. Magnification
II. Illumination
III. Documentation
IV. Mounting a microscope

I. MAGNIFICATION

Magnification is determined by four key variables in a dental microscope.

1. Power of the Eyepiece

Eyepieces are generally available in powers of 10×, 12.5×, 16×, and 20×. The most commonly used are 10× and 12.5×.

2. Focal Length of the Binoculars

Binoculars often come in different focal lengths. In choosing binocular focal lengths, it is important to remember that the longer the focal length, the greater the magnification and the narrower the field of view. Shorter-length binoculars allow the operator to have a wider field of view and to be little closer to the patient.

3. Magnification Changer Factor

Magnification changers are available as three-, five-, or six-step manual changers. Manual step changers consist of lenses that are mounted on a turret.

A conventional three-step changer has one set of lenses and blank space on the turret and thus has three fixed powers of magnification. A five-step or six-step manual changer has a second set of lenses mounted on the turret and produces five or six fixed powers of magnification, respectively.

4. Focal Length of the Objective Lens

As the focal length increases, it implies that the distance of the lens from the object of interest is also increasing. Hence,

an increase in the focal length causes a decrease in magnification. Hence, an objective lens of 250 mm would provide a *lower* magnification at every level of magnification compared to a 200-mm focal length objective lens.

Clinical Note

Magnification increases and the field of view decreases by any one of the following variables:
- Increasing the power of the eyepieces
- Increasing the focal length of the binoculars
- Increasing the magnification factor

Magnification decreases and the field of view increases, and illumination decreases by the following:
- Increasing the focal length of the objective lens

II. ILLUMINATION

One of the advantages of using a microscope is its ability to provide *coaxial illumination*. Coaxial illumination means that the light-source path and the line-of-sight path are similar. This enables a microscope to illuminate the object of interest clearly without any shadows.

Powerful LEDs are used as the light source in conventional microscopes.

III. DOCUMENTATION

Documentation of clinical work and the ability of a co-observer to visualize what a clinician is seeing in real time are possible by attaching a *beam splitter* between the magnification changer and the binocular of a microscope.

The beam splitter divides the incoming light into two parts in prefixed ratios (e.g., 50:50). One part of the light goes to the eyepiece in the binocular while the other part is sent to the documentation port/co-observer (**Fig. 9.4**).



Figure 9.4 (1) HDMI direct-to-monitor video camera. (2) X-Mount Adapter for camcorder or digital cameras. (3) SLR X-Mount Adapter for SLR cameras. (4) Beam splitter: this optical component divides the incoming light into two beams and thus allows the connection and combination of video/digital cameras for documentation purposes. (*Courtesy: Global Surgical Corporation.*)

IV. MOUNTING A MICROSCOPE

To reduce the inadvertent movement of the body of the microscope, it should be firmly fixed to a rigid surface. Hence, to have adequate movement around the working area of the patient without restricting access to the oral cavity for the operator, the body of the microscope is supported by a counterbalanced arm that can be attached to the floor, wall, or ceiling (**Fig. 9.5**).



Figure 9.5 Various options of mounting a microscope. (*Courtesy: Global Surgical Corporation.*)

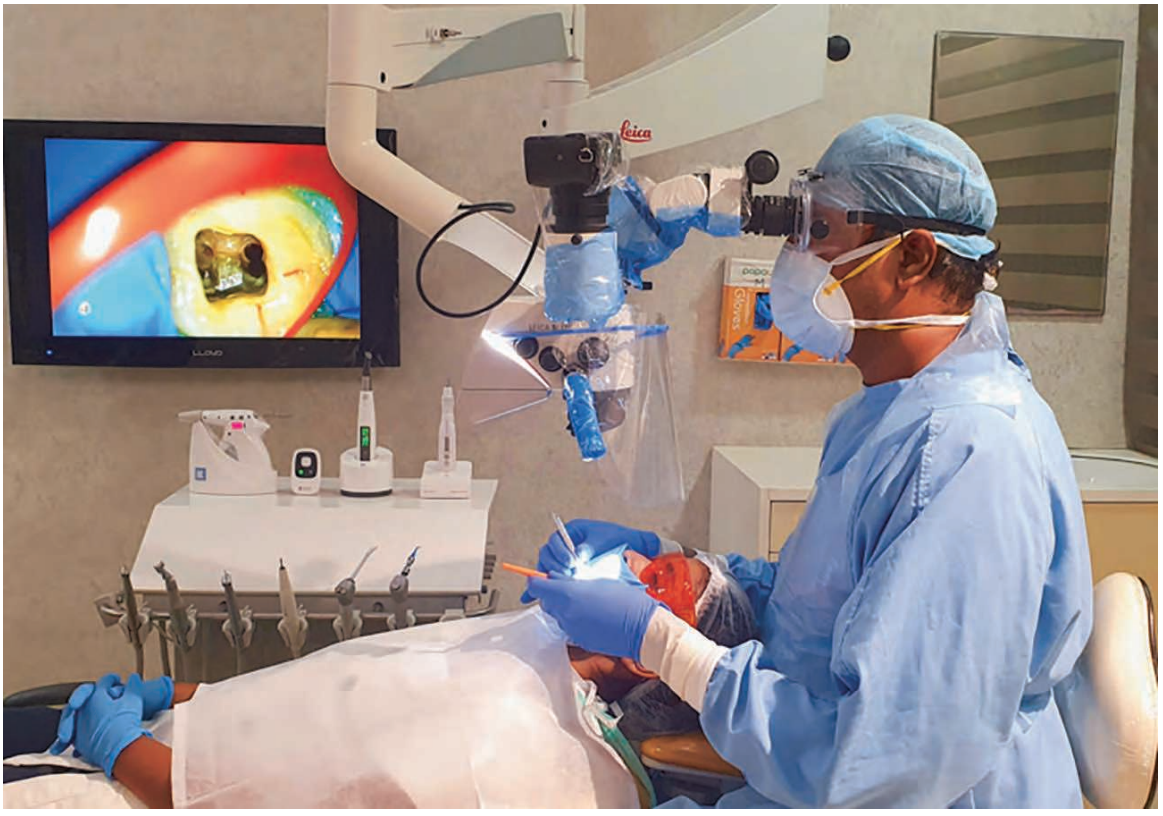


Figure 9.6 Clinical setup while performing endodontic procedures under a dental operating microscope.

CLINICAL APPLICATIONS

The use of a DOM enables a clinician to perform a wide variety of complex clinical procedures in a very comfortable posture (**Fig. 9.6**). It also enables a clinician to visualize the area of interest in various levels of magnification (**Fig. 9.7**).

The use of a front surface mirror (**Fig. 9.8a**) helps in clear visualization when using a DOM while special hand instruments such as the micro-openers are useful while negotiating calcified canals (**Fig. 9.8b**). The various clinical applications of a DOM are given in **Box 9.2**.

Box 9.2

Clinical Applications of Dental Operating Microscope (DOM) in Endodontics

- Enhanced clinical visualization of area of interest (**Fig. 9.9a**)
- Diagnosis of cracks (**Fig. 9.9b**)
- Conservative access refinement, removal of pulp stones (**Fig. 9.10**), and tracing missed/calcified canals (**Fig. 9.11**)
- Identifying atypical root canal anatomy
- Assessment during shaping, cleaning, and obturation procedures (**Fig. 9.12**)
- Prevention and management of endodontic mishaps including:
  - Perforation management
  - Retrieval of separated instruments
- Retreatment of endodontic failures
- Microsurgical endodontics for creating smaller osteotomy, inspection of resected root surface, retropreparation, retrofill, and microsuturing (refer Chapter 22)

CLINICAL USES OF A MICROSCOPE AT DIFFERENT LEVELS OF MAGNIFICATION

Low Magnification (2.5× to 5×)

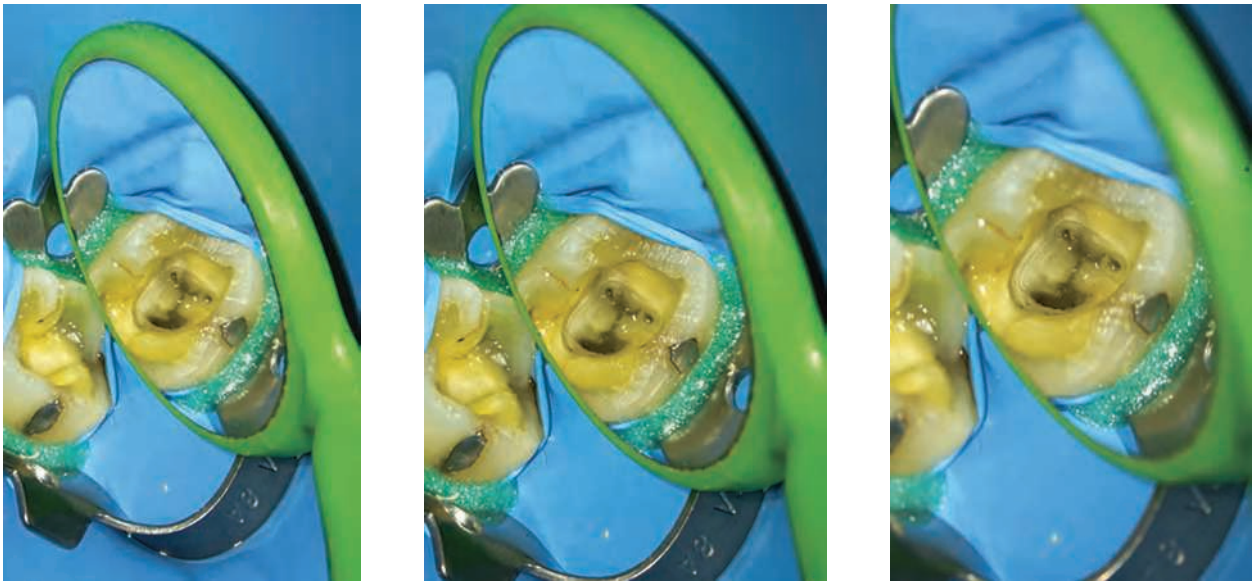
It is ideal for tooth examination and initial access preparation. The wider field of view is useful to gain orientation in relation to adjacent teeth and anatomic structures.

Medium Magnification: (5× to 12×)

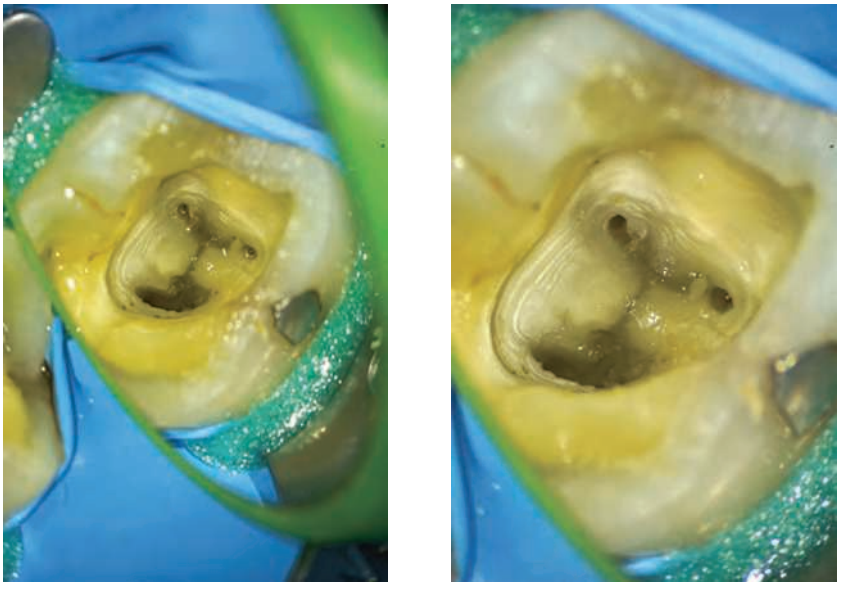
It is most commonly used for most nonsurgical and surgical endodontic procedures. This range of magnification provides adequate field of view and depth of field.

High Magnification (12× to 20×)

It is used sparingly during minute procedures such as instrument retrieval. It is also used during documentation of clinical work. However, the limited field of view and loss of focus during minor movements make clinical work at these levels of magnification a challenge.

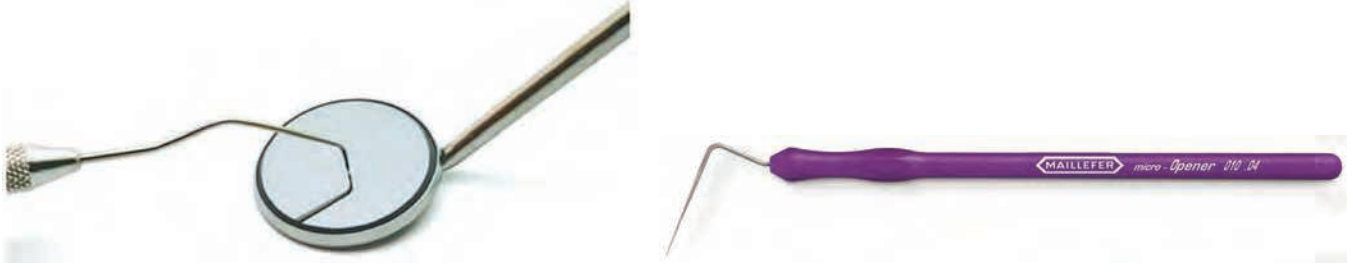


(a) (b) (c)



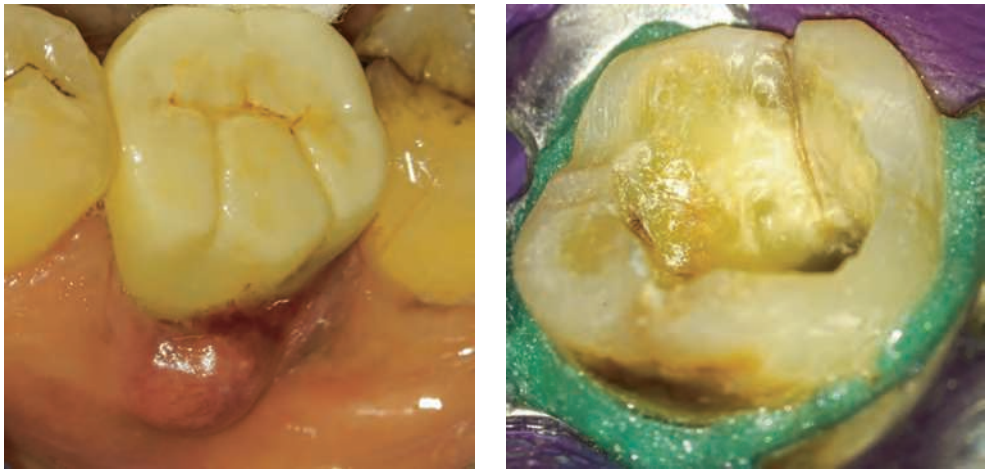
(d) (e)

Figure 9.7 Coronal pulp space and orifice visualization at various levels of magnification. (a) 2.5×. (b) 4×. (c) 6×. (d) 8×. (e) 12×.



(a) (b)

Figure 9.8 (a) Front surface mirror enables clear visualization without creating double images that are often associated with back surface mirrors. (b) Micro-openers for negotiating calcified orifices under magnification. (*Courtesy: Dentsply Sirona.*)



(a) (b)

Figure 9.9 (a) Clinical view of a root canal–treated tooth with a full-coverage crown with an abscess under magnification. (b) Clinical microscopic view of a crack propagating from the distal marginal ridge and extending into the pulp chamber.

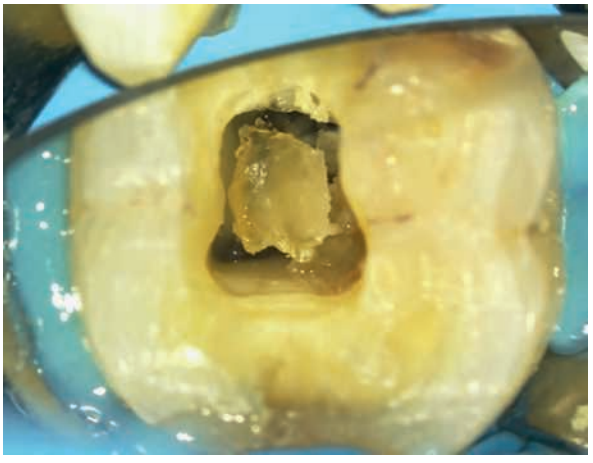
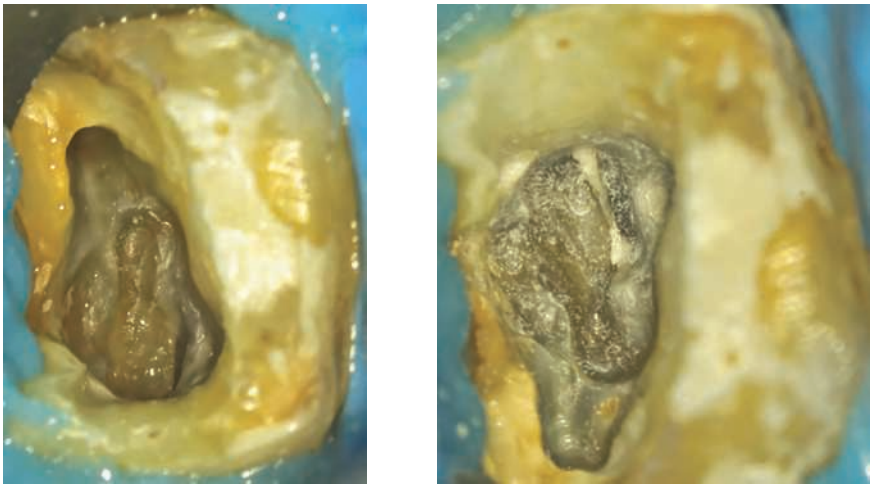
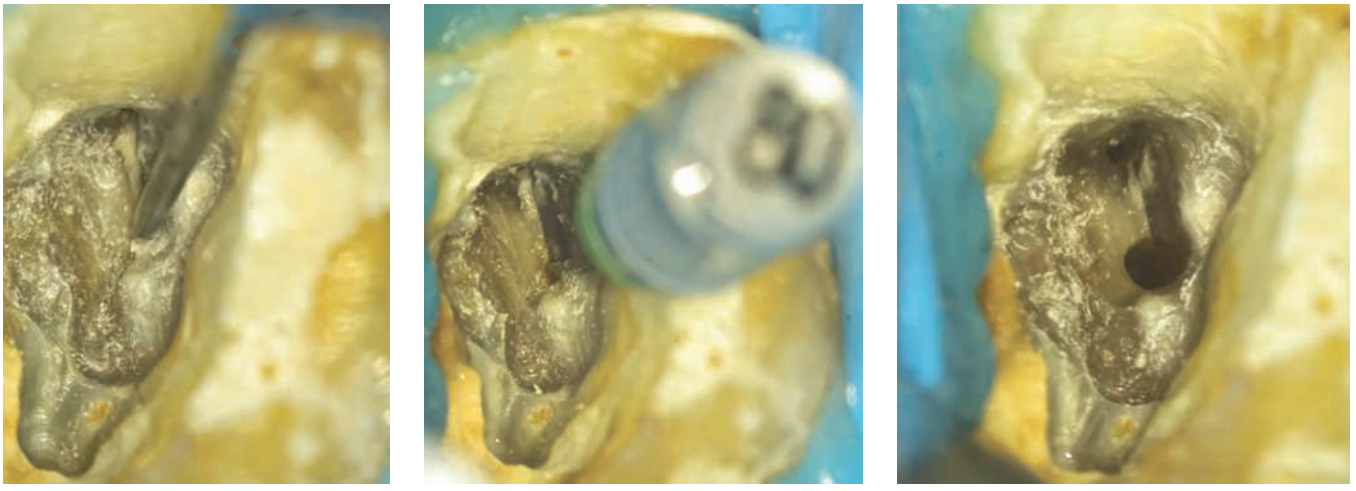


Figure 9.10 Clinical visualization of a pulp stone under magnification.



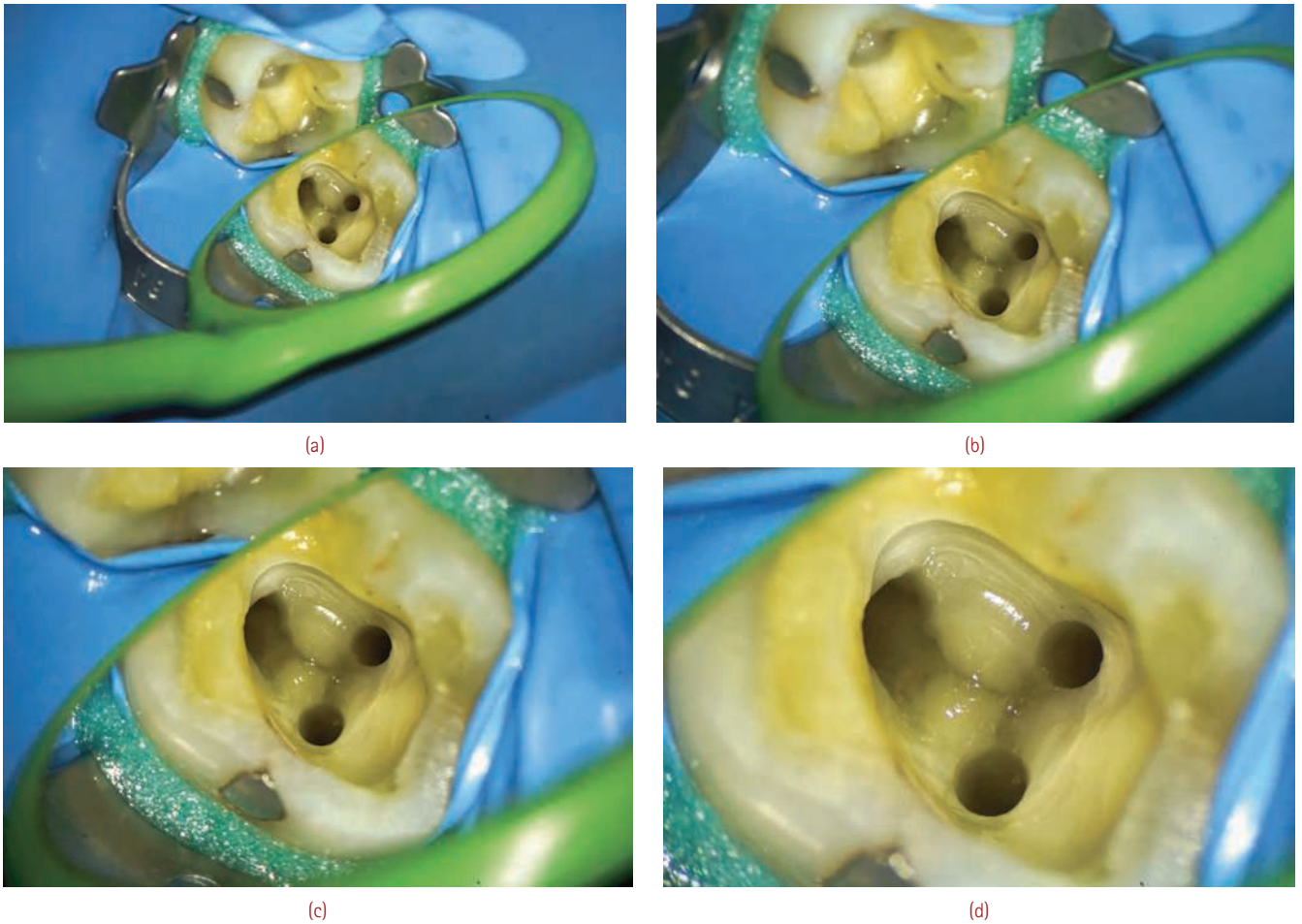
(a) (b)

Figure 9.11 (a) Clinical view of a referred case with calcified mesiobuccal canals. (b) After troughing the pulpal floor with ultrasonic tips. Note the white debris areas indicating the potential location of the mesiobuccal 1 (MB1) and mesiobuccal 2 (MB2) root canal orifices. *(continued)*



(c) (d) (e)

Figure 9.11 *(continued)* (c) Locating the MB2 canal orifice with a DG 16 probe. (d) Tracing the glide path with the help of size 8 K-file. (e) Clinical view of the shaped MB2 canal.



(a) (b)

(c) (d)

Figure 9.12 Assessment of the pulp chamber after completion of shaping and cleaning procedures. (a) 2.5×. (b) 4×. (c) 8×. (d) 12×.

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10 Principles of Endodontic Treatment

Quality is, doing the little things right when nobody is looking.
—George Bernard Shaw

The basic principles underlying the treatment of teeth with endodontic problems are those underlying surgery in general. An aseptic technique, debridement of the wound, drainage, and gentle treatment of the tissues with both instruments and drugs—all are cardinal principles of surgery. Specifically, pain must be controlled with the help of local anesthesia. During treatment, all pulp tissue must be removed, the root canal enlarged and irrigated, the pulp space disinfected, and the root canal well obturated to prevent the possibility of reinfection.

LOCAL ANESTHESIA

At the start of root canal therapy, local anesthesia is used. Anesthesia should not be administered without a thorough knowledge of the patient's medical and dental history. Any prior allergic reactions or untoward episodes during dental treatment must be investigated and evaluated to avoid any future reaction to medication.

The most commonly employed anesthetic agents in endodontics are as follows:

- *2% lidocaine with 1:100,000 epinephrine:* It is the most commonly employed local anesthetic agent.
- *4% articaine with 1:100,000 epinephrine:* It is one of the most commonly used alternatives to 2% lidocaine with 1:100,000 epinephrine.

The other less commonly employed anesthetic agents in endodontics are as follows:

- *0.5% bupivacaine with 1:200,000 epinephrine:* It is a long-acting local anesthetic which has been advocated in cases requiring prolonged pain control. Although the onset of action of this drug is slower than that of 2% lidocaine, the duration of pulpal anesthesia in mandibular teeth is for about 4 hours.
- *2% mepivacaine with 1:20,000 levonordefrin:* The clinical efficacy and systemic effects are similar to those of 2% lidocaine with 1:100,000 epinephrine.
- *4% prilocaine with 1:200,000 epinephrine:* Not commonly used.

Clinical Note

The Committee on Medical Education of the American Heart Association and the Council on Dental Therapeutics of the American Dental Association have approved a report of a conference at which it was stated that *"the concentrations of vasoconstrictors normally used in dental local anesthetic solutions are not contraindicated in patients with cardiovascular disease when administered carefully and with preliminary aspiration."*

I. INFILTRATION ANESTHESIA

- Infiltration anesthesia is the injection of a local anesthetic into the soft tissues in the region of the root apex. This technique is preferred to achieve anesthesia for any of the *maxillary teeth*.
- Infiltration is probably the simplest, safest, and fastest method of producing anesthesia for removal of a dental pulp. The injection of an anesthetic stops any pain and makes pulp removal possible. The injection is made as for removal of a tooth; one inserts the needle into the mucobuccal fold slightly mesial of the tooth to be anesthetized and carries it toward the root apex until bone is encountered. An effective, long-lasting anesthetic solution such as 2% lidocaine (Xylocaine) with 1:100,000 epinephrine is preferred, although other local anesthetics are also effective.
- Generally, one carpule of the anesthetic solution (1.8 mL) is sufficient, but administration of more anesthetic solution is often required for pulp extirpation than for extraction of a tooth. Despite care in injection, complete anesthesia may not follow.
- A subperiosteal injection should then be made by inserting the needle near the apex of the tooth, just under the periosteum, and slowly depositing about 0.5 mL of anesthetic solution.

Anesthetic techniques described in this text are limited to those necessary for painless endodontic treatment. For a more comprehensive understanding of local and general anesthesia, one should consult other texts specifically on that subject.

Clinical Note

A greater palatine nerve block for maxillary teeth is unnecessary for achieving pulpal anesthesia for endodontic procedures.

II. BLOCK (CONDUCTION) ANESTHESIA

- Due to the increased density of the buccal alveolar plate, infiltration anesthesia alone is *ineffective* in the mandibular posterior region of the mouth, particularly for the removal of pulps in molar and premolar teeth. In such cases, *inferior alveolar nerve block (IANB)*, or conduction anesthesia of the inferior alveolar and long buccal nerves, should be used.
- At times, however, the inferior alveolar nerve may be difficult to anesthetize because of its anomalous distribution; for example, it may give off a branch that runs anterior to the mandibular foramen and enters the mandible through an opening anterior and inferior to the foramen.
- When the injection is properly executed, it is probably the most effective method for producing the anesthesia necessary for removal of a pulp, particularly in posterior teeth. A *modified technique* for injecting the inferior alveolar nerve by inserting the needle about half an inch higher than the place of the conventional injection has also been used. It has been reported that complete anesthesia was obtained in all cases with this technique. Because the buccal nerve is above the level of the inferior alveolar nerve, it is possible to anesthetize both nerves by diffusion of solution from one injection.
- The *Gow-Gates mandibular block* is another type of mandibular block anesthesia. It differs from the inferior alveolar block in that the anesthesia is deposited in the lateral aspect of the neck of the condyle below the insertion of the lateral pterygoid muscle instead of in the mandibular sulcus. Advocates of the Gow-Gates technique claim a higher success rate than with the conventional technique, although the onset of anesthesia is slower. This technique can be used either routinely or when the conventional technique fails to produce anesthesia.

The endodontist may also use other forms of regional anesthesia: posterior superior alveolar, infraorbital, greater palatine, nasopalatine, maxillary, or second-division blocks. These nerve blocks are indicated when infiltration anesthesia is inadequate.

The IANB injections tend to fail in spite of profound lip anesthesia. The probable causes for difficulty in achieving good anesthesia could be as follows:

- Lack of sufficient quantity of the anesthetic to block the sodium channels in the axons
- Accessory innervation from the nerve to the mylohyoid
- Inaccurate positioning of needle/deflection of needle from optimal site of deposition of anesthetic
- Wide variation in the course of the inferior alveolar nerve
- Accessory path for innervation from contralateral inferior alveolar nerve especially in relation to the mandibular anterior teeth
- At times, it is difficult to obtain adequate anesthesia with an injection of a local anesthetic solution because of the inflamed state of the pulp. The reason for the inefficiency of the anesthetic solution in areas of inflammation may be an increase in peripheral nerve activity or a decrease in pH of the inflamed tissues that allows few anesthetic molecules to reach the nerves and thereby prevents full anesthesia

Clinical Note

A clinician should be aware of certain considerations in order to avoid failure in administering local anesthesia. These include the following:

- Proper knowledge of the anatomy of the inferior alveolar nerve.
- Although lip numbness does not always indicate effective pulpal anesthesia, *the absence of lip numbness indicates a failed inferior alveolar nerve block injection* prompting a second injection.
- Malamed has stated that at times 3.0 mL of anesthetic solution might be required to obtain sufficient pulpal anesthesia.

III. TECHNIQUES TO AUGMENT INFILTRATION AND CONDUCTION ANESTHESIA

A. Articaine by Buccal Infiltration

Recent clinical trials have shown that supplementing an IANB with *4% articaine buccal infiltration (0.9–1.2 mL) at the apex of the tooth to be treated* is a very effective supplemental method to achieve pulpal anesthesia in mandibular teeth with symptomatic irreversible pulpitis.

B. Periodontal Ligament (PDL) Injection

The PDL or intraligamentary injection is used to augment incomplete dental anesthesia.

The objective of this injection is to anesthetize the PDL of the tooth undergoing endodontic therapy and to thereby block the pulpal nerves. Damage to the PDL from this injection is minimal and is usually confined to the crestal area where the needle penetrates.

- Special pressure syringes have been developed for the intraligamentary injection (**Fig. 10.1**).
- These syringes are manufactured to deliver a preset volume of anesthetic (0.14–0.22 mL) with minimal effort and without breaking the anesthetic carpule.
- A short 27- or 30-gauge needle is inserted interproximally with positive pressure as deeply as possible along the root of the tooth, with the bevel of the needle toward the crestal bone.
- In posterior teeth, the needle is bent to a convenient angle and the trigger is squeezed to deliver around 0.2 mL



Figure 10.1 Special pressure syringes developed for intraligamentary injection: VibraJect. (*Courtesy: Miltex Inc., USA.*)

intraligamentally alongside the mesial and distal roots of multirooted teeth.

- The onset of anesthesia is immediate, and the effect lasts an average of 27 minutes when using 2% lidocaine containing epinephrine 1:50,000.
- This technique is most frequently used in mandibular molars and is approximately 92% effective.
- Newer computer-assisted local anesthetic delivery systems known as *Wand* and *CompuDent* have been recently developed. These are modifications of the intraligamentary supplemental injection. It accommodates a standard local anesthetic agent which is attached to a disposable handheld handpiece with a Luer-Lok needle attached to the end. A foot control activates and controls the rate of infusion.

Clinical Note

The ability to anesthetize a single tooth makes the periodontal ligament injection technique invaluable in the diagnosis of diffuse pain of unknown origin (anesthetic test).

C. Intraosseous Injection

- Intraosseous anesthesia is a valuable adjunct to achieving optimal pain control in difficult-to-manage clinical situations.
- Most commonly employed intraosseous systems are the *Stabident system* (Fairfax Dental Inc., USA) and the *X-Tip system* (Dentsply, USA).
  - ***Stabident system*** comprises a slow-speed handpiece-driven perforator and a solid 27-gauge wire that is used to drill a small hole through the cortical plate (**Fig. 10.2a**). The anesthetic agent is placed into the cancellous bone with the help of a 27-gauge ultrashort injector needle placed through the channel prepared by the perforator (**Fig. 10.2b**).
  - ***X-Tip system***, on the other hand, employs a special hollow needle that serves as the drill penetrating the cortical plate, after which it is separated and withdrawn. This guide sleeve is used to insert a 27-gauge needle and inject the anesthetic solution.



(a)



(b)

Figure 10.2 (a) Perforation site for the intraosseous injection. (b) Stabident system.

D. Intrapulpal Anesthesia

- Intrapulpal injection produces pain control by a combination of the pharmacologic action of the local anesthetic and the pressure applied during the process.
- This direct injection into the body of the exposed pulp can be done only if the exposure of the pulp is large enough to admit a hypodermic needle.
- Too large an exposure, however, may cause a backflow of solution, with little or no solution entering the pulp to anesthetize it. This problem can be prevented by introducing the needle into the root canal until it binds and by forcing the anesthetic solution into the radicular pulp. In many cases, it is necessary to bend the needle to penetrate the root canals.
- 0.2–0.3 mL anesthetic solution is injected into the pulp and the resulting anesthesia is effective and immediate.

Clinical Note

It is a painful injection and should be used when all other supplemental anesthetic techniques are either not available or ineffective.

RUBBER DAM ISOLATION

The discovery of the application of rubber dam is credited to **Dr. S.C. Barnum** in the year 1864 and he stated that "*the most time consuming thing about the rubber dam is the time required to convince the dentist to use it.*" This discovery made decades ago is still a boon in restorative dentistry and endodontics.

- All restorative and endodontic applications require mandatory use of rubber dam. In fact, use of rubber dam in dentistry, and endodontics in particular, is the **recognized standard of care**.
  - To achieve the first principle of endodontic treatment, a ***safe and aseptic operating technique*** needs to be maintained. For this, application of rubber dam is mandatory. It is the only sure safeguard against bacterial contamination from saliva and accidental swallowing of root canal instruments. All endodontic operations should be performed under the rubber dam. Treatment of any tooth should not be attempted under cotton rolls.
  - In some cases, it is first necessary to replace a missing wall with a restoration or to cement a stainless steel band to prevent the rubber dam clamp from slipping off the tooth. In other cases, a gingivectomy may need to be done, with removal of about 2-mm gingival tissue to provide enough tooth structure for application of a rubber dam clamp.
- To risk operating without a rubber dam is to risk one's professional reputation. The risk of losing an instrument down the patient's trachea or esophagus is too great to warrant this practice. A variety of objects used in endodontic practice may be swallowed accidentally if the rubber dam is not applied. Root canal instruments swallowed during endodontic treatment have been reported (**Fig. 10.3**).

If an instrument is swallowed or aspirated during endodontic treatment without a rubber dam, one is likely to be confronted with a lawsuit. Grossman has stated that "*in the eyes of the court, when an endodontic instrument escapes from the dentist's fingers and is ingested or aspirated, expert opinion is unnecessary to justify claims of negligence.*"

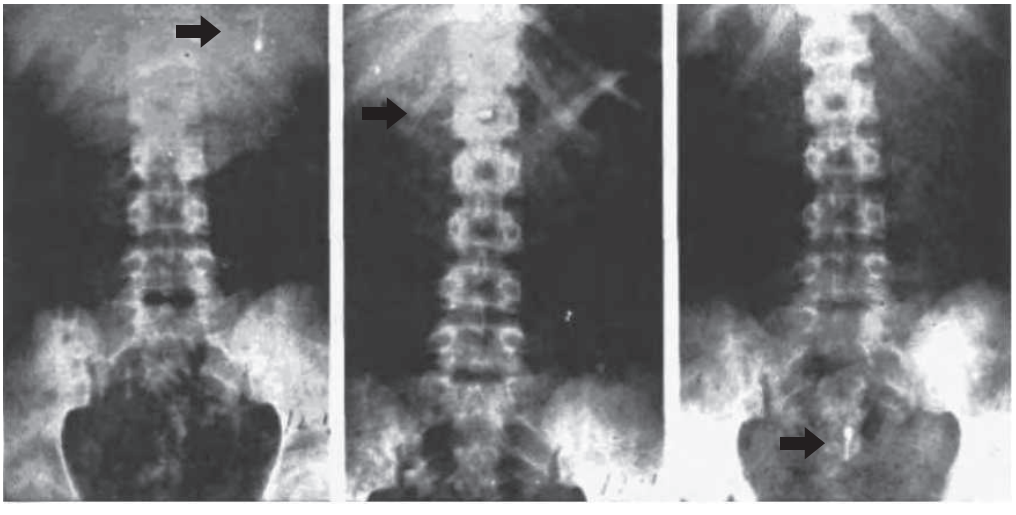
Clinical Note

- ***The rubber dam can be applied in less than 2 minutes and often within 1 minute.***
- ***In most cases***, only the tooth to be operated on should be isolated. This limitation consumes less operating time and lessens the possibility of contamination from adjacent teeth and saliva.

ADVANTAGES

In addition to the features of the rubber dam mentioned in the previous text, following are the advantages of rubber dam in endodontics:

- Dry aseptic field
- Protects patient's soft tissues from sodium hypochlorite irrigation and other caustic medicaments
- Prevents aspiration of endodontic instruments
- Improves access and visibility
- Prevents contamination of root canal with oral microbial flora



(a) (b) (c)

Figure 10.3 Radiographic views of the trail of a swallowed endodontic instrument.

COMPONENTS OF RUBBER DAM KIT

Use of rubber dam and high-power suction go hand in hand. The rubber dam kit (**Fig. 10.4**) comprises the following:

- Rubber dam material
- Rubber dam clamps
- Rubber dam clamp carrying forceps
- Rubber dam punch
- Rubber dam frames (Young's metal frame, U-shaped plastic frame, hinged dental dam frame, and HandiDam)
- Rubber dam template
- Wedget cord
- Dental silk floss
- Rubber dam napkin
- Flowable block-out materials

Clinical Note

- Apart from those mentioned earlier, recently introduced systems include the **OptraDam** (Ivoclar Vivadent; **Fig. 10.5a**), which is considered to be an anatomically shaped rubber dam which can be used with or without clamps.
- **Insti-Dam** (**Fig. 10.5b**) is a disposable rubber dam system available in both latex and nonlatex materials.

A. Rubber Dam Material

- Rubber dam material (**Fig. 10.6**) is available in *heavy*, *medium*, and *light* weight thicknesses and also in different colors and standard sizes. Medium weight thickness is usually recommended for endodontic purpose.

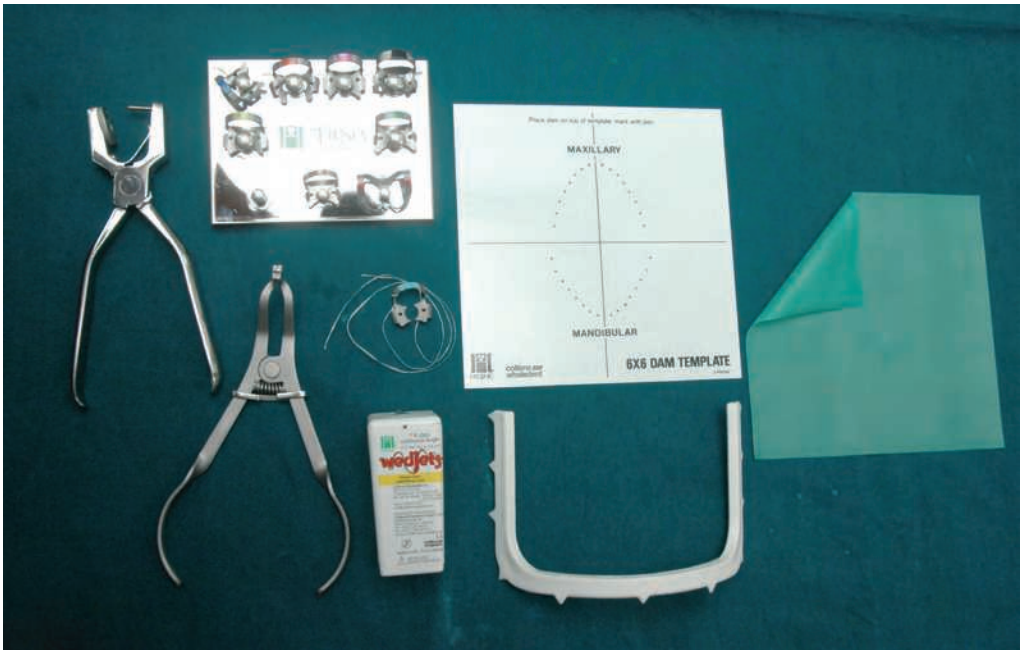
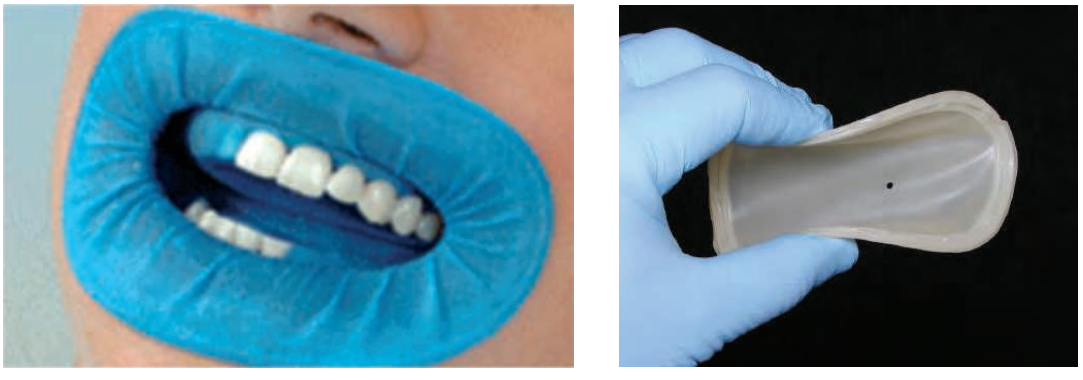


Figure 10.4 Rubber dam kit.



(a) (b)

Figure 10.5 (a) OptraDam and (b) Insti-Dam.

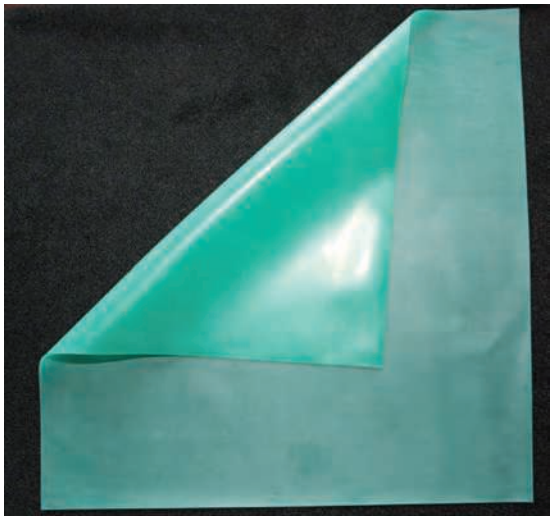


Figure 10.6 Rubber dam material.

- Readymade sheets are available in sizes 5 × 5 and 6 × 6 inches, and rolls according to need which may be conveniently cut into necessary size.
- The rubber dam material is usually a latex material. However, for patients with known allergy, nonlatex rubber dam material should be made available in the clinic.

B. Rubber Dam Clamps

- Different types of clamps are available according to the tooth to be isolated (**Fig. 10.7a**).
  - *Winged clamps:* Clamps with wings (**Fig. 10.7b**) lead to more rapidity of work and efficiency.
  - *Wingless clamps:* These clamps are used for the most posterior teeth in cases where placement of winged clamps is difficult or if the winged clamp is impinging on the cheek of the patient.
- *Plastic clamps* are also available from Moyco Union Broach in two sizes, large and small, basically to see that the radiographs are not overlapped by the shadow of metal clamps.
- Most anterior teeth may be clamped satisfactorily with an Ivory No. 9 clamp.
- When the tooth is small, as in the case of upper lateral incisors or lower anterior teeth, the Ivory No. 12 clamp or its equivalent may be used.



(a)



(b)



(c)(i)



(c)(ii)

Figure 10.7 (a) Parts of a clamp: (1) Bow, (2) (i) central wing and (ii) anterior wing, (3) jaws, (4) prongs, (5) notch, and (6) hole. (b) Winged and wingless clamps. (c) Commonly used rubber dam clamps: For anterior teeth, (i) HF 9 and (ii) HF 212; and for premolars and molars, *(continued)*



(c)(iii) (c)(iv) (d)

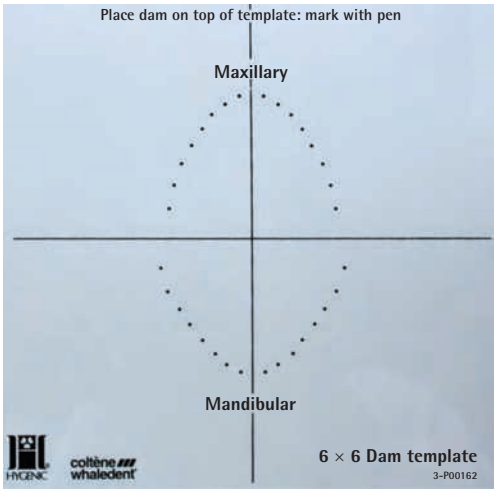


(e)



(f)

Figure 10.7 *(continued)* (iii) HF 1 and (iv) HF 14. (d) Rubber dam clamp forceps (*Courtesy: Hu-Friedy Mfg. Co., USA.*). (e) Rubber dam punch. (f) Different types of dam frame. *(continued)*



(g)



(h)

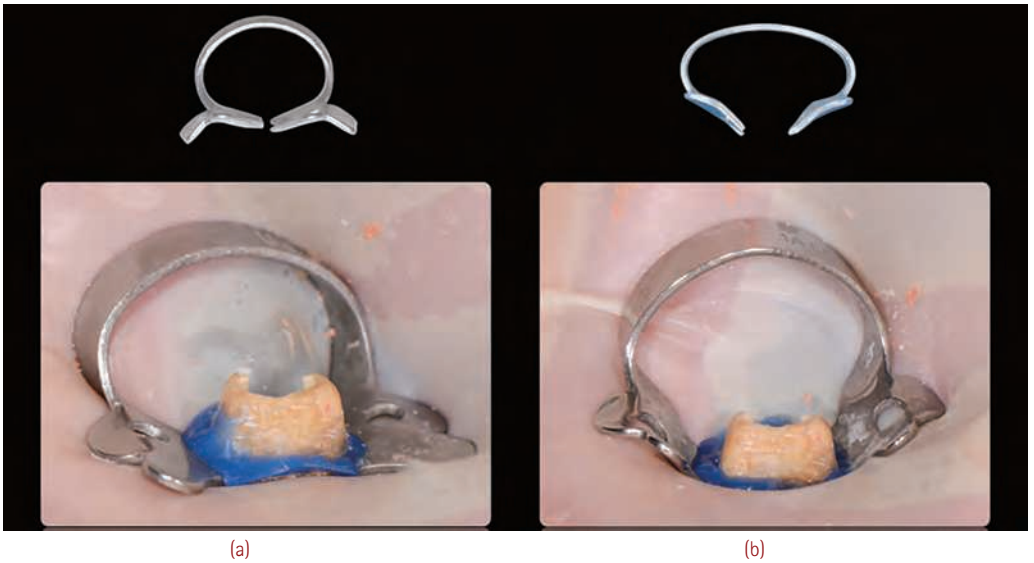
Figure 10.7 *(continued)* (g) Dam template. (h) Wedget cord.

- In posterior teeth, the HF or Ivory No. 27 clamp (wingless) may be used on all premolars and the HF No. 26 clamp or its equivalent on all molars.
- In tapering, young upper anterior teeth that have not completely erupted, an HF No. 27 (premolar) clamp can often be applied to advantage.
- Moreover, if a No. 27 clamp slips toward the cervical and pinches the gingiva when applied on a lower premolar, a No. 9 clamp may at times be substituted for it. When two adjacent anterior teeth are to be treated, one clamp may be applied to one tooth while the other is simply ligated, so that both teeth may be treated simultaneously. One may also use two No. 27 HF clamps, one facing mesially and the other distally.
- Three adjacent anterior teeth can be treated simultaneously by applying the Ivory No. 9 ON clamp over only one tooth and by tucking the rubber dam under the gingiva of the adjacent teeth. The handling of similar unusual clinical situations is left to the ingenuity of the operator.

Clinical Note

- In summary, only five clamps are needed for applying the rubber dam to most teeth:
  - For anterior teeth: HF 9 (**Fig. 10.7c[i]**)
  - For premolars: HF 1 and HF 2 (**Fig. 10.7a** and **10.7c[iii]**)
  - For molars: HF 7 and HF 14 A (**Fig. 10.7c[iv]**)

- The more tilted the jaws of the clamp, easier would be the possibility to find a stable clamp retention in molars; however, using a clamp with flat jaws, the tooth gets actually more exposed and is more accessible (**Fig. 10.8a**).



(a) (b)

Figure 10.8 (a) Using a clamp with flat jaws, the tooth gets actually more exposed and is more accessible. (b) Using clamps with strongly tilted jaws, the tooth is going to look more "sunk" into operative field and less accessible to the clinician. (*Courtesy: Filippo Cardinali, Italy*)

On the contrary, if isolation is performed using clamps with strongly tilted jaws, the tooth is going to look more "sunk" into the operative field and less "approachable" to the practitioner (**Fig. 10.8b**).

C. Rubber Dam Clamp Carrying Forceps

It is available from different companies such as Ash, Ivory, and Hu-Friedy (**Fig. 10.7d**). This is used to carry the rubber dam clamp on to the tooth.

D. Rubber Dam Punch

This is used to punch the rubber dam for application on specific tooth or teeth (**Fig. 10.7e**). The rubber dam punch has a moving table with holes of different diameters. The smallest one is for the lower anterior teeth and the largest is for the posterior teeth.

E. Rubber Dam Holder or Frame

The type of rubber dam holder (**Fig. 10.7f**) one uses is a matter of individual preference, but whichever one chooses, it should not interfere with the endodontic operation. The two commonly used frame designs are referred to as follows:

1. *Young's frame:* This is a metal frame.
2. *Nygaard-Ostby frame:* This is a plastic frame.

Both kinds of frames can be applied quickly and effectively. The plastic frames, contoured facially, have the additional advantage of being transparent and do not have to be removed when taking working radiographs of the tooth during treatment.

F. Rubber Dam Template

The rubber dam template is provided to the clinician to make an exact punch on the tooth in question for both upper and lower teeth (**Fig. 10.7g**). The holes in the rubber dam should be punched approximately over the center of the incisal or occlusal surface of the teeth to be engaged using a rubber dam template below the rubber dam sheet.

G. Wedget Cord

A wedget cord (**Fig. 10.7h**) is used to stabilize the interproximal area of the rubber dam. It is a flexible elastic material that can be passed over the dam interproximally below the contact area.

H. Dental Silk Floss

Silk floss is required for rubber dam application, especially for endodontic procedures or during in-office nonvital or vital bleaching. Two additional holes are provided by the manufacturer for securing the rubber dam clamp by passing silk floss and holding the free end of the floss outside the patient's mouth. This is a safety measure while removing the rubber dam clamp if it snaps.

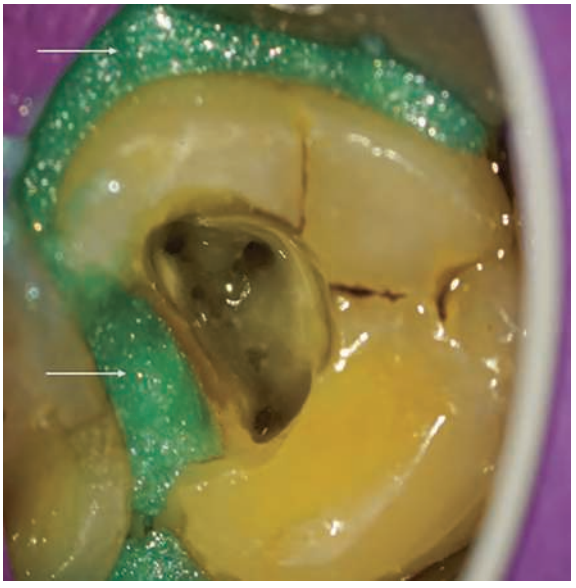


Figure 10.9 White arrows indicating placement of green colored rubber dam block out material to aid in proper isolation of areas that are not accessible by the rubber dam.

I. Rubber Dam Napkin

The rubber dam napkin is placed between the dam and the patient's skin in order to avoid any potential latex-related allergic reactions.

J. Flowable Block-Out Materials

Certain teeth requiring endodontic treatment may be badly broken down. Such complex conditions will not allow the normal rubber dam to completely isolate the tooth. In such cases, having a *syringeable light-cured block-out material* would ensure proper isolation, e.g., Kool-Dam (Pulpdent) and OpalDam (Ultradent) (**Fig. 10.9**).

TECHNIQUES OF RUBBER DAM APPLICATION

Application of rubber dam with high-power suction when used in conjunction with totally sterile instruments may take care of infection control to a greater extent. The following methods are used while applying rubber dam in different teeth in the oral cavity:

- Anterior tooth isolation using rubber dam (**Fig. 10.10a–10.10c**)
- Molar tooth isolation using rubber dam (**Fig. 10.11a–10.11f**)
- Isolation of multiple teeth—clamp first followed by dam (**Fig. 10.12a–10.12i**)
- OptraDam application (**Fig. 10.13a–10.13c**)

When a clamp is used on an anterior tooth (**Fig. 10.10a–10.10c**), the rubber dam should first be slipped over the tooth. One should stretch the dam over the tooth between the thumb and the index finger of the left hand, while the clamp is adjusted with the right hand. In posterior teeth, the clamp is preferably inserted half way into the previously

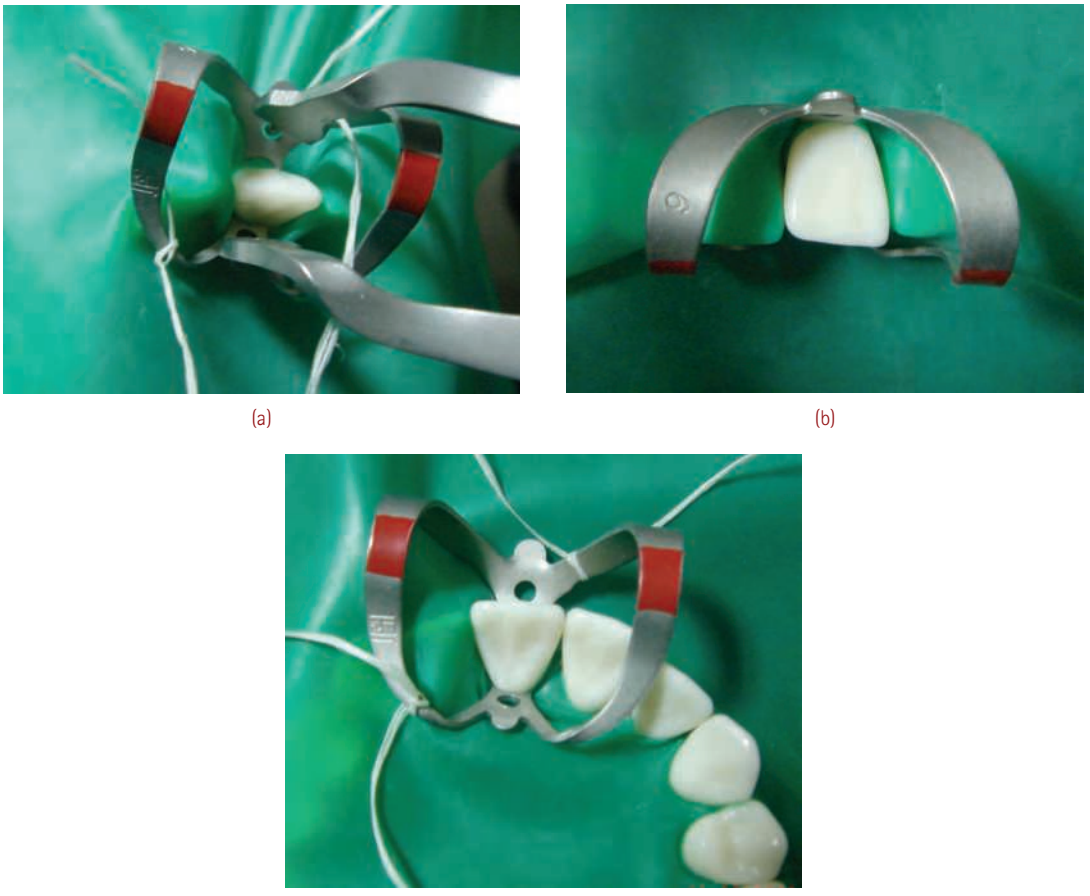


Figure 10.10 (a) The dam is stretched and placed over the incisor. This is followed by placement of the clamp. (b) The jaws of the clamp must rest on sound tooth structure. (c) Palatally, the jaws of the clamp engage the tooth gingival to the cingulum.

punched hole in the rubber dam, and the arms of the clamp are then spread apart with clamp forceps. The rubber dam is held in the left hand and is kept from obstructing the view, while the clamp is slipped over the tooth with the right hand. The forceps are then disengaged from the clamp, and the rubber dam is slipped under the anterior arms of the clamp. If a wing clamp is used, the wing of the clamp is inserted into the hole of the rubber dam, the clamp is applied to the tooth, the clamp forceps are removed, and the rubber dam is slipped under the arms of the clamp.

SPECIAL CONSIDERATIONS IN RUBBER DAM APPLICATION

Isolation Challenges in a Badly Broken Down Tooth

- In upper or lower anterior teeth, little is left of the crown as a result of caries (**Fig. 10.14**) or when the crown has been broken off by traumatic injury. In such cases, generally enough root surface is still exposed on which to attach a *cervical clamp* when the rubber dam has been pulled taut over the exposed crown or root surface. Although access to the pulp chamber may be obtained in such cases before applying the rubber dam, all other endodontic procedures should be done only after the rubber dam has been applied.
- In partially erupted anterior teeth, in which the rubber dam clamp may slip off or when one of the surfaces is completely broken away, a *narrow orthodontic band* may be fitted and cemented in place, over which the rubber dam can then be attached.

Canal projection technique

In badly broken down posterior teeth, it may be necessary to build up the crown of the tooth with a stainless steel band (**Fig. 10.15**) and to contour and cement the band in place before endodontic treatment is begun. An aluminum or stainless steel crown may be cemented instead of a band. A core of gutta-percha is first placed in the pulp chamber to

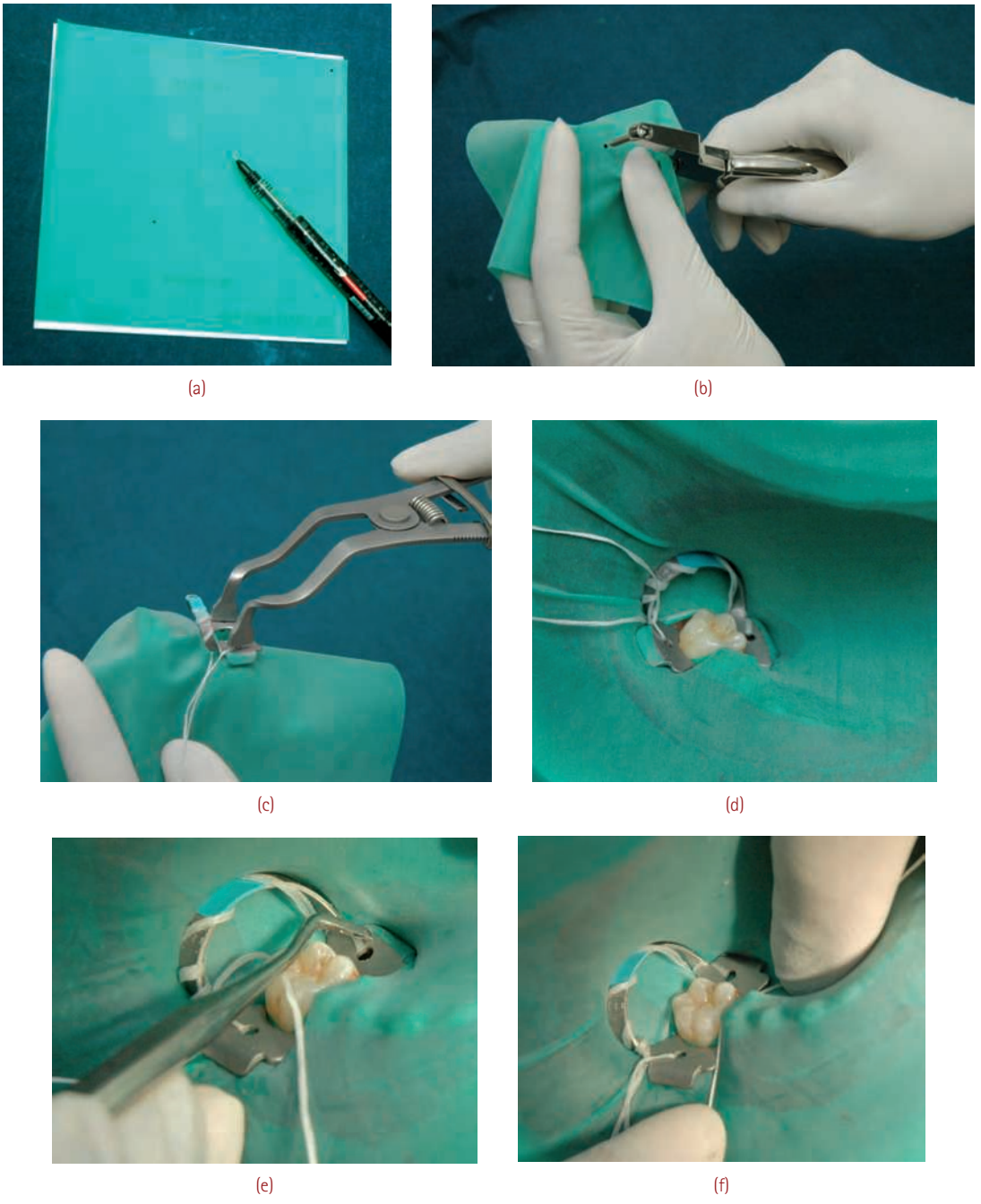


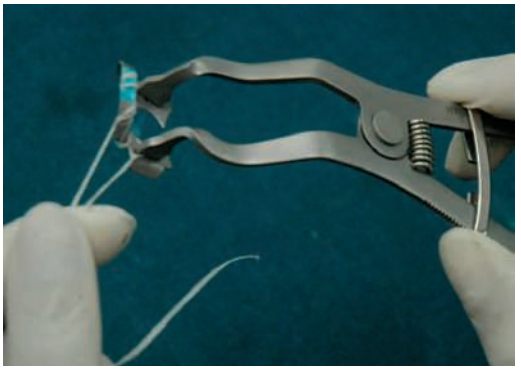
Figure 10.11 (a) The rubber dam sheet is placed on the rubber dam template and the tooth to be isolated is marked. Note that the dull side of the dam faces the operator. (b) Hole is punched using a rubber dam punch. (c) The wings of the clamp engage the dam through the punched hole. The entire assembly can be carried to the tooth to be isolated. (d) The dam is secured with the rubber dam frame. Note that the dam material is engaged on the wings of the clamp. (e) The dam is gently teased away from the wing of the clamp using a blunt hand instrument. (f) Dental floss is passed mesially and distally to ensure inversion of the dam for isolation.

keep cement out of the root canals. The band is cemented with glass ionomer cement, and the excess cement and core of gutta-percha, lying within the approach to the root canal, are then removed. The band should remain in place until the endodontic operation is completed.

- In some cases where the crown is badly broken down, *gingivectomy* (**Fig. 10.16a–10.16c**) may be necessary before a rubber dam clamp can be applied. In other cases, it may also be necessary to cement a band after a gingivectomy has been done to ensure against leakage of the medicament.



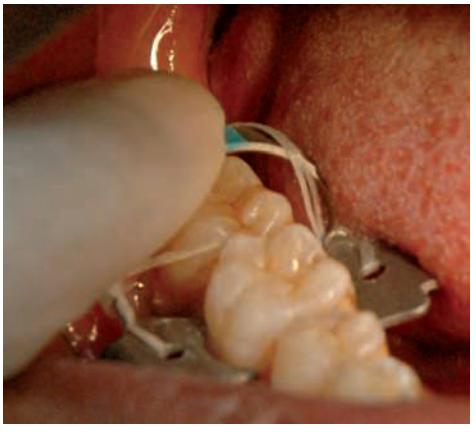
(a)



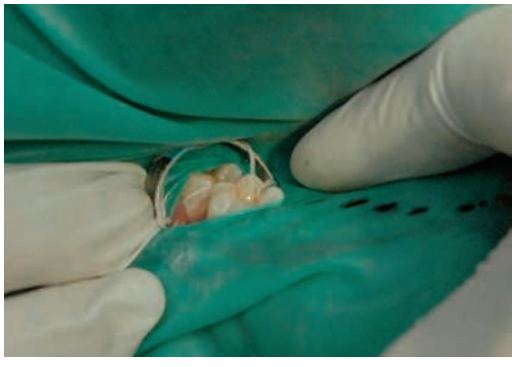
(b)



(c)



(d)



(e)



(f)



(g)

Figure 10.12 (a) Testing and lubricating the proximal contact. (b) The clamp is engaged with the clamp forceps and the forceps is secured with the lock. (c) The clamp is transferred to the tooth. The jaws of the clamp engage the tooth gingival to the height of contour along the four axial line angles of the tooth. (d) The stability of the dam is checked with the index finger on the bow of the clamp. The clamp should not rock. (e) The dam is first passed over the bow of the clamp. (f) The dam is stretched over the teeth and passed below the contact area with the help of dental floss. (g) After securing the dam on the anterior anchor, the dam is carefully passed around the clamp. *(continued)*

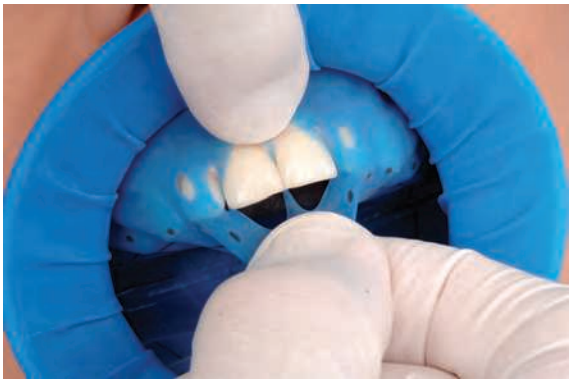


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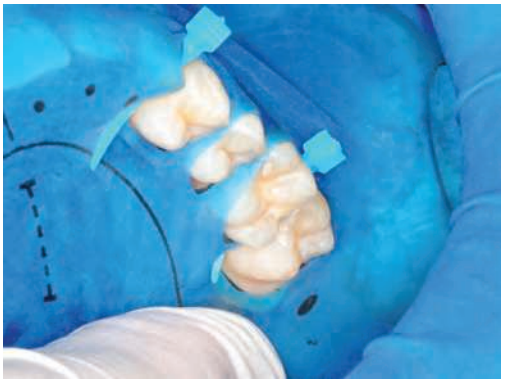


(i)

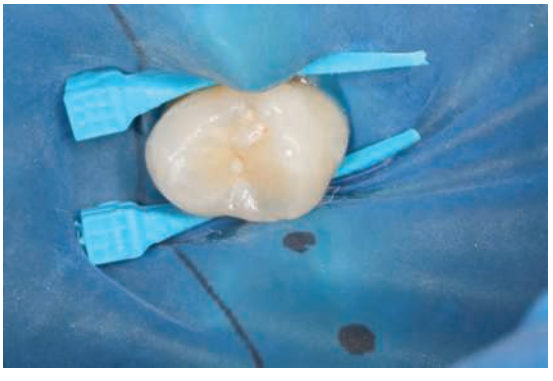
Figure 10.12 *(continued)* (h) The dam is secured by the clamp posteriorly and by wedgets anteriorly. (i) While removing the dam, the clamp is first removed and the dam is cut at the interdental septal region for easy removal.



(a)



(b)



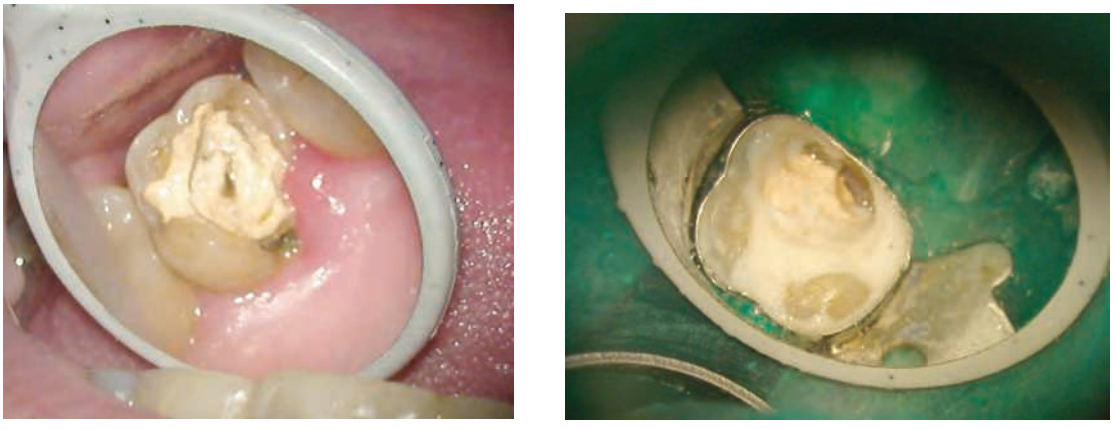
(c)

Figure 10.13 (a) OptraDam is being overstretched over the teeth that are supposed to be isolated. (b) In order to isolate posterior teeth, two wedges are being placed at the beginning and at the end of the area that is supposed to be isolated. Then, OptraDam is being overexpanded over the teeth going from mesial to distal (double-wedge technique). (c) Single tooth isolation using two wedges.



(a) (b)

Figure 10.14 Isolation of a badly broken down anterior tooth with cervical clamp. (*Courtesy: Venkat Canakapalli, New Zealand.*)



(a) (b)

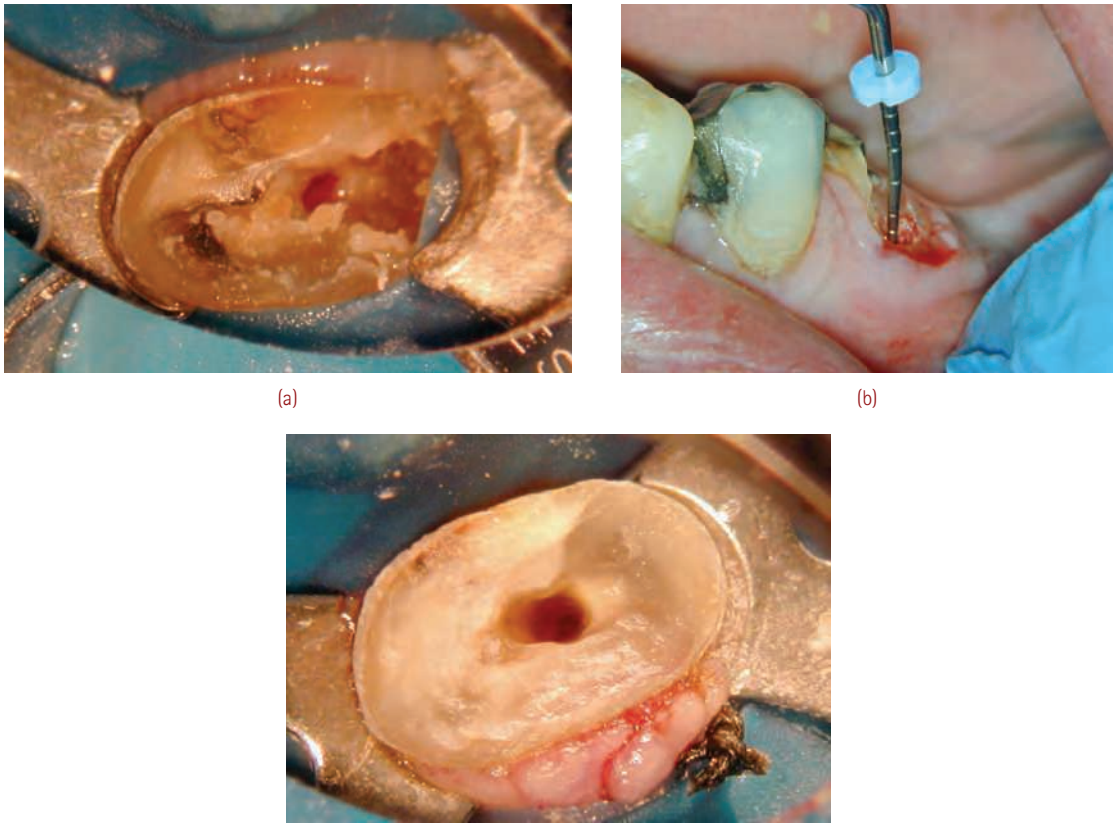
Figure 10.15 Isolation of badly broken down teeth using stainless steel band. (*Courtesy: Venkat Canakapalli, New Zealand.*)

Isolation Challenges in Prosthodontically Prepared Tooth

- The coronal tooth structure would have lost its normal anatomical contour in a prosthodontically prepared tooth or in a tooth after disassembly of a crown or a bridge. It would be difficult to enable the clamp to have four-point prong contact. In such cases, the clamp would not be retentive. Such cases can be managed by following one of the following clinical recommendations:
  - Placing the prongs of the clamp on cementum of the root (**Fig. 10.17a** and **10.17b**)
  - *Bonded composite button technique:* Direct composite buttons can be bonded onto the cervical aspect of the buccal/labial and/or lingual/palatal crown surfaces to act as an undercut for providing retention for the prongs of the clamp (**Fig. 10.17c** and **10.17d**).

Multiple Tooth Isolation Requirements

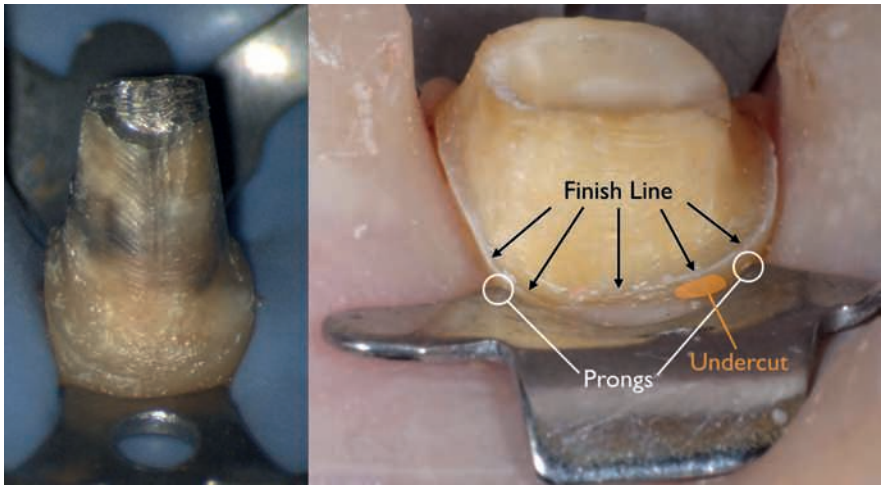
- When a *proximal carious cavity* is present in an involved posterior tooth, the adjacent tooth must also be isolated under the rubber dam (**Fig. 10.18**). If the cavity is mesio-occlusal, the involved tooth may be clamped and the tooth immediately anterior to it may be ligated. If the cavity is disto-occlusal, the tooth distal to the involved tooth may be clamped and the involved tooth may be ligated. In some posterior teeth, it may be necessary to ligate the clamped tooth as well, to bring the distal fold of rubber dam down into the interproximal space and thereby to prevent leakage around the clamp.
- When one of the *abutments of a fixed bridge* (**Fig. 10.19a–10.19d**) is to be treated, it is recommended to make two punch cuts on the rubber dam sheet and connect the two holes by cutting the sheet between the holes with the help of scissors. This technique is known as "*split dam technique*."



(a) (b)

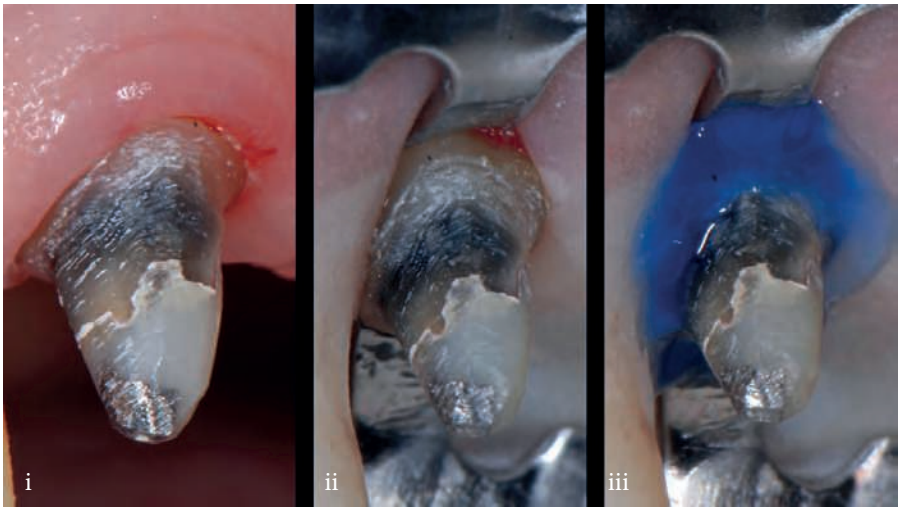
(c)

Figure 10.16 (a) Gross destruction and subgingival caries resulting in leaking margins around the clamp. (b) Gingival probing revealed adequate depth for gingivectomy. (c) Complete isolation after performing gingivectomy. (*Courtesy: Venkat Canakapalli, New Zealand.*)

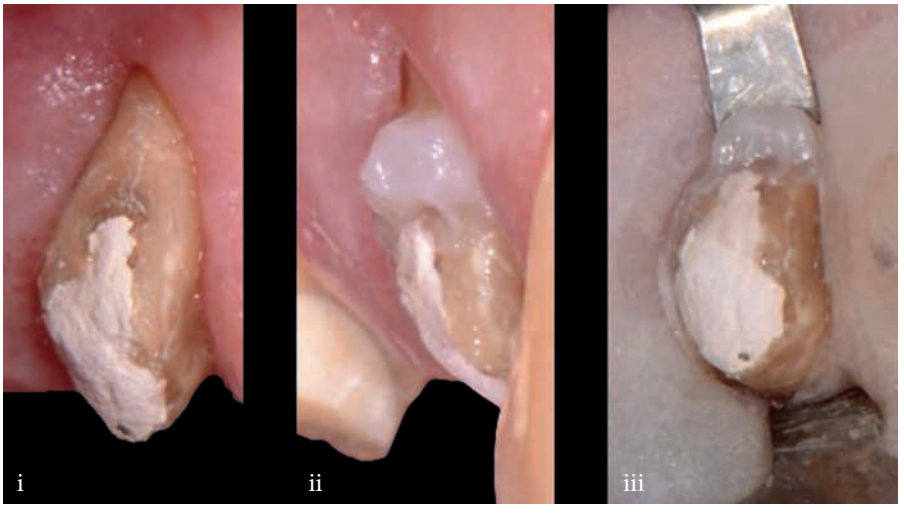


(a)

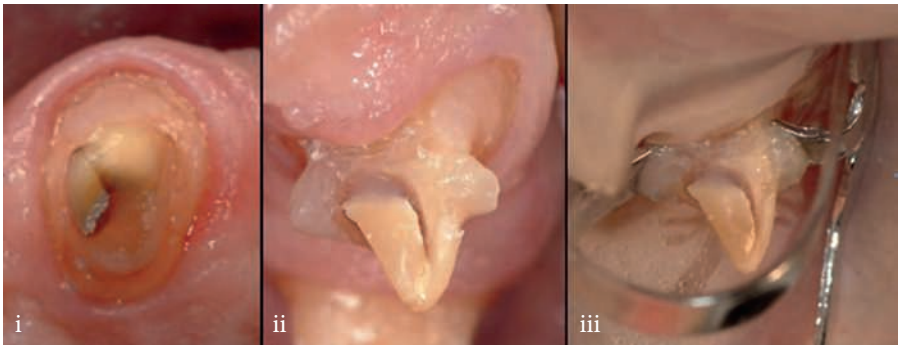
Figure 10.17 (a) To get a proper isolation, the clamp has to grab with the four prongs the tooth apical to the finish line. This is generally located as an undercut given by the physiologic shape of the root. *(continued)*



(b)



(c)

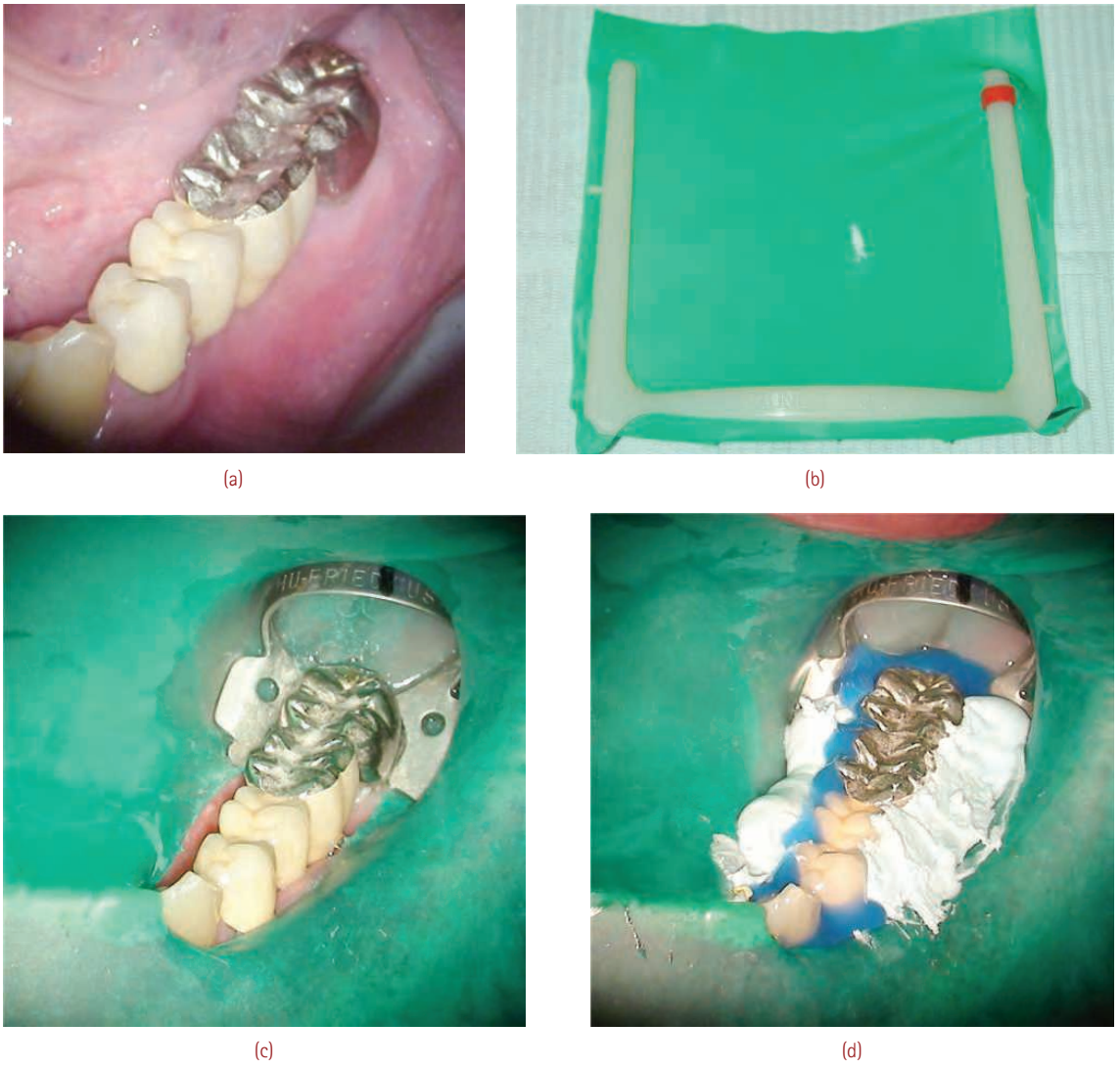


(d)

Figure 10.17 *(continued)* (b) To grab the tooth with the four prongs, the clamp during its application moves the gingival margin in apical direction (i and ii). After the application of the sheet, it is possible to easily get a proper leakage control with the help of a light-cured flowable block-out material (iii). (c) If it is not possible to find a stable clamp position due to the presence of a knife-edged preparation (i), it is possible to create an artificial undercut with a *"bonded composite button"* in the buccal surface (ii) in order to create a retention for the clamp (iii). (d) If the buccopalatal width of a tooth is so wide that the clamp cannot be positioned apical to the prosthetic preparation end line (i), then bonded composite buttons can be created on the buccal and palatal walls to aid in clamp retention (ii and iii). (*Courtesy: Filippo Cardinali, Italy.*)



Figure 10.18 For teeth with proximal cavities, the adjacent tooth is also isolated.



(a) (b)

(c) (d)

Figure 10.19 (a) Isolation of abutment teeth in fixed dental prosthesis using split dam technique. (b) Two punch holes are made on the dam and then split using scissors to create a horizontal slit on the dam. (c) The dam is then secured on the posterior tooth using a clamp and stretched to the anterior tooth. (d) Margins around the prosthesis are sealed using resin dam and OraSeal. (*Courtesy: Venkat Canakapalli, New Zealand.*)

STERILIZATION OF INSTRUMENTS

With the whole world looking at eradication of existing infectious diseases and preventing any new infections, sterilization of instruments is significant to ensure optimal patient care. In contemporary endodontic practice, instruments directly come into contact with tissues, blood and tissue fluids, saliva, and gingival crevicular fluid which may seep through the rubber dam if not properly placed.

To maintain the cycle of asepsis, processing and sterilization of reusable instruments become mandatory in all specialties of dentistry. Each patient deserves a new set of sterile packed instruments which includes the entire endodontic tray setup. In order to achieve this, surgical instruments and other similar items require appropriate reprocessing between patients. This should take the form of a clearly defined process of decontamination.

Clinical Note

- The universal norm is that if you can sterilize an instrument, sterilize it; otherwise, dispose it off.
- All endodontic instruments which are reusable have to be autoclaved.

DECONTAMINATION CYCLE

Decontamination is a combination of processes, including cleaning, disinfection, and/or sterilization, used to make reusable surgical instruments safe for further use.

The effective decontamination of reusable medical devices is essential in reducing the risk of transmission of infectious agents.

Figure 10.20 identifies all elements of the decontamination cycle.

- *Cleaning:* Cleaning can be achieved by either manual or mechanical means. The mechanical method is considered preferable as it is more effective than manual cleaning and can be validated. Not only does it provide higher standards of cleanliness, but it also reduces the risk of infection of the staff involved. Whichever method is chosen, effective cleaning is vital to the overall efficiency of the disinfection and sterilization stages of the decontamination process. If an item is not clean, it cannot achieve sterility when autoclaved. "Washer disinfectors are more efficient at presterilization cleaning than ultrasonic cleaners. Hand cleaning must not be used as a substitute for sterilization procedures."
- *Disinfection:* Disinfection is a process which uses chemical substances and/or heat to reduce the number of microorganisms present, but may not inactivate some viruses and bacterial spores. Again, mechanical disinfection is preferable as it is consistent and reduces the risk of injury from contact with hazardous chemicals used in manual disinfection. Disinfection should not be used as a substitute for sterilization.
- *Inspection:* Inspection should be performed before sterilization in order to ensure that appropriate safety levels are being maintained. The instruments should be examined to ensure that they are clean with no sign of debris remaining and there is no evidence of damage. Substandard instruments should be removed from the cycle immediately. If dirty, they should be recleaned. If damaged, they should be sterilized before repair work is carried out. Alternatively, they should be destroyed if repair is not an option.
- *Packaging:* Packaging is required for items which are to be stored for later use. Packed items should be processed only in a vacuum autoclave.
- *Sterilization:* Sterilization is a process to render an object free from viable microorganisms, including bacterial spores and viruses. Sterility can be theoretically described as "not more than 1 living microorganism present in 1 million sterilized units of the final product." Items are required to attain this standard in order to achieve the term "sterile." Sterilization of instruments can be achieved in a number of ways, including hot air, gas, irradiation, and steam. Some of these methods are not suited to hospitals or clinics as they can be both lengthy and hazardous processes requiring specialized handling and equipment. In contrast, steam sterilization (autoclaving) is both quick and effective, offering a simple yet reliable method (**Fig. 10.21a–10.21c**; **Table 10.1**).

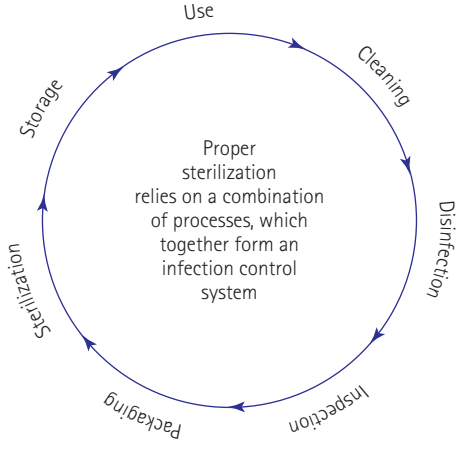


Figure 10.20 Decontamination cycle.

Table 10.1 Steam Sterilization (Autoclave): Temperature and Pressure Settings

Items	Pressure (pounds)	Temperature (°C)	Time (minutes)
Blunt instruments dressing, glass, silicon materials, linen vessels	20	121	30
Rubber items	20	121	20
Liquids	20	110	30



(a) (b)

(c)

Figure 10.21 (a) Benchtop autoclave. (b) Cleaned instruments packaged and loaded in trays for sterilization. (c) Sterilized instruments ready for storage.

The four accepted methods of sterilization are as follows:

- Steam pressure sterilization (autoclave)
- Chemical vapor pressure sterilization (chemiclave)
- Dry heat sterilization (dryclave)
- Ethylene oxide (ETOX) sterilization

A comparison of the various techniques of sterilization is given in **Table 10.2**.

Steam sterilization is the most practicable method for sterilizing reusable medical devices in healthcare premises because it has high lethality, it is rapid, and it is nontoxic.

- *Storage:* The storage of instruments should be suited to their subsequent use (*see* the subsequent text, Use—levels of risk). In all cases, storage areas should be clean and dust free.
- *Use—levels of risk:* Whether an instrument needs to be sterile at the point of use depends on the procedure to be carried out and the associated risk of infection to the patient. Methods of processing and storage are also affected by the level of risk associated with the procedure to be performed (i.e., if the instrument is required to be sterile at the point of use). Risk levels are categorized as low, medium, or high.
  - *Low-risk procedures* are those in which items come into contact only with intact skin, such as stethoscopes, skin thermometers, and blood pressure cuffs. It is not necessary to sterilize these items but they should be cleaned in accordance with manufacturers' instructions.
  - *Medium-risk procedures* are those in which instruments come into contact with intact mucous membrane or

Table 10.2 Techniques of Sterilization

Features	Steam Pressure Sterilization	Chemiclaving	Dry Heat Sterilization	Ethylene Oxide Sterilization (ETOX)
Technique	121–134°C at 15–30 pounds for 15 minutes	Chemical vapor under pressure at 131°C at 30 pounds	Dry heat exceeding 160°C for 60–90 minutes	Operates at temperatures below 100°C
Clinical recommendations	It is the most effective method for sterilizing most endodontic instruments	Carbon steel and corrosion-sensitive instruments can be sterilized without rusting	Currently replaced by more effective alternative techniques of sterilization	Best way to sterilize rotary handpieces

body fluids, such as gingiva and teeth. These instruments must be cleaned and sterilized after use, but do not need to be sterile at the point of use. They can therefore be stored after autoclaving in a clean environment. Examples of such instruments include mouth mirrors and probes used for routine examination.

– *High-risk procedures* are those in which instruments come into contact with breaches in the skin or mucous membrane or when they enter a sterile body cavity, such as endodontic microsurgical procedures. In this instance, the instruments must be sterile at the point of use, either being used immediately after autoclaving or taken from sterile storage.

The clinician should also be aware of the currently recommended sterilization protocols (**Table 10.3**).

STERILIZATION RECOMMENDATIONS

- It is preferable to protect the points of instruments with cotton in order to prevent bag perforation.
- Sterilize instruments with hinges in an open position.
- Never overfill a sterilizer.
- In a desktop autoclave, place the bags and trays vertically and not horizontally.
- Allow the drying cycle to finish completely.
- All instruments that have been sterilized should be bagged prior to storage.

Table 10.3 Recommended Sterilization Protocols

Process	Result	Method	Examples	Healthcare Application	
				Type of Patient Care Item	Environmental Surface
Sterilization	Destroys all microorganisms including bacteria and spores	Heat automated • High temperature • Low temperature Liquid immersion	Steam, dry heat, unsaturated chemical vapor Ethylene oxide gas, plasma sterilization Chemical sterilants, glutaraldehyde, glutaraldehyde with phenol, hydrogen peroxide, hydrogen peroxide with peracetic acid, peracetic acid	Heat-tolerant critical and semicritical Heat-sensitive critical and semicritical Heat-sensitive critical and semicritical	Not applicable
High-level disinfection	Destroys all microorganisms, but not necessarily high numbers of bacterial spores	Heat automated Liquid immersion	Washer-disinfector Chemical sterilants/high-level disinfectants. Glutaraldehyde, glutaraldehyde with phenol, hydrogen peroxide, hydrogen peroxide with peracetic acid, *ortho*-phthalaldehyde	Heat-sensitive semicritical	Not applicable
Intermediate-level disinfection	Destroys vegetative bacteria and the majority of fungi and viruses. Inactivates *Mycobacterium bovis*. Not necessarily capable of killing bacterial spores	Liquid contact	U.S. Environmental Protection Agency (EPA)–registered hospital disinfectant with label claim of tuberculocidal activity (e.g., chlorine-containing products, quaternary ammonium compounds with alcohol, phenolics, iodophors, EPA-registered chlorine-based products)	Noncritical with visible blood	Clinical contact surfaces; blood spills on housekeeping surfaces
Low-level disinfection	Destroys the majority of vegetative bacteria, certain fungi, and viruses. Does not inactivate *M. bovis*	Liquid contact	EPA-registered hospital disinfectant with no label claim regarding tuberculocidal activity. The Occupational Safety and Health Administration also requires label claims of human immunodeficiency virus (HIV) and hepatitis B virus (HBV) potency for clinical contact surfaces (e.g., quaternary ammonium compounds, some phenolics, some iodophors)	Noncritical without visible blood	Clinical contact surfaces; housekeeping surfaces

- Instruments that have been bagged are considered sterilized for 4 months if the bag is intact.
- Store sterilized instruments in a dry and low-traffic area.

COLD STERILIZATION

Sterilization by cold chemical solution is *not recommended* for three reasons:

1. The process is not effective against all varieties of microbial life.
2. The length of time necessary to destroy microorganisms against which these solutions are effective, namely, a minimum of 20 minutes, is too long.
3. Cold sterilization can be incorporated into the dental sterilization protocol as a *method for chair-side disinfection of noncritical instruments and chair-side accessories* and cannot replace the role of steam sterilization.
   a. Quaternary ammonium compounds are effective against vegetative organisms.
   b. Ethyl alcohol and isopropyl alcohol are effective against vegetative bacteria and tubercle bacilli.
   c. Alcohol–formalin solutions are effective against vegetative bacteria, tubercle bacilli, and spores.
   d. *Ortho*-Phenylphenol and benzyl-*para*-chlorophenol are effective against vegetative bacteria, tubercle bacilli, certain fungi, and viruses, but not spores.
   e. The cold-sterilizing solution (Sporicidin) consisting of phenol (7.05%), sodium tetraborate (2.35%), glutaraldehyde (2.0%), and sodium phenate (1.2%) claims that the solution disinfects cleaned instruments in 10 minutes at room temperature, kills aerobic spore formers including *Bacillus subtilis* in 3 hours, and achieves sterilization in 6–7 hours.

Clinical Note

Glass bead (hot salt) sterilizers used to consist of either hot salt or glass beads as a medium for dry heat sterilization. The temperature range employed was between 425°F (218°C) and 475°F (246°C). However, these *glass bead/hot salt sterilizers are no longer recommended for clinical use*.

BIOLOGICAL MONITORING

Biological monitoring evaluates the ability of the sterilization process to operate effectively regardless of the equipment, medical device sterilized, and sterilizing agent used. This involves the use of a device impregnated with a known number and type of microorganism and is used to verify that all the conditions necessary for sterilization have been met. The use of biological indicator, however, does not guarantee sterility, but rather provides an additional mechanism for monitoring the sterilization cycle beyond the graphic temperature–pressure recording and the physical–chemical indicators.

Spore strip biological indicators are the only process indicators that directly measure sterilization. However, the disadvantage could be delay in getting result due to the laboratory process. Monthly sterilization monitoring for all sterilizers is necessary. These spore strips used for testing the efficacy of sterilizers need to be mailed out to a monitoring service.

Clinical Note

The clinician should remember that the success of the endodontic procedure not only lies in the eradication of the pathologic process but also lies equally in the *isolation of the operating field* and the *optimal sterilization* of the instruments employed.

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11 Vital Pulp Therapy and Apexification

Never must the physician say the disease is incurable. By that admission he denies God, our Creator; he doubts Nature with her profuseness of hidden powers and mysteries.
—Paracelsus

The unaffected, exposed vital pulp possesses an inherent capacity for healing through cell reorganization and bridge formation when a proper biological seal is provided and maintained against microbial leakage. Throughout the life of a tooth, vital pulp tissue contributes to the production of secondary dentin, peritubular dentin, and reparative dentin in response to biological and pathological stimuli. The pulp tissue with its circulation extending into the tubular dentin keeps the dentin moist, which in turn ensures that the dentin maintains its resilience and toughness (**Fig. 11.1**).

HISTORICAL PERSPECTIVE

The earliest account of vital pulp therapy was in 1756, when Phillip Pfaff packed a small piece of gold over an exposed vital pulp to promote healing. By 1922, in the light of his experiences with similar antiseptic treatments, Rebel summarized his thoughts in the expression, *"the exposed pulp is a doomed organ."* He concluded that recovery of the vital unaffected pulp when exposed to the oral environment was invariably doomed and that one must consider it as a lost organ.

Despite Rebel's much-quoted statements, the realization gradually evolved that the dental pulp did at times possess definite powers of recuperation and repair. Major advances in the practice of vital pulp therapy have been made and the emphasis has shifted from the "doomed organ" concept of an exposed pulp to one of *"predictable repair and recovery."*

Clinical Note

The Pulp as an organ in children and young adults is very well perfused and has a tremendous ability for repair and healing.

MATERIALS USED FOR VITAL PULP THERAPY

Cohen and Combe have given the requirements of an ideal pulp capping agent (**Fig. 11.2**):

- It should maintain pulp vitality.
- It should stimulate reparative dentin formation.
- It should be either bactericidal or bacteriostatic in nature and should be able to provide bacterial seal.

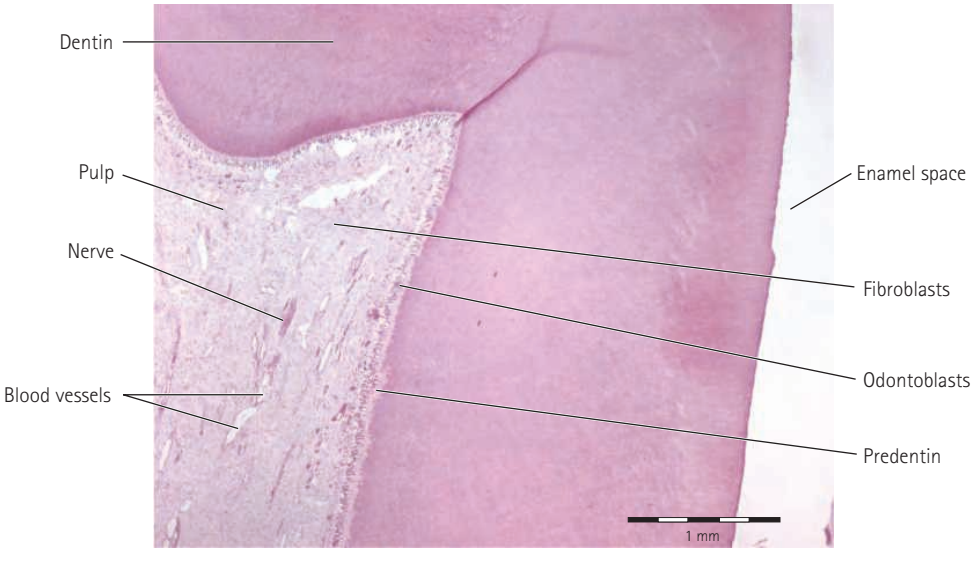


Figure 11.1 Longitudinal section of a demineralized tooth showing dentin, predentin, and pulp. Stain: H+E. (*Courtesy: Mathias Nordvi, University of Oslo, Norway.*)

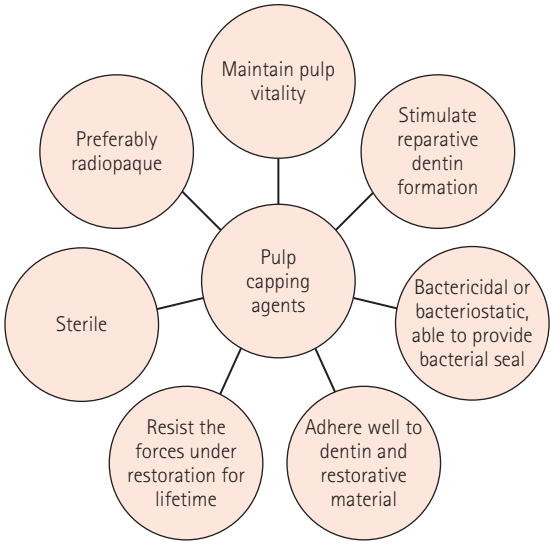


Figure 11.2 Ideal properties of a pulp capping agent.

- It should adhere well to both the dentin and the overlying restorative material.
- It should be able to resist the forces under the restoration during the lifetime of the restoration.
- It should be sterile.
- It should be preferably radiopaque.

Many materials have been employed as potential pulp capping agents. These include calcium hydroxide, mineral trioxide aggregate (MTA), zinc oxide eugenol, tricalcium phosphate, tetracalcium phosphate, calcitonin, calcium hydroxide, direct bonding agents, growth factors, resin-modified glass ionomer cement (RMGIC), intermediate restorative material (IRM), and dentin shavings.

However, the three materials that are currently recommended on the basis of in vitro and clinical research (**Table 11.1**) are as follows:

(1) Calcium hydroxide
(2) MTA (mineral trioxide aggregate)
(3) Calcium silicate-based cements (CSCs)

Table 11.1 Comparative Analysis of Properties of Commonly Recommended Materials Used in Vital Pulp Therapy

Properties	Calcium hydroxide $Ca(OH)_2$	Mineral trioxide aggregate (MTA)	Calcium silicate-based cements (CSCs)
Advantages	• Antibacterial • Resist penetration of bacteria	• Excellent bacteria tight seal • Good pulp capping agent • Can be used as base for final restoration • Microbial entombment and neutralization • Strong capacity to generate reparative calcific barrier • Biocompatible • Antibacterial [resist the penetration of bacteria than $Ca(OH)_2$] • Promoting repair and maintaining prolonged pulp vitality • Ability to harden in the presence of blood and moisture (hygroscopic) • Superior marginal adaptation and non-resorbable • Used for direct pulp capping and pulpotomy procedures • Biocompatible with pulpal and periodontal tissues	• Bioinductive capacities • Shortest setting time of 10 mins • Used for both direct and indirect pulp capping procedures • Sealing property similar to MTA • Excellent cytocompatibility • Used for perforations, apexification, root-end fillings, pulp capping and bulk fill cavity • Does not stain teeth • Excellent radio-opacity • Micro-mechanical anchorage • Has higher compressive strength which preserves pulp and promotes healing • Microleakage resistant
Disadvantages	• Pulp cell apoptosis • Poor marginal adaptation to dentin • Inconsistent stimulation of reparative hard tissue formation • Ineffective in providing long-term seal against microleakage when used as a pulp capping agent • Causes pulpal irritation, pulpal calcification and potential canal obliteration • 3–4 hours of setting time	• Long duration to set (6 hours) • Relatively expensive • Gray MTA causing discoloration	• Relatively expensive
pH	• High pH of 12.5 (causing liquefaction necrosis)	• high pH similar to $Ca(OH)_2$ • pH 12.5	Initial pH of 11 and final pH of >12
Examples	Pulpdent, Dycal	Pro Root MTA (Gray), White MTA	Biodentine, BioAggregate, CEM (Calcium enrich mixture)

I. CALCIUM HYDROXIDE

In 1920, a new era in the treatment of exposed pulp began when Hermann introduced a calcium hydroxide mixture that induced bridging of the exposed pulp with reparative dentin. Calcium hydroxide serves as a protective barrier for pulpal tissues, not only by blocking patent dentinal tubules but also by neutralizing the attack of inorganic acids and their leached products from certain cements and filling materials. The examples of calcium hydroxide products that have been widely used are *Pulpdent* paste (**Fig. 11.3**) and *Dycal* (*see* **Fig. 11.11a**).

Mechanism of Action

Calcium hydroxide has the unique potential to induce mineralization even in tissues that have not been programmed to mineralize. Sciaky and Pisanti in 1960 observed that calcium ions present in the applied calcium hydroxide do not become incorporated in the mineralized repaired tissue, which derives its mineral content solely from the dental pulp, presumably via blood supply. Forman observed that *calcium hydroxide is an initiator rather than a substrate for repair.*

Hard-setting calcium hydroxide preparations are recommended, as these cements release fewer hydroxyl ions than pure calcium hydroxide and are gentler to the pulp. Some failures may result from faulty techniques when extrapulpal blood clots are left between the calcium hydroxide and the cut tissue. In these cases, the hydroxyl ions would be trapped in the clot and the requisite induction of odontoblast differentiation does not occur. The mechanism of calcium hydroxide–induced mineralization is illustrated in **Figure 11.4**.

Healing With $Ca(OH)_2$ Products of High pH (Fig. 11.5)

Zone of Obliteration

The pulp tissue immediately in contact with calcium hydroxide is usually completely deranged and distorted because of the caustic effect of the drug. This zone consists of debris, dentinal fragments, hemorrhage, blood clot, blood pigment, and particles of calcium hydroxide. This zone of obliteration is due to the chemical injury as a result of high concentration of hydroxyl ions and due to the high pressure of the medicament application.



Figure 11.3 Pulpdent paste.

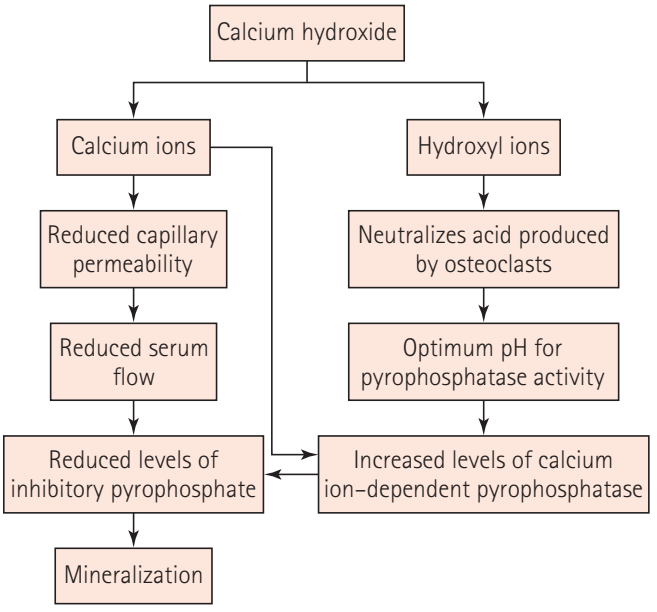


Figure 11.4 Mechanism of action of calcium hydroxide.

Zone of Coagulation Necrosis

The tissue together with its plasma proteins within the zone of obliteration takes the brunt of the calcium hydroxide chemical thrust. A weaker chemical effect reaches the subjacent, more apical tissues and results in a zone of coagulation necrosis and thrombosis, also called Schroder's layer of "firm necrosis" and Stanley's "mummified zone."

Zone of Dentin Bridge Formation

This is an area of mineralization initiated by calcium hydroxide. The difference between this zone of mineralization and the formation of natural secondary dentin is that there is no distinct structural configuration present in calcium hydroxide–initiated mineralization. This zone could range from 0.3 mm to 0.7 mm thickness.

Line of Demarcation

A line of demarcation develops between the deepest level and the subjacent vital pulp tissue. Glass and Zander believed that this line resulted from the reaction of the calcium hydroxide with the tissue protein to form proteinate globules.

II. MINERAL TRIOXIDE AGGREGATE (MTA)

In 1993, Mohammad Torabinejad centered his research in the development of MTA at the Loma Linda University, California.

Composition

MTA is primarily composed of:

- Tricalcium silicate
- Dicalcium silicate
- Tricalcium aluminate

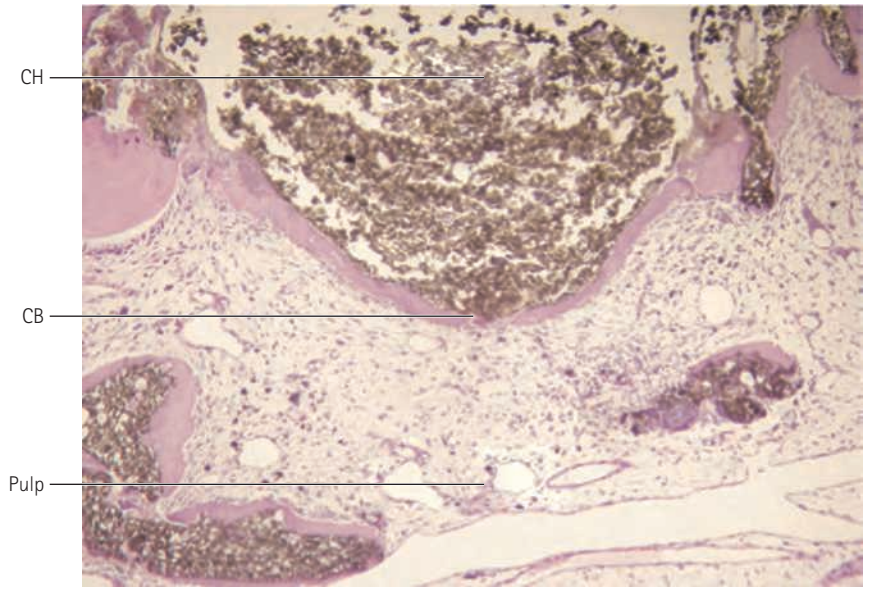


Figure 11.5 Histological reaction of a direct pulp capping procedure with calcium hydroxide (Dycal) (CH). Formation of a thin calcified bridge (CB) at pulp–Dycal interface (33100). (*Courtesy: Saeed Asgary, Iran.*)

- Tetracalcium aluminoferrite (present only in Gray MTA)
- Bismuth oxide (added to the cement as a radiopacifier)

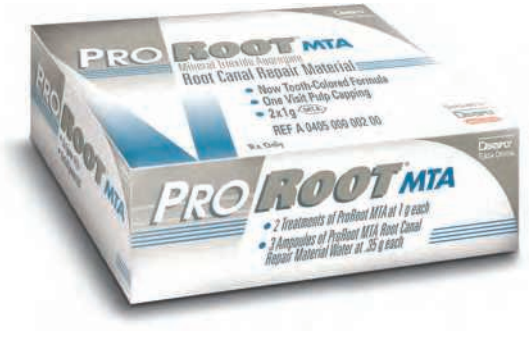
MTA may also contain:

- Traces of free crystalline silica
- Trace constituents such as calcium oxide, free magnesium oxide, potassium, and sodium sul-fate compounds

Commercial MTA exists in both *gray* (**Fig. 11.6a**) and *white* forms (**Fig. 11.6b**). MTA not only appears to demonstrate acceptable biocompatible behavior but also exhibits acceptable in vivo biological performance when used for root-end fillings, perforation repair, pulp capping, pulpotomy, and apexification treatment.



(a)



(b)

Figure 11.6 (a) Gray MTA. (b) White MTA. *(Courtesy: Dentsply Tulsa.)*

Setting Reaction

The setting reaction of MTA is illustrated in **Box 11.1**.

Advantages

MTA can be used as an alternative to calcium hydroxide in both direct pulp capping and pulpotomy procedures because of the following advantages:

- Produces more dentinal bridging with superior structural integrity than $Ca(OH)_2$ in a shorter time span with significantly lesser inflammation (**Fig. 11.7**)

Box 11.1

The Setting Reaction of MTA

MTA powder (tricalcium silicate, dicalcium silicate, tricalcium aluminate)

↓

Hydration (in the presence of water or blood)

↓

Calcium silicate hydrogel	$Ca(OH)_2$
↓ (3–4 hours)	↓ (3–4 hours)
Porous gel solidifies to a hard crystalline structure	Increase in pH to 12.5

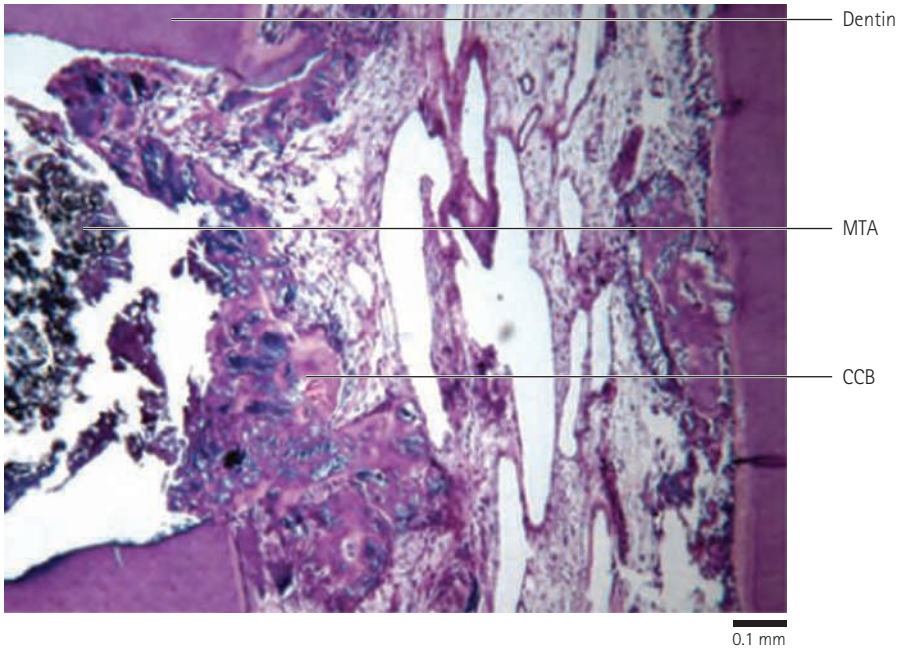


Figure 11.7 Complete calcified bridge (CCB) formations after 2 weeks in White MTA.

- Has a superior ability to resist the future penetration of bacteria than $Ca(OH)_2$
- Has significant antimicrobial property on some of the facultative bacteria
- Highly biocompatible with pulpal and periodontal tissues
- Hydrophilic—sets hard in the presence of water
- Set MTA is alkaline (pH of 12.5) and may induce dentinogenesis
- The presence of blood has little impact on the degree of leakage of MTA

III. CALCIUM SILICATE-BASED CEMENTS (CSCs)

- Biodentine
- BioAgggregate
- Calcium-Enriched Mixture (CEM)

Biodentine

Biodentine is a *calcium silicate*–based material used for repair of perforations and resorption, apexification, and root-end fillings (**Fig. 11.8**). The material can also be used in class II fillings as a temporary enamel substitute and in large carious lesions as a permanent dentin substitute. The manufacturer points out the biocompatibility and the bioactivity of the material, which are important since the use of the material involves indirect and direct pulp capping and pulpotomy. According to the manufacturer, Biodentine preserves pulp vitality and promotes its healing process.

Composition

- Powder
  - Tricalcium silicate
  - Dicalcium silicate
  - Calcium carbonate
  - Zirconium dioxide
- Liquid
  - Calcium chloride in aqueous solution with an admixture of polycarboxylate



Figure 11.8 Biodentine. (*Courtesy: Septodont, France.*)

Setting Reaction

- The powder is dispensed in a capsule that is mixed with the liquid in a triturator for 30 seconds.
- Hydration of the tricalcium silicate produces a hydrated calcium silicate gel and calcium hydroxide. The unreacted

tricalcium silicate grains are surrounded by layers of calcium silicate hydrated gel, which are relatively impermeable to water, thereby slowing down the effects of further reactions.

- Biodentine sets in approximately 10 minutes.

Clinical Note

The clinician should ensure that there is no salivary contamination of Biodentine during its initial setting time (10 minutes).

Advantages

- Biodentine can be used for pulp capping and to bulk fill the cavity.
- It does not stain the tooth.
- It has excellent radiopacity.
- There is no need for surface preparation or tedious bonding due to the micro-mechanical anchorage.
- Biodentine has higher compressive strength than dentin, preserves pulp, and promotes pulp healing.
- The microleakage resistance is enhanced by the absence of shrinkage due to the resin-free formula.

Bioaggregate

Bioaggregate is another bioactive CSC that has shown excellent capacity to stimulate hard tissue bridge formation. The cement has been shown to promote mineralization in osteoblast cells, inhibit osteoclast differentiation, and inhibit inflammatory bone resorption in vivo, similarly to MTA.

Calcium-Enriched Mixture

Calcium-enriched mixture is another CSC with excellent bioactivity and remarkable efficacy when used in vital pulp therapy.

VITAL PULP THERAPY

Definition: *Vital pulp therapy is the treatment initiated on an exposed pulp to repair and maintain the pulp vitality.*

The two primary aims of vital pulp therapy are:

i. To treat reversible pulpal injuries in order to maintain pulp vitality in both primary and permanent teeth.
ii. To induce the formation of a protective hard tissue barrier.

Vital pulp therapy includes four distinct therapeutic approaches:

1. *Indirect pulp capping*
2. *Direct pulp capping*
3. *Partial pulpotomy*
4. *Pulpotomy*

Clinical Note

The clinical decision to choose between direct and indirect pulp capping would be based on the clinician's ability to clinically distinguish between Soft dentin (formerly known as Infected dentin) and Firm dentin (formerly known as Affected dentin) (**Table 11.2**).

INDIRECT PULP CAPPING

Definition: *Indirect pulp capping is defined as a procedure wherein the deepest layer of the remaining firm carious dentin is covered with a layer of biocompatible material in order to prevent pulpal exposure and further trauma to the pulp.*

Objective

The ultimate objective is to preserve the vitality of the pulp by completely removing the carious-firm dentin followed by placement of a material that would enable the firm dentin to remineralize by stimulating the underlying odontoblasts to form tertiary dentin.

Studies have shown that physiological remineralization can occur only if the firm dentin layer contains sound collagen fibers and living odontoblastic processes. The sound collagen fibers function as a base to which apatite crystals attach (**Table 11.2**). The living odontoblastic processes supply calcium phosphate from the vital pulp for physiological remineralization.

In indirect pulp therapy, the outer layers of carious dentin, i.e., soft dentin, are removed. Thus, most of the bacteria are eliminated from the lesion. When the lesion is sealed, the substrate on which the bacteria act to produce acid is also removed. With the arrest of the carious process, the reparative mechanism is able to lay down additional dentin and avoid a pulp exposure. Exposure of the pulp occurs when the carious process advances faster than the reparative mechanism of the pulp.

Table 11.2 Differences Between Soft and Firm Dentin

Soft Dentin (formerly known as Infected dentin)	Firm Dentin (formerly known as Affected dentin)
• Soft and demineralized dentin teeming with bacteria • Collagen is irreversibly denatured • Cannot remineralize • Soft necrotic tissue followed by dry leathery dentin which flakes away with an instrument	• Demineralized dentin, not yet invaded by bacteria • Collagen cross-linking remains • Can act as template for remineralization if appropriate biocompatible material is placed over it • Discolored and softer than normal dentin that does not flake easily

Rationale

Indirect pulp capping therapy can be justified by the following desirable results:

- Disinfection of the residual firm dentin is more readily accomplished.
- It eliminates the need for more difficult pulp therapy by arresting the carious process and allowing the pulp reparative process to occur.
- Patient comfort is immediate.
- Rampant dental decay is halted when all carious teeth are treated.

Diagnostic Data

History

The patient complains of a tolerable, dull pain with mild discomfort associated with eating. Mild-to-moderate pain is experienced on thermal stimulation. There is no history of spontaneous or excruciating pain.

Clinical Examination

On examination, a large carious lesion is found *without* any frank pulpal exposure. There is a positive response to electric pulp sensitivity test, thermal stimulation, and test cavity. The tooth responds normally to percussion.

Radiographic Examination

Radiograph shows a large carious lesion with a possible pulp exposure. The extent of caries penetration depth is up to three-fourth of the entire thickness of dentin or more when evaluated by a radiograph. The lamina dura appears normal. A pretreatment radiograph is always recommended to rule out any periradicular pathosis (**Fig. 11.9**).

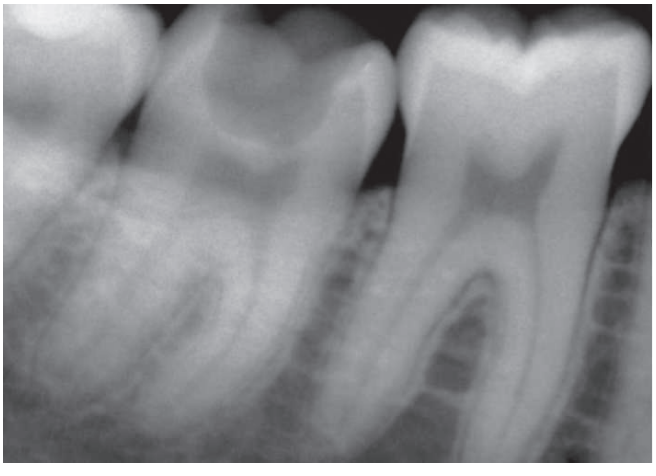


Figure 11.9 Deep carious lesion in a mandibular molar without pulpal involvement.

Clinical Procedure

Indirect pulp capping can be performed as a single- or two-step approach (stepwise excavation).

Stepwise excavation is a technique in which caries is removed in increments in two or more appointments over a period of few months instead of trying to remove the caries in a single sitting.

This technique is indicated for deep carious lesions with no symptoms of irreversible pulpitis. In this technique, only a part of the soft dentin caries is removed at the first visit and the cavity is restored and reopened after few weeks. Further excavation is then done before giving the final restoration in the second visit.

The objectives of this technique are as follows:

- Arrest caries lesion progression and allow formation of reparative dentin
- Pulpal exposure is less likely in vital teeth with deep carious lesions

The two-step stepwise excavation approach is recommended for the following reasons:

- A two-step approach avoids unintentional pulpal exposure which may deteriorate the pulpal prognosis.
- The dentist gets a chance to assess the reaction of the tooth as well as gain information of the changes in caries activity.
- Two-step appointment gives an opportunity to remove the slowly progressing lesion in slightly infected, discolored, demineralized dentin before the placement of the final restoration.
- The final excavation of the caries is safer in the second sitting as it is easier to remove the dry carious dentin.

Clinical Note

The two most important factors determining the success of indirect pulp capping are as follows:

1. *Remaining dentin thickness*: This is the amount of remaining dentin present between the floor of the cavity and the pulp space. Studies have shown that a *remaining dentin thickness (RDT) of* ***2.0–0.5 mm has a good prognosis*** as the secretion of the reactionary dentin is more in such cases. When the RDT is between 0.5 and 0.25 mm, the reactionary dentin is reduced due to decreased odontoblastic activity. This in turn reduces the prognosis.

   The rate of reparative dentin deposition has been shown to ***average 1.4 µm/day*** in dentin of human teeth. The rate of reparative dentin formation decreases markedly after 48 days. Dentin is laid down fastest during the first month after indirect pulp therapy and the rate then diminishes steadily with time. Dentin formation occurs with longer treatment times, and greater dentin formation is observed in primary teeth than in permanent teeth.
2. *Choice of an indirect pulp capping agent*: Practically, all bacteria are destroyed under ***calcium hydroxide*** dressing sealed in deep carious lesions. Calcium hydroxide has a long track record as a time-tested indirect pulp capping material basically due to its high alkalinity and its ability to produce a dentinal barrier or a dentinal bridge.



Figure 11.10 Endodontic spoon excavator. (*Courtesy: Hu-Friedy Mfg. Co., USA.*)

Box 11.2 depicts the clinical decision chart between direct and indirect pulp capping (two-step excavation).

Figure 11.10 depicts a spoon-shaped excavator used for caries excavation.

Figure 11.11a depicts the commercial hard-set calcium hydroxide preparation (Dycal, Dentsply Sirona) and

Box 11.2

Clinical Decision Chart Between Direct and Indirect Pulp Capping

Deep carious lesion

↓

Anesthesia and rubber dam isolation

↓

Removal of caries
A. Infected dentin partially removed with a round bur (#6 or #8) in a slow-speed handpiece
B. Peripheral carious dentin removed with a spoon-shaped excavator (31 and 33 L)

↓

No pulpal exposure and no signs of irreversible pulpitis

↓

Remaining infected dentin is covered with $Ca(OH)_2$ and an overlying base of IRM

↓

Wait for 3-8 weeks

↓

Patient asymptomatic

↓

Anesthesia and rubber dam isolation

↓

Temporary filling material is removed carefully

↓

Carefully further excavation and clinically confirm the changes in color and hardness of firm dentin

↓

Hard set $Ca(OH)_2$ is placed followed by an RMGIC base and a bonded composite restoration/amalgam

2nd appointment

Pulpal exposure

↓

Direct pulp capping/ Cvek's partial pulpotomy/ full pulpotomy



(a)



(b)

Figure 11.11 (a) Dycal—hard-set calcium hydroxide preparation. (*Courtesy: Dentsply Sirona.*) (b) IRM—reinforced zinc oxide–eugenol preparation. (*Courtesy: Dentsply Sirona.*)

Figure 11.11b represents the reinforced zinc oxide–eugenol preparation (e.g., IRM, Dentsply Sirona).

CLINICAL MANAGEMENT OF PULPAL EXPOSURE IN CASES WITH REVERSIBLE PULPITIS

The clinician has to decide upon one of the following treatment options when faced with an exposed pulp:

I. Direct pulp capping
II. Partial/Cvek's pulpotomy
III. Full pulpotomy

Factors Affecting Prognosis of Pulpal Exposures (Fig. 11.12)

According to Seltzer and Bender, carious pulpal exposure is normally associated with inflammation and subsequent necrosis. Hence, mechanical exposures always have a better prognosis than a carious exposure. The next most important prognostic factor is the sizes of exposure, with larger exposures having lower healing potential than smaller pinpoint exposures.

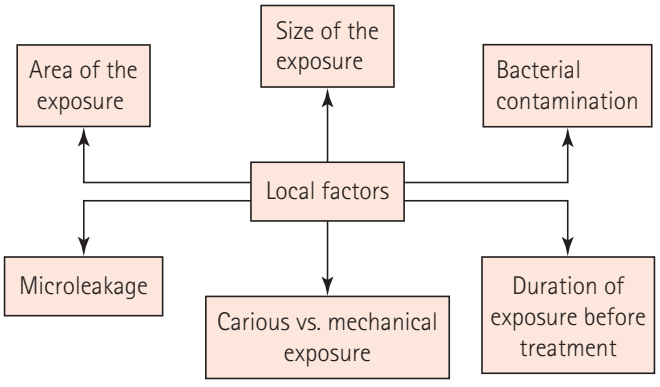


Figure 11.12 Factors affecting prognosis of direct pulp capping.

The time gap between the exposure and the pulp capping procedure is critical, as the longer the time gap, the higher the chances of bacterial microleakage and contamination of the pulp space. Mechanical exposures should be pulp-capped *immediately*. Care should be taken to ensure that the bleeding is controlled before the pulp is capped.

Clinical Note

The following four variables make the clinical outcome of a pulpal exposure favorable:

i. Pulpal exposure due to traumatic injuries is more favorable than carious pulpal exposure.
ii. Control of the hemorrhage is achieved within 10 minutes.
iii. Size of the exposure is less than 1 mm.
iv. Treatment is done within 48 hours of exposure.

The flowchart depicting the clinical management of pulpal exposure is given in **Box 11.3**.

I. DIRECT PULP CAPPING

Definition: *Direct pulp capping is defined as a procedure in which the exposed vital pulp is covered with a protective dressing or base placed directly over the site of exposure in an attempt to preserve pulpal vitality.*

Indications

- Asymptomatic (no spontaneous pain, normal response to thermal testing, and pulp is vital before the operative procedure)
- Small exposure, less than 0.5 mm in diameter
- Hemorrhage from the exposure site is easily controlled (within 10 minutes)
- The exposure occurred is clean and uncontaminated (rubber dam isolation)
- Atraumatic exposure and little desiccation of the tooth with no evidence of aspiration of blood into the dentin (dentin blushing)

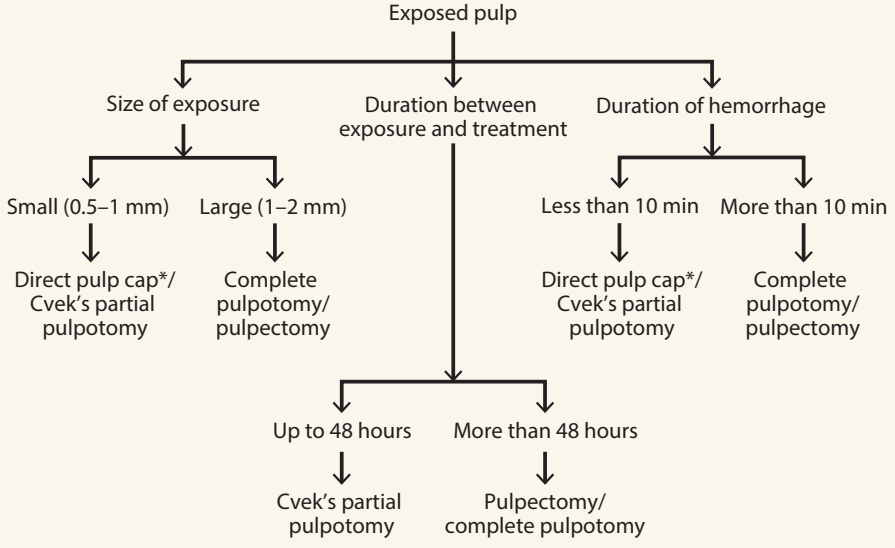
Techniques of Direct Pulp Capping

Two techniques have demonstrated success with direct pulp capping: calcium hydroxide technique MTA/CSC technique. Caries removal is accomplished with the #2 carbide bur (**Fig. 11.13**) and spoon excavators.

The flowchart for the clinical protocol for direct pulp capping is given in **Box 11.4**.

Box 11.3

Clinical Decision Making Chart for Management of Pulpal Exposure



*Direct pulp capping procedure is not recommended in cases of carious pulpal exposures.



Figure 11.13 Slow-speed carbide bur.

Figure 11.14 demonstrates a case report of direct pulp capping using Biodentine.

Clinical Note

- Direct pulp capping is not clinically recommended in cases of carious pulpal exposures.
- A ***minimum thickness of 1.5 mm of MTA/CSC is*** recommended to be placed over the site of exposure.

II. PULPOTOMY

Definition: *Pulpotomy is defined as a procedure in which a portion of the exposed coronal vital pulp is surgically removed as a means of preserving the vitality and function of the remaining radicular portion.* This procedure is similar in concept to direct pulp capping except in the *amount* and *extent* of pulp tissue removal.

Objectives

- *Preservation of vitality of the radicular pulp*: Through the surgical excision of the coronal pulp, the infected and inflamed area is removed, leaving vital, uninfected pulpal tissue in the root canal
- *Relief of pain in patients with acute pulpalgia and inflammatory changes in the tissue*: Removal of the inflamed portion of the pulp affords temporary, rapid relief of pulpalgia.
- *Ensuring the continuation of normal apexogenesis in immature permanent teeth by retaining the vitality of the radicular pulp*: The remaining pulp may undergo repair while completing apexogenesis, i.e., root-end development and calcification.

Rationale

The inflamed coronal portion of the pulp is removed, and a dressing is placed over the pulp stump to protect it and to

Box 11.4

Clinical Protocol for Direct Pulp Capping

Pulp exposure
↓
Anesthesia and rubber dam
↓
Hemostasis with 6% sodium hypochlorite within 10 minutes
↓

Calcium hydroxide technique	MTA/CSC Technique (Currently recommended technique)
↓	↓
$Ca(OH)_2$	Mix MTA/CSC according to manufacturer's instruction
↓	↓
RMGIC (resin-modified glass ionomer cement) base	Place a minimum thickness of 1.5 mm of MTA/CSC directly over exposed pulp and surrounding dentin
↓	↓
Final restoration with bonded composite/amalgam	Place a moist gauze pellet over the entire area of MTA/CSC
	↓
	Provide a provisional restoration with an unbonded composite material over gauze pellet
	↓
	If patient is clinically asymptomatic, schedule for second appointment after 5–10 days
	↓
	Remove provisional restoration gauze pellet and place permanent bonded (self-etching) composite restoration



Figure 11.14 (a) Pulp exposure at two sites during complete caries excavation in relation to tooth 15. (b) For filling the cavity and for direct capping, Biodentine™ was applied to the cavity with cement pluggers using light pressure. Carving instruments were used for occlusal adjustment. Biodentine™ should not be prepared with rotating instruments and should not come into contact with water. After allowing 12–15 minutes for Biodentine™ to set, the bite was checked. Subsequent polishing of the Biodentine™ filling should be omitted. (c) Three months later, the patient returned to have the cavity definitively filled with composite. At this visit, the Biodentine™ filling showed marginal material loss. (d) Biodentine™ reduced to a base/dentin substitute level. (e) Before restoring the cavity with composite, a matrix band (Composi-Tight 3D; Garrison, Spring Lake, MI, USA) and wedges were put in place. (f) Cavity filled with resin composite (Grandio; VOCO, Cuxhaven, Germany). (g) Finalized and polished composite filling. (h) The dental film recorded 6 months after direct capping does not show any pathological periradicular findings in relation to tooth 15. (*Courtesy: Till Dammaschke, Germany.*)

promote healing. The two most commonly used dressings contain either $Ca(OH)_2$ or MTA/CSCs.

The severity of the inflammatory process dictates the quality and quantity of reparative dentin produced in the dentinal bridge. Severe inflammation produces limited reparative dentin devoid of dentinal tubules. Mild inflammation produces reparative dentin with varying numbers of dentinal tubules. Although the term "bridge" implies a solid barrier and a seal between the surface of the new reparative dentin and the pulp, communications exist in the form of openings. Experiments have shown that the formation of reparative dentin bridges is reduced in the presence of an inflammatory process. Therefore, in the *presence of severe inflammation of the pulp, pulpotomy procedures to preserve pulp vitality are contraindicated.*

Indications

- Mechanical or carious exposure in permanent teeth with incomplete root formation.
- Traumatic exposures of longer duration where coronal pulp is likely to be inflamed in young permanent teeth. Pulpotomy should be undertaken in teeth with healthy, hyperemic, or slightly inflamed pulps, such as a child's permanent anterior tooth with a wide-open apex that is fractured during sports or in an automobile accident.
- Pulpotomy is indicated in pulpally involved permanent teeth of children in which the root apex is not completely formed; in such cases, pulp extirpation and obturation are contraindicated because of the immature root and wide-open foramen, and extraction is not justified because of the effect on the eruption of adjacent teeth and the development of the dental arches. The open foramen contraindicates root canal therapy, which should be postponed until the foramen matures. The pulpotomy procedure permits the completion of apexogenesis, the physiological maturation of the root. Even if only the apical 3 or 4 mm of the pulp tissue is still vital, the root apex can complete development.

Contraindications

- Patients with irreversible pulpitis
- Abnormal sensitivity to heat and cold
- Chronic pulpalgia
- Tenderness to percussion or palpation because of pulpal disease
- Periradicular radiographic changes resulting from extension of pulpal disease into the periradicular tissues
- Marked constriction of the pulp chamber or root canals (calcification)

Prognosis

The success of this procedure depends upon the following:

- Vitality of the majority of the radicular pulp
- Absence of adverse clinical signs or symptoms such as prolonged sensitivity/pain or swelling
- No radiographic evidence of internal resorption or abnormal canal calcifications
- No breakdown of periradicular supporting tissues
- No harm to succedaneous teeth

Classification

The pulpotomy procedure can be classified on the basis of the following:

I. Amount of pulpal tissue removed
   A. Partial pulpotomy (Cvek's pulpotomy)
   B. Complete pulpotomy (Cervical pulpotomy)

II. Type of medicament employed
   A. Calcium hydroxide pulpotomy
   B. MTA/CSCs pulpotomy
   C. Formocresol pulpotomy

i. ***Based on the Amount of Pulpal Tissue Removed***

There are two types of pulpotomy based on the amount of pulpal tissue removed:

A. *Partial pulpotomy (Cvek's pulpotomy)*: A kind of pulpotomy in which only a *portion of the coronal pulp is removed* or removal of tissues until normal tissue that is free of inflammation is reached before placing a medicament.

B. *Complete pulpotomy (Cervical pulpotomy)*: It involves the *complete removal of the coronal portion of the dental pulp*, followed by placement of a suitable dressing or medicament that will promote healing and preserve the vitality of the tooth.

Clinical Protocol for Partial Pulpotomy (Cvek's Pulpotomy)

- When the coronal pulp is exposed by trauma or operative procedures or caries, it produces inflammatory changes in the tissue.
- The uninfected vital pulp tissue can be preserved in the root canal by the surgical excision of the inflamed coronal pulp.
- The removal of the infected portion of the pulp affords temporary, rapid relief of pulpalgia, and further the remaining tissue may undergo repair while completing apexogenesis (root-end development and calcification).
- Partial pulpotomy has been recommended for crown-fractured teeth that have a pinpoint exposure and can be treated within 15–18 hours of the accident (**Fig. 11.15**) and in carious exposure of an asymptomatic permanent tooth with an open apex (**Fig. 11.16**).

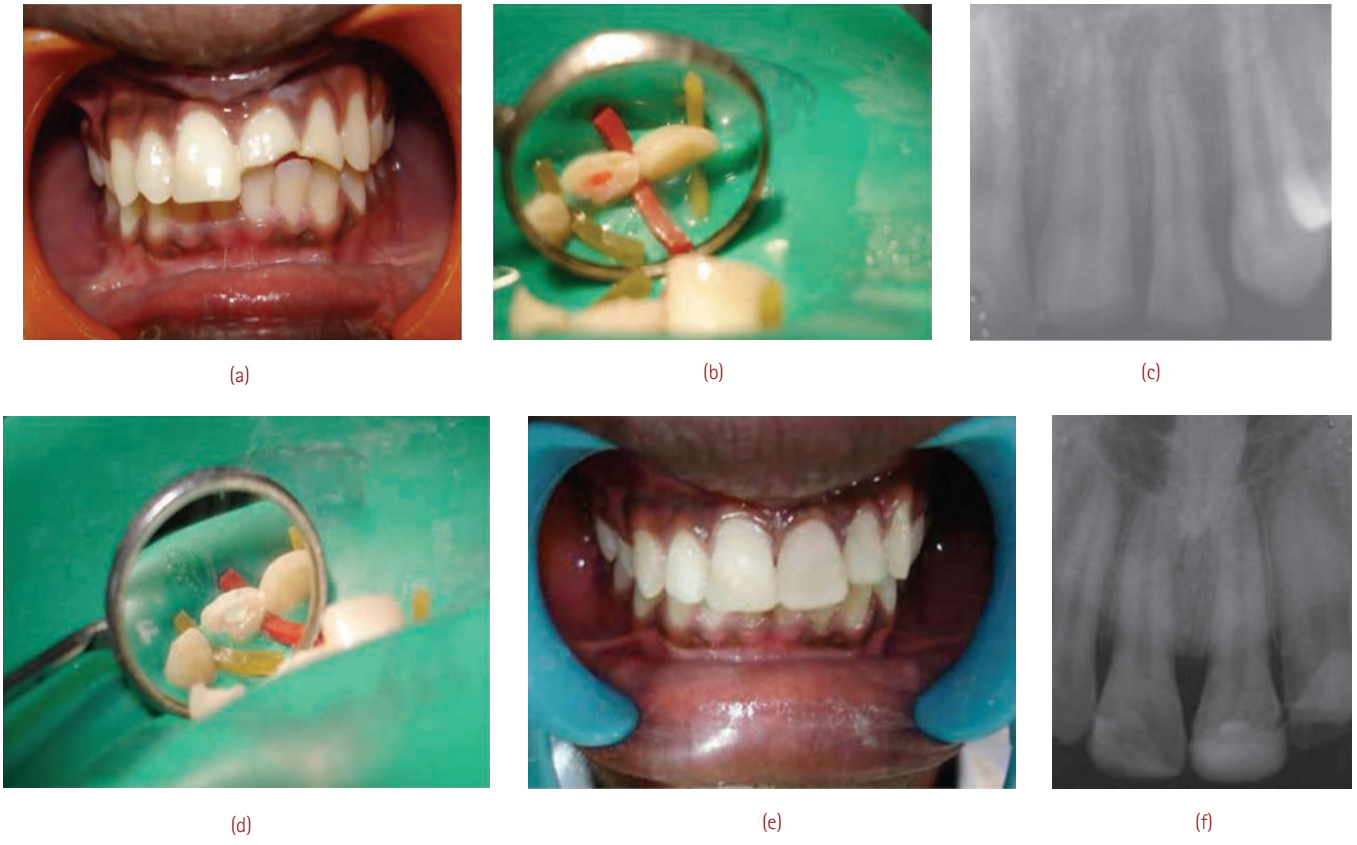


Figure 11.15 (a) and (b) Preoperative photograph showing Ellis class III fracture in 21 with pulp exposure. (c) Preoperative radiograph revealing fracture in 21 with pulp involvement. (d) Partial pulpotomy performed in 21 and MTA placed over the exposed pulp. (e) Two-year postoperative photograph. (f) Postoperative radiograph after 2 years showing no radiographic changes. (*Courtesy: Abarajithan, India.*)

Clinical Note

- Partial pulpotomy and direct pulp capping are considered to be similar procedures and differ only in the amount of undestroyed tissue remaining after the procedure.
- Studies indicate that the success rate of partial pulpotomy is 95% while that of direct pulp capping is 80% in young permanent teeth.

Clinical Protocol for Complete (Cervical) Pulpotomy (Figs 11.17–11.19)

Diagnosis A diagnostic radiograph should be examined to determine the approach to the pulp chamber, to evaluate the shape and size of the root canals, and to ascertain the condition of the periradicular tissues. The tooth should be tested for vitality and the result should be recorded.

Anesthesia The tooth is anesthetized with a local anesthetic, using either infiltration or conduction methods.

- *Isolation and caries removal:* A rubber dam is applied for isolation. On removal of carious tooth structure, access is gained to the pulp chamber along a straight line, using the area of exposure as a starting point and removing the roof of the pulp chamber entirely with a sterile bur.
- *Hemorrhage control:* Bleeding may be controlled with:
  - Hemostatic agent, e.g., 6% sodium hypochlorite
  - Pressure application with moist cotton pellet
  - Electrosurgery
  - Lasers
- *Instrumentation:* During the pulpotomy procedure, the pulp is amputated with any one of the following methods:
  - Sharp spoon excavator
  - Large rotating round bur in slow speed
  - Diamond drill in high speed
  - Lasers
  - Electrosurgery

The coronal portion of the pulp is removed with a sharp, sterile, large spoon excavator or periodontal curette. High-speed drill with coolant is superior to a spoon excavator or a slow-speed round bur and is least traumatic to the underlying pulp.

- It may be necessary to use a bur to remove the coronal portion of the pulp in anterior teeth in which the pulp chamber is small and indistinct from the root canal. In anterior teeth, the bulbous portion up to, but not beyond, the cervical third of the root canal should be removed. In posterior teeth, the bulbous portion of the pulp contained in the pulp chamber down to the orifices of the root canals should be removed.

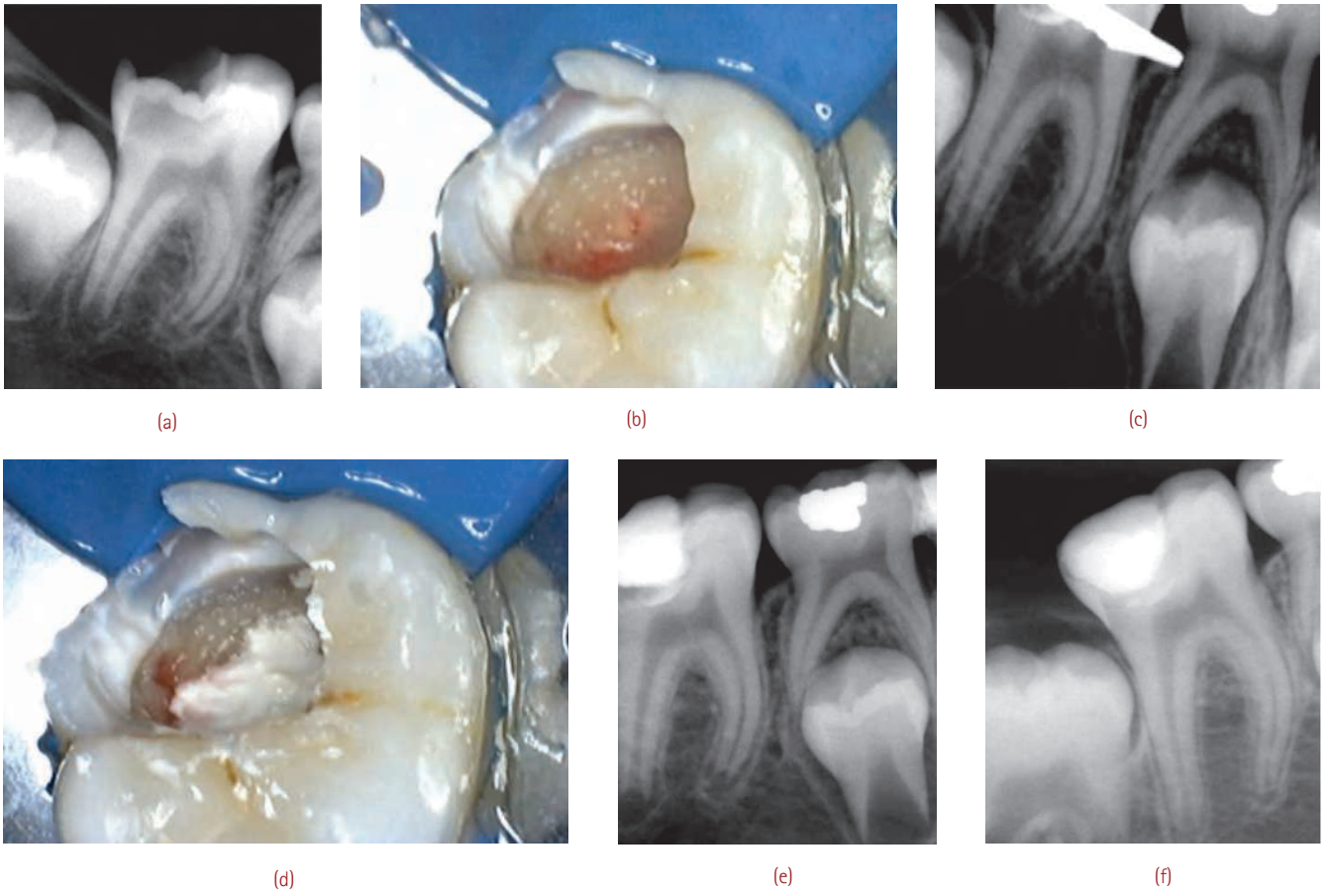


Figure 11.16 (a) Preoperative radiograph of a mandibular molar with open apex having pupal exposure due to caries. (b) Partial pulpotomy performed in relation to 46. (c) Radiographic view after completion of pulpotomy procedure. (d) MTA placed. (e) Temporary restoration placed over MTA till the completion of the setting time of MTA. (f) Two-year follow-up radiograph showing asymptomatic tooth with a permanent restoration and closure of the apex. (*Courtesy: Harsh Vyas, India.*)

- As much pulp tissue as possible should be left in the root canal to allow maturation of the entire root rather than just of a portion of it. A partially matured root is weak and susceptible to fracture by occlusal forces.
- Excavators with extra long shanks are often necessary for reaching into the pulp chambers of molar teeth to scoop out pulp remnants adhering to the pulpal floor. A sharp No. 31 L endodontic excavator is excellent for this purpose.
- Twisting of the pulp stump compresses the tissue, with consequent necrosis. The pulp tissue at the entrance to the root canals and that confined within the root canals should not be disturbed.

ii. ***Based on the Type of Medicament Employed***

a. Calcium Hydroxide Pulpotomy

Calcium hydroxide is presently recommended as one of the medicaments for vital pulp therapy in the permanent dentition, but *not indicated* as an agent for pulpotomy in primary teeth.

Calcium hydroxide is applied to the amputated pulp and is tamped against the pulp with a sterile pledget of cotton. The pulp chamber should be filled to a depth of at least 1–2 mm with calcium hydroxide, on which a base of resin-modified glass ionomer cement or a flowable compomer is applied.

Calcium hydroxide can be used in many forms. Some of the forms are as follows:

- A paste made by mixing calcium hydroxide powder with one of the following media, namely, saline, distilled water, local anesthetic solution, or glycerin
- A fast-setting commercial paste, such as Dycal

b. MTA/CSC Pulpotomy

- The MTA powder/CSCs is mixed as per the manufacturer's instructions (3:1 MTA:distilled water) to get a *wet sand consistency* (**Fig. 11.20a–11.20e**).
- MTA/CSCs has been proved to be a better material of choice than calcium hydroxide in terms of healing, quality of seal provided, and superior biocompatibility (**Fig. 11.21**).
- This MTA/CSCs mix is placed over the amputated pulp with the help of an MTA carrier gun or an amalgam carrier.
- It should be placed in the pulp chamber and condensed lightly with moist cotton pellet.

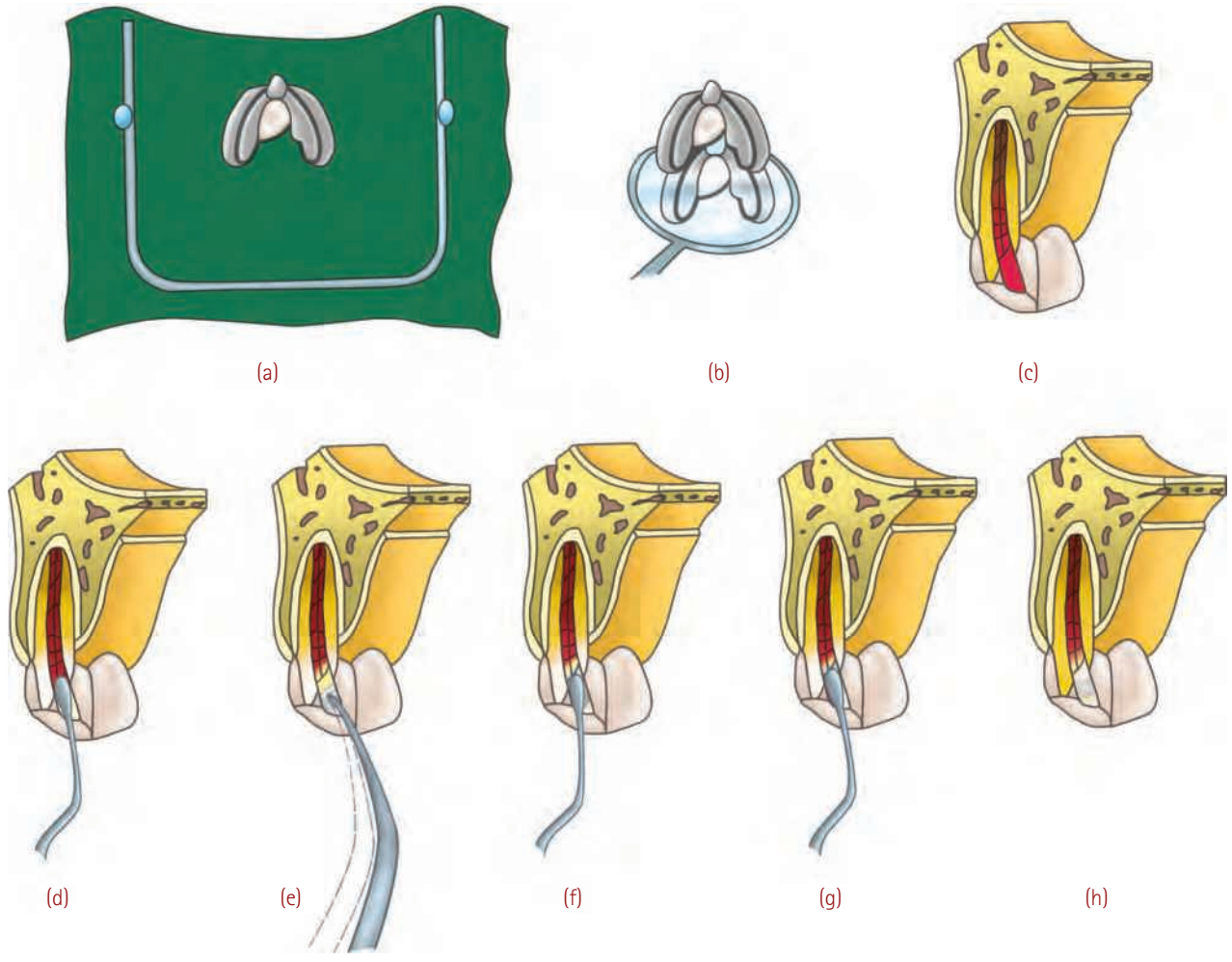


Figure 11.17 Anterior pulpotomy: (a) and (b) The rubber dam is applied. (c) Access is gained into the pulp chamber. (d) The coronal portion of the pulp is removed with a sharp spoon excavator. (e) The pulp chamber is irrigated with sterile water and is dried with a sterile cotton pledget. (f) Calcium hydroxide/MTA or CSC paste is applied to the pulp stump. (g) A resin-modified glass ionomer base/flowable compomer is applied. (h) The tooth is restored by composite restoration.

- Care must be taken to ensure that a minimum thickness of 2 mm of the material is placed.

c. Formocresol Pulpotomy

- It is indicated for pulpotomy of primary teeth only.
- It has been a popular pulpotomy medicament in the primary dentition for the past 70 years since its introduction by Sweet in 1932.
- A cotton pellet containing formocresol liquid is placed over the amputated pulp for a period of 3–5 minutes.
- There is a lot of controversy and discussion across the world regarding the use of formocresol in pediatric dentistry, mainly due to concerns over the carcinogenicity of formocresol.

Permanent Restoration

- A resin-modified glass ionomer or flowable compomer base is recommended over the MTA or CSC/$Ca(OH)_2$ medicament.
- A permanent bonded composite/amalgam restoration is placed over this base.
- The rubber dam is then removed and the occlusion is checked. A radiograph should be taken as a record of the operation for future comparison of apical closure, bridge formation, internal resorption, calcific degeneration, or development of periradicular disease.

Follow-Up

- The tooth should be checked with radiographs and vitality tests every 3 months.
- In the event of pain or death of the pulp, the root canal contents should be removed as soon as possible, and endodontic therapy should be started if the apex is mature. If the apex is immature, apexification therapy should be initiated.

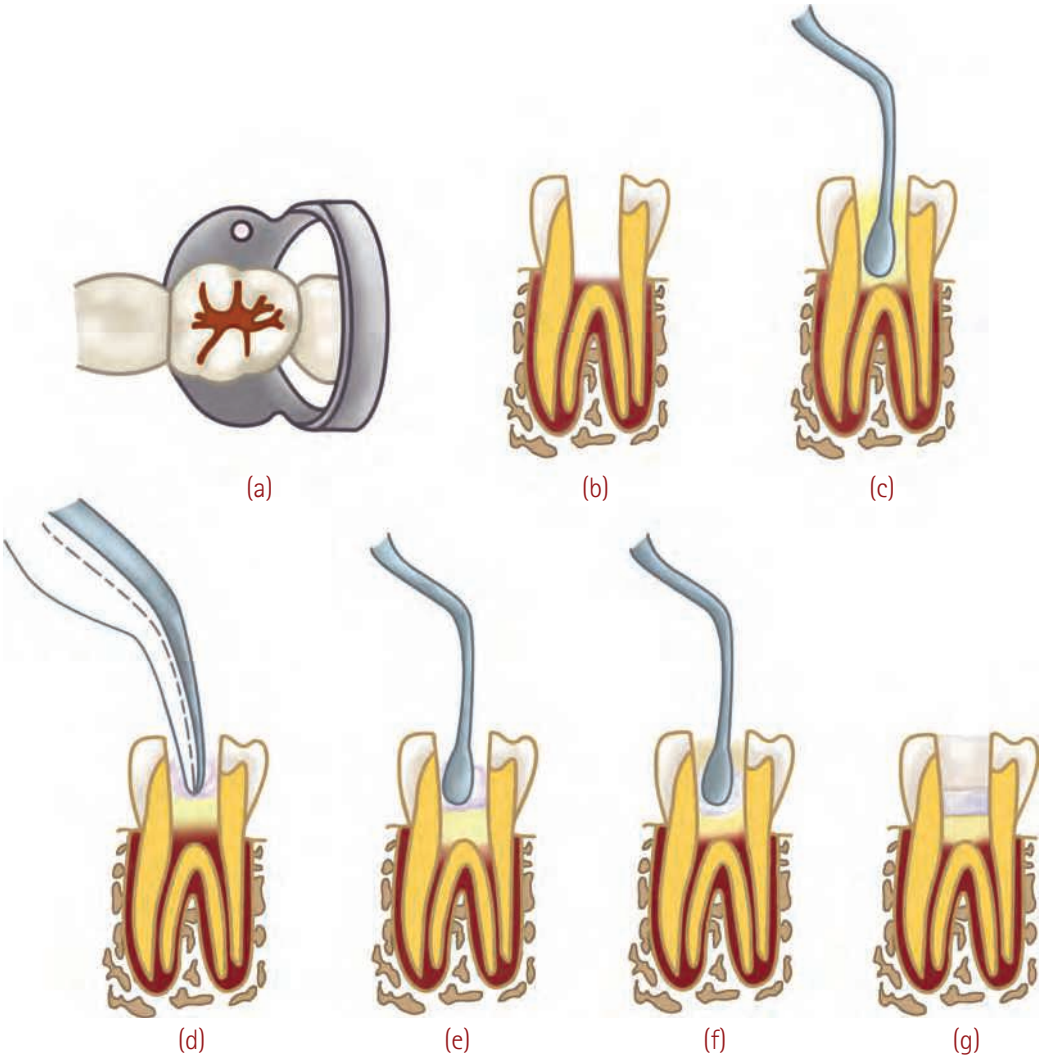


Figure 11.18 Posterior pulpotomy: (a) The rubber dam is applied. (b) Access is gained into the pulp chamber. (c) The coronal portion of the pulp is removed with a sharp spoon excavator. (d) The pulp chamber is irrigated with 6% sodium hypochlorite and is dried with a sterile cotton pledget. (e) Calcium hydroxide/MTA or CSC paste is applied to the pulp stump. (f) A resin-modified glass ionomer/flowable compomer base is applied. (g) The tooth is restored by permanent restoration.

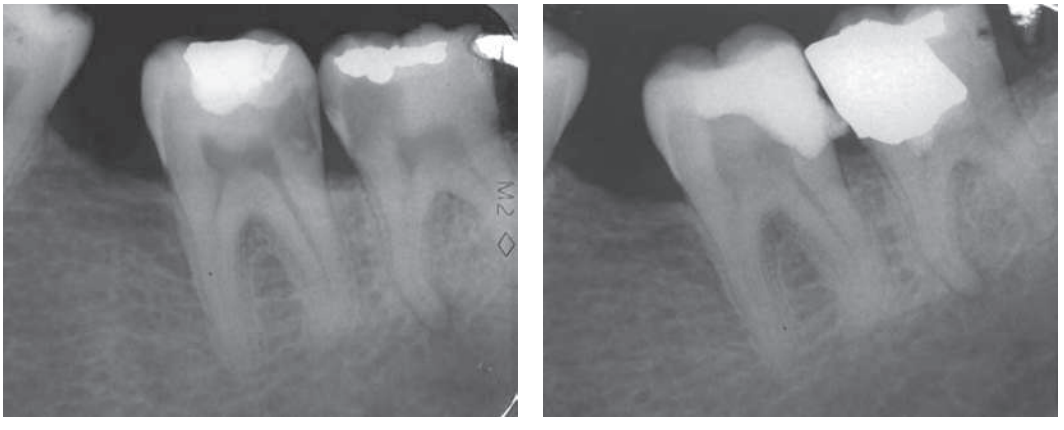
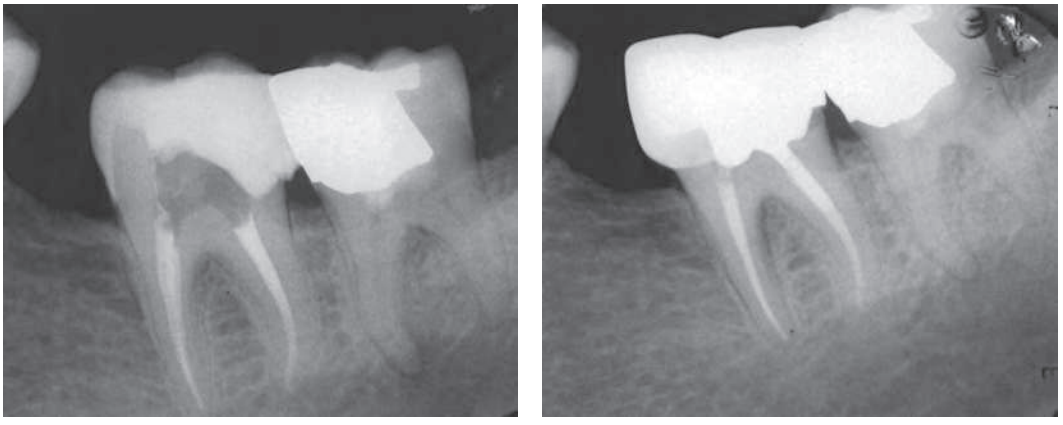
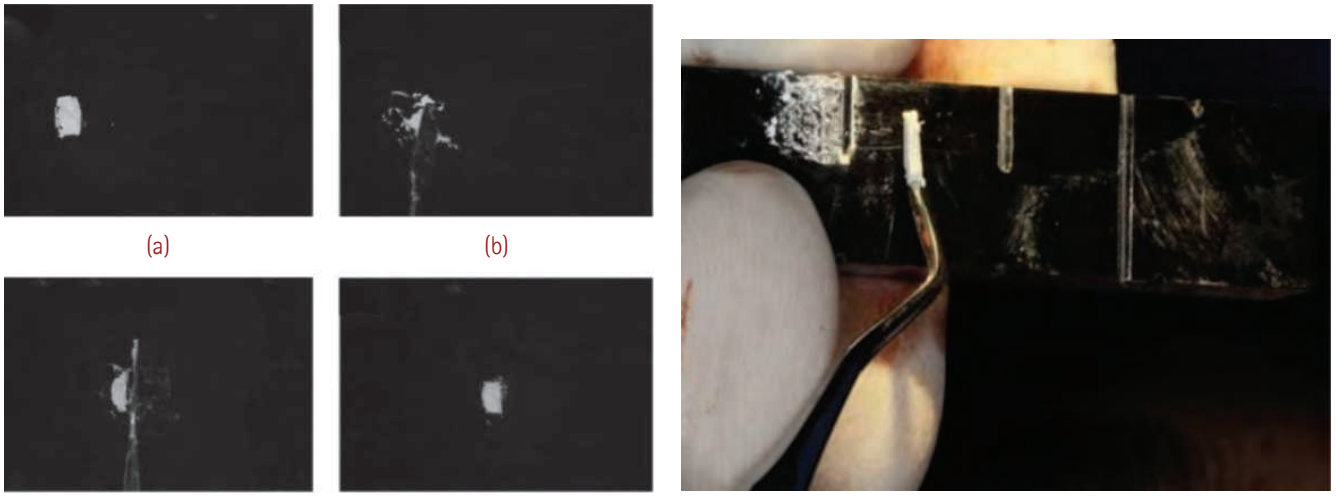


Figure 11.19 (a) Preoperative radiograph of the second and the third lower left molars shows deep interproximal carious lesions. The patient's chief complaint was severe lingering pain with sensitivity to percussion in both the involved teeth. (b) Pulpotomy treatment was performed on the third lower molar accompanied with permanent restoration. Emergency treatment for the second molar was carried out in the same session. *(continued)*



(c) (d)

Figure 11.19 *(continued)* (c) Immediate postoperative radiograph of second molar after a week. (d) Twelve-month follow-up radiograph showing favorable outcomes. The treated teeth are in function and periradicular tissues are normal. (*Courtesy: Saeed Asgary, Iran.*)



(a) (b) (c) (d) (e)

Figure 11.20 (a) Dispensing MTA powder and liquid on a clean and sterile glass slab. (b) Incorporating liquid into powder. (c) Mixing to get a wet sand-like consistency. (d) Completed mix ready for application. (e) MTA collected on an instrument through the carrier block.

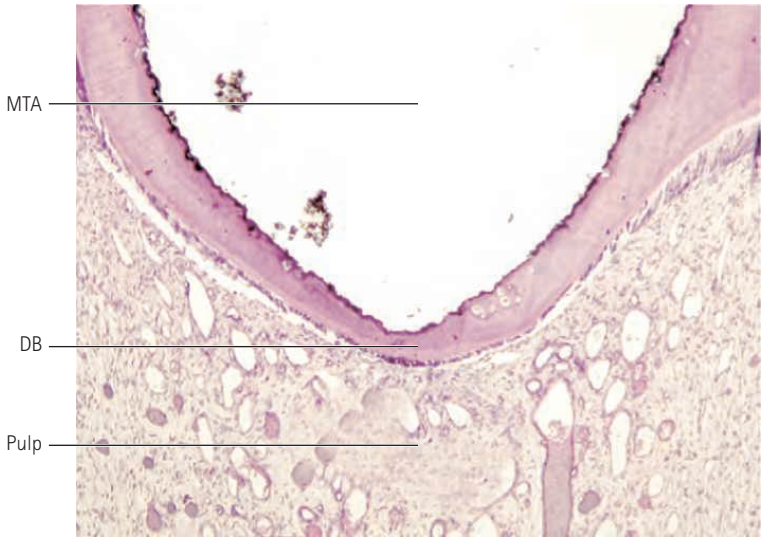


Figure 11.21 Pulp capping with MTA. Formation of a thick dentinal bridge (DB) at the pulp–MTA interface (×100). (*Courtesy: Saeed Asgary, Iran.*)

APEXIFICATION

Definition: *Apexification is defined as a method to induce a calcific barrier across an open apex of an immature, pulpless tooth.*

Objective

The aim of apexification is to induce either closure of the open apical third of the root canal or the formation of an apical "calcific barrier" against which obturation can be achieved.

Rationale

Although apexification had been attempted in the past, the technique was given impetus by the description of three cases of apexification by Frank in 1966. This report was followed by a series of experimental procedures by others to elucidate some factors in apexification. Actual root growth does not occur as a result of apexification, but radiographic evidence of a calcified mass at the root apex gives that impression.

Speculations about apexification are that the residual pulp tissue, if any, and the odontoblastic layer associated with the pulp tissue resume their matrix formation and subsequent calcification, guided by the reactivated sheath of Hertwig. The fact that the sheath of Hertwig and the pulp tissue were once damaged may explain why some of the apical formations appear atypical.

From all experimental studies reported, it appears that disinfection of the root canal is indispensable to apical closure. Infection prevents further root-end development. Normal linear growth of the root does not occur in the absence of a vital pulp. If apexification is successful, a hard substance, histologically described variously as bone, dentin, osteodentin, or cementum, will develop against which dense obturation of the root canal can be done. Several materials have been used, such as collagen-calcium phosphate gel or tricalcium phosphate, yet none is as effective in promoting a calcific barrier as calcium hydroxide or MTA.

Clinical Note

Apexification differs from apexogenesis **(Table 11.3)**, which is defined as the physiological process of root development in a tooth.

I. MULTIPLE-STEP APEXIFICATION WITH CALCIUM HYDROXIDE

Calcium hydroxide is the most common and traditional material employed for inducing apexification. However, this technique is typically a multiple-visit approach, which takes a period of 6 months to 4 years to complete.

Table 11.3 Apexification versus Apexogenesis

Apexification	Apexogenesis
Definition: Apexification is defined as a method to induce a calcific barrier across an open apex of an immature, pulpless tooth.	Definition: It is defined as the treatment of a vital pulp by capping or pulpotomy in order to permit continued growth of the root and closure of the open apex.
It is a clinical procedure to induce or close the open apical third of a NON-VITAL tooth.	It is a physiological process of inducing normal root development in an inflamed/infected VITAL tooth.

Technique (Figs 11.22 and 11.23)

Box 11.5 depicts the multiple-visit apexification procedure with calcium hydroxide.

Clinical Note

- Long-term use of intracanal $Ca(OH)_2$ can cause weakening of root dentin leading to root fracture.
- In apexification procedures, every effort should be made to preserve any vital apical pulp tissue that will help the closure of the immature apex.
- Apexification is usually complete in 6 months, or 2 years at most.

II. SINGLE-STEP APEXIFICATION WITH MTA/CSC CEMENTS

Calcium hydroxide has been the most widely used material for induction of an apical barrier. However, the time needed to induce a barrier varies from months to even years. The advent of MTA/CSCs has provided the clinician with a simple and more effective method of creating an apical barrier. MTA/CSCs has demonstrated good biocompatibility and a better ability to seal and produce a superior barrier.

Technique (Fig. 11.24)

Box 11.6 depicts the single-visit apexification procedure with MTA/CSC.

Clinical Note

- Tissue pH may affect the hydration reaction and the final physical properties of MTA. It has been advised to medicate the canal for 1 week with calcium hydroxide to raise the acidic pH of inflamed periradicular tissue before permanently sealing with MTA.
- MTA is mixed in a 3:1 ratio using sterile distilled water to a wet sand consistency and introduced into the canal with the help of MTA carriers and sequentially checked with multiple radiographs. Pre-selected pluggers are used to gently condense the MTA into an apical 3- to 4-mm barrier.

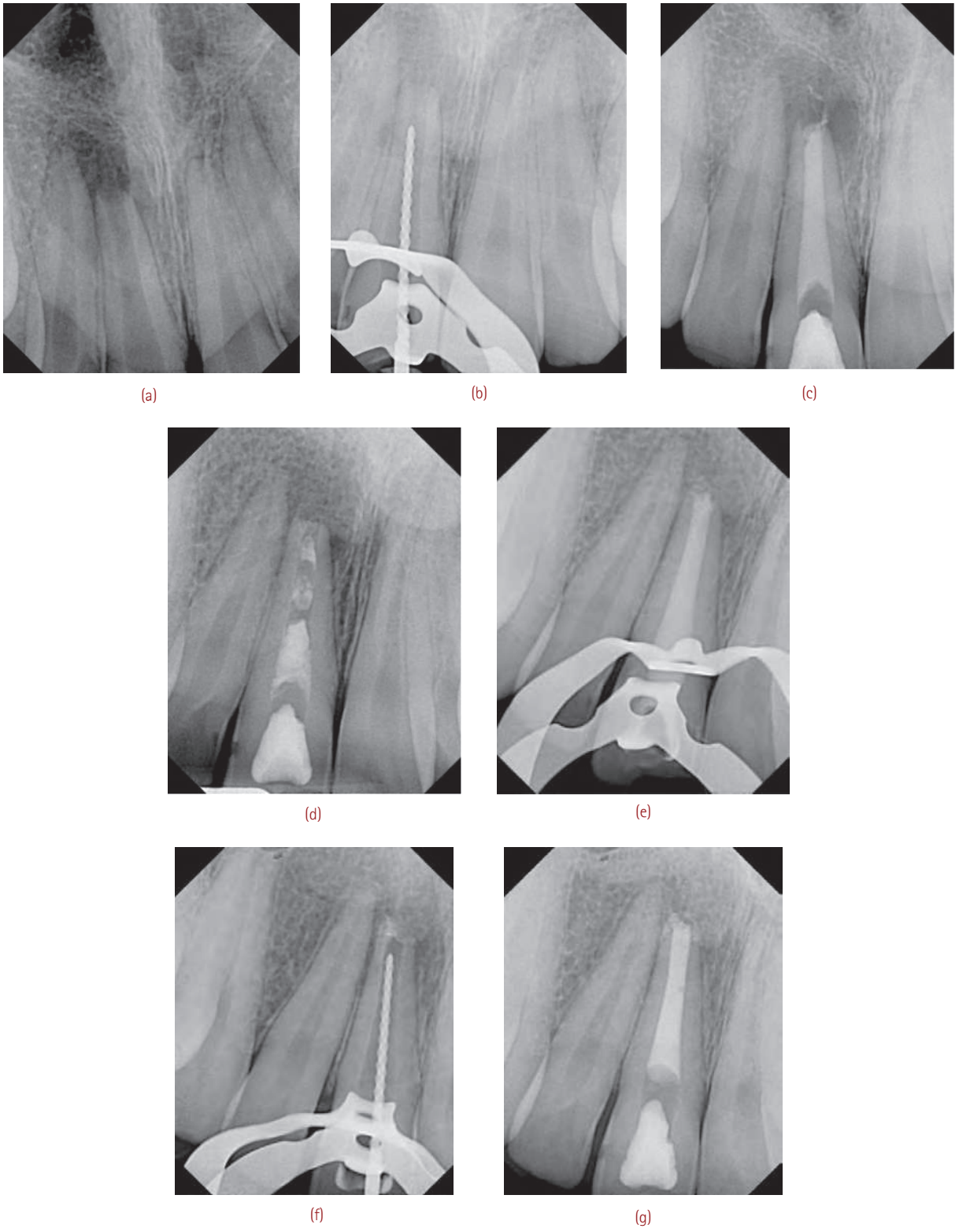


Figure 11.22 (a) A 15-year-old patient has a history of trauma to the maxillary central incisor. Trauma occurred at an age before apical closure occurred. The tooth was diagnosed with necrotic pulp and symptomatic apical periodontitis. Note the large periapical lesion. (b) Tooth debrided 2 mm short of the apex. (c) $Ca(OH)_2$ placed into the canal up to the apex. (d) Three-month check shows resorption of $Ca(OH)_2$, but the apex still open. Apical lesion almost completely healed. (e) $Ca(OH)_2$ placed again. (f) Ten-month re-evaluation. Apical barrier present. (g) Obturation completed. (*Courtesy: Jason J. Hales, USA.*)

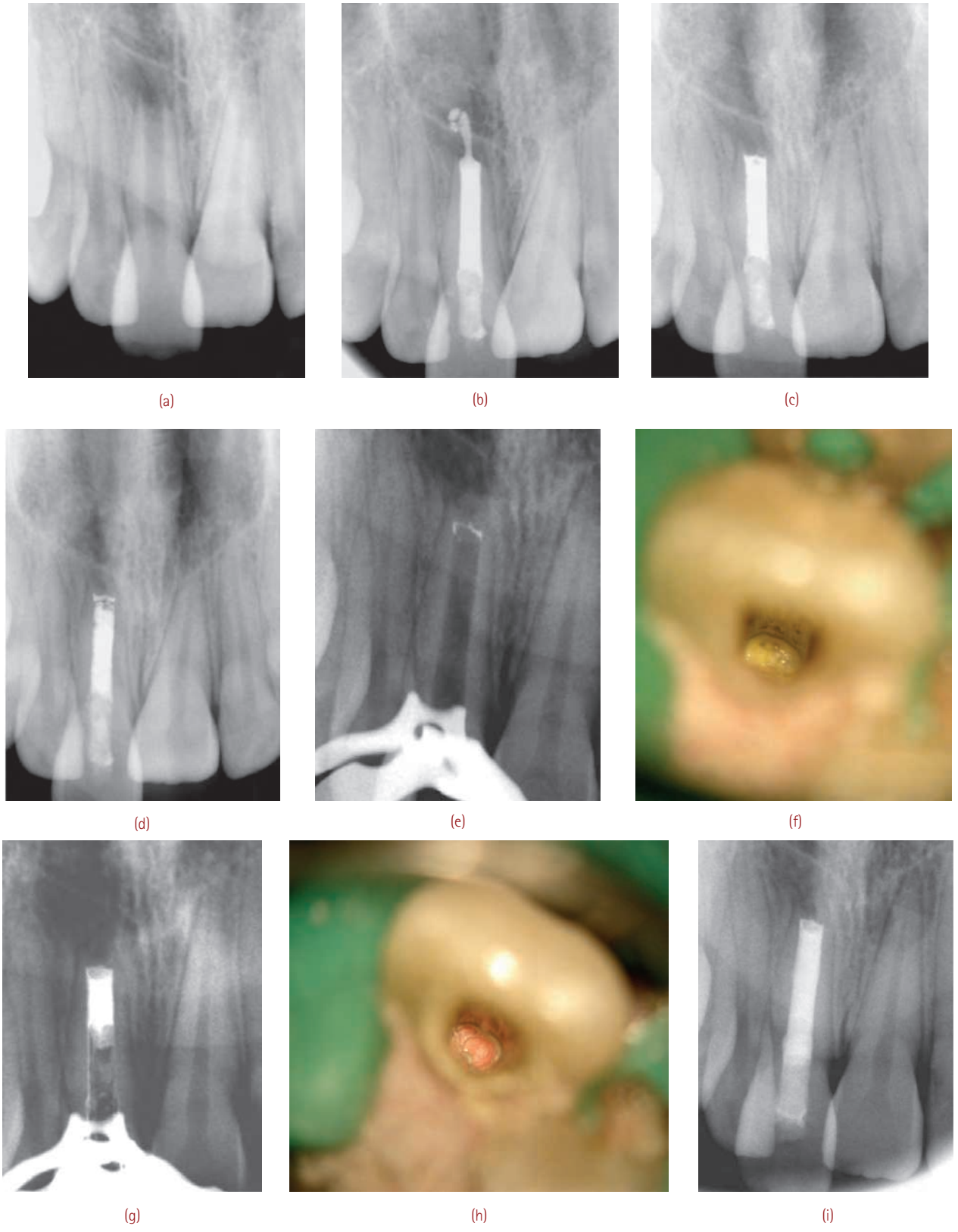


Figure 11.23 (a) Central incisor with open apex. (b) Intracanal $Ca(OH)_2$ placed and GIC entrance filling given. (c) Six-month follow-up. (d) Twenty-month follow-up. (e) Calcium hydroxide removed and evidence of a calcific barrier. (f) Calcific barrier seen through the microscope. (g) Thermoplasticized backfill obturation done. (h) View through the microscope. (i) Two-year recall shows good healing. (*Courtesy: Siju Jacob, India.*)

Box 11.5

Multiple-Visit Apexification Procedure with Calcium Hydroxide

Anesthesia, rubber dam isolation, and access opening

↓

Working length should be at least 2 mm short of the radiographic apex of the tooth

↓

Circumferential enlargement is effected by lateral pressure against the walls with a large file

↓

Drying the canal with paper points

↓

$Ca(OH)_2$ is mixed with sterile water to a thick consistency

↓

The paste is delivered into the canal with a carrier and condensed with finger pluggers

↓

The entire root canal is filled with $Ca(OH)_2$ paste, ensuring that the material is in contact with the periapical tissues

↓

The access cavity is sealed with RMGIC (resin-modified glass ionomer cement)

↓

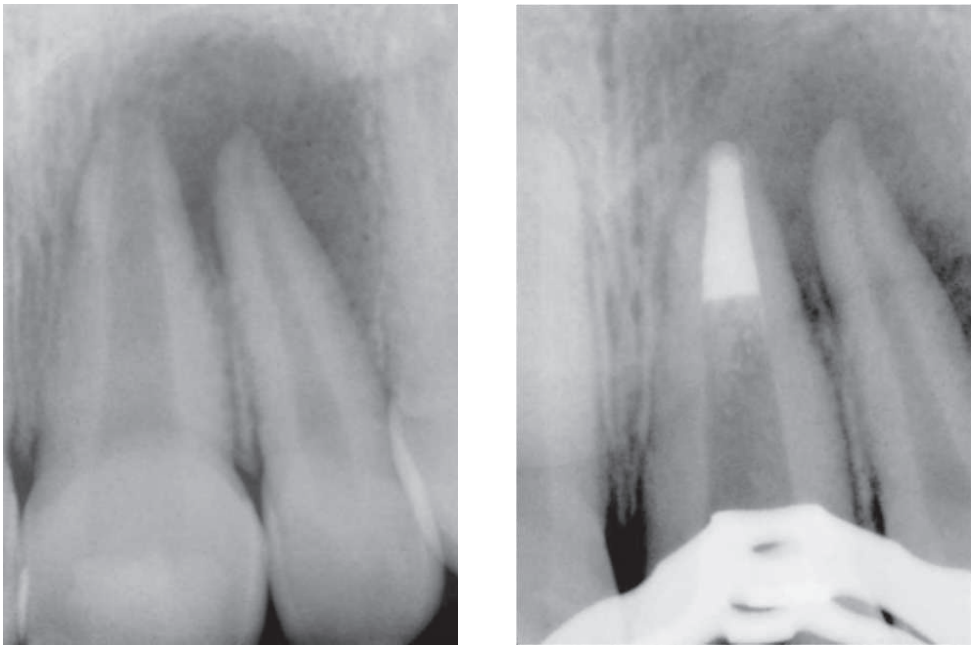
Patient recalled after 3 months

↓

Radiographic evidence of calcific barrier at or near the root apex → No → $Ca(OH)_2$ dressing is changed and patient recalled every 3 months till evidence of calcific barrier is seen

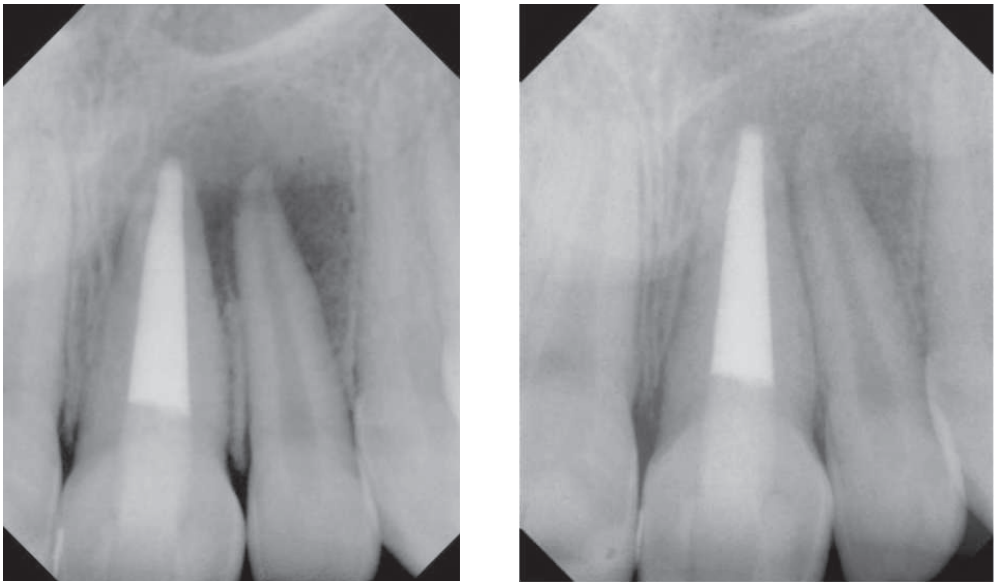
Yes ↓

Obturation using thermoplasticized technique ←



(a) (b)

Figure 11.24 (a) Maxillary central incisor with open apex. (b) Single-visit MTA apical barrier created. *(continued)*



(c) (d)

Figure 11.24 *(continued)* (c) Obturation completed with thermoplasticized obturation. (d) One-year follow-up showing the tooth being clinically and radiographically asymptomatic. (*Courtesy: Julian Webber, England.*)

Box 11.6

Single-Visit Apexification Procedure with MTA/CSC

Anesthesia, rubber dam isolation, and access opening

↓

Working length should be at least 2 mm short of the radiographic apex of tooth

↓

Circumferential enlargement is effected by lateral pressure against the walls with a large file

↓

Drying the canal with paper points

MTA	CSC
MTA is mixed in 3:1 ratio using sterile distilled water to wet sand consistency	CSC cement is mixed according to the manufacturer's instruction
↓	↓
The MTA paste is delivered into the canal with an MTA carrier and condensed with prefitted pluggers	The mixed CSC cement is delivered into the canal with a carrier

↓

Material is condensed into a 3–4 mm apical plug

↓

Moist cotton pellet is placed over the MTA/CSC cement

↓

Patient is recalled after 48 hours and the set MTA/CSC cement is verified

↓

Obturation using a thermoplasticized technique

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12 Regenerative Endodontics

Two roads diverged in a wood, I took the one less traveled by,
and that has made all the difference.
—Robert Frost

Current endodontic therapy aims to maintain the health of the pulp in cases of inflammation, but a much-desired objective is the regeneration of a healthy pulp–dentin complex. The management of immature permanent teeth with open apices and pulpal necrosis is a significant challenge. Apexification procedures have been used traditionally for the management of these teeth. However, regenerative endodontic procedures have, of late, emerged as valuable alternatives. The significant contributions in the evolution of regenerative endodontic procedures are listed in **Box 12.1**.

Concept

Normal, sterile granulation tissue should be developed within the root canal for revascularization. This will stimulate the cementoblasts or the undifferentiated mesenchymal cells at the periapex and lead to the formation of a calcific material at the apex and lateral dentinal walls. Conventional calcium hydroxide or mineral trioxide aggregate (MTA)–induced apexification resulted in the formation of a calcific barrier at the apex. On the contrary, regenerative procedures showed normal maturation of root in the radiograph.

Figure 12.1 represents a case of regenerative endodontics on an immature mandibular premolar with 6-year follow-up.

The goals of regenerative endodontic procedures are as follows:

- *Primary goal:* Elimination of symptoms and the evidence of bony healing
- *Secondary goal:* Increased root wall thickness and/or increased root length
- *Tertiary goal:* Positive response to vitality testing

Box 12.1

Historical Background of Regenerative Endodontics

- *Nygaard-Ostby, 1961:* Use of a revascularization procedure for regeneration of the pulp–dentin complex in immature teeth with pulpal necrosis
- *Rule and Winter, 1966:* Use of double antibiotic paste
- *Hoshino, 1993:* Use of triple antibiotic paste
- *Iwaya, 2001:* Evoked intracanal bleeding step
- *Banchs and Trope, 2004:* Case reports on immature mandibular premolars

Definitions

- *Regenerative endodontics* are biologically based procedures designed to replace damaged structures, including dentin and root structures, as well as cells of the pulp–dentin complex.
- *Revascularization*, as defined by Andreasen, is the restoration of the vascularity to a tissue or organ.
- *Repair* is the restoration of tissue continuity without the loss of original architecture and function.
- *Revitalization* is described as an ingrowth of vital tissue that does not resemble the original lost tissue.

COMPONENTS OF REGENERATIVE ENDODONTICS

Figure 12.2 demonstrates the three key elements of tissue regeneration, namely, stem cells, growth factors, and scaffold.

STEM CELLS

According to Diogenes et al., regenerative endodontic procedures are stem cell–based therapies. Stem cells are undifferentiated cells that are capable of differentiating into various specialized cell types. They can be pluripotent or multipotent in nature. These cells are located in specialized regions within the tissues termed *stem cell niches*. The various types of stem cells are listed in **Box 12.2**.

According to Hargreaves, the first five stem cells listed in **Box 12.2** are the most commonly employed stem cells in regenerative endodontics. These cells have the capability of differentiating into odontoblast-like cells facilitating a progressive repopulation of the radicular pulp space, promoting organized tissue repair, angiogenesis, and reinnervation. **Figure 12.3** presents the schematic representation of stem cells.

GROWTH FACTORS

Biological factors regulate stem cells to form the desirable cell type. There are five major families of growth factors, of which bone morphogenetic proteins (BMPs) are significant for tooth regeneration. These factors promote the differentiation of mesenchymal stem cells into odontoblast-like cells.

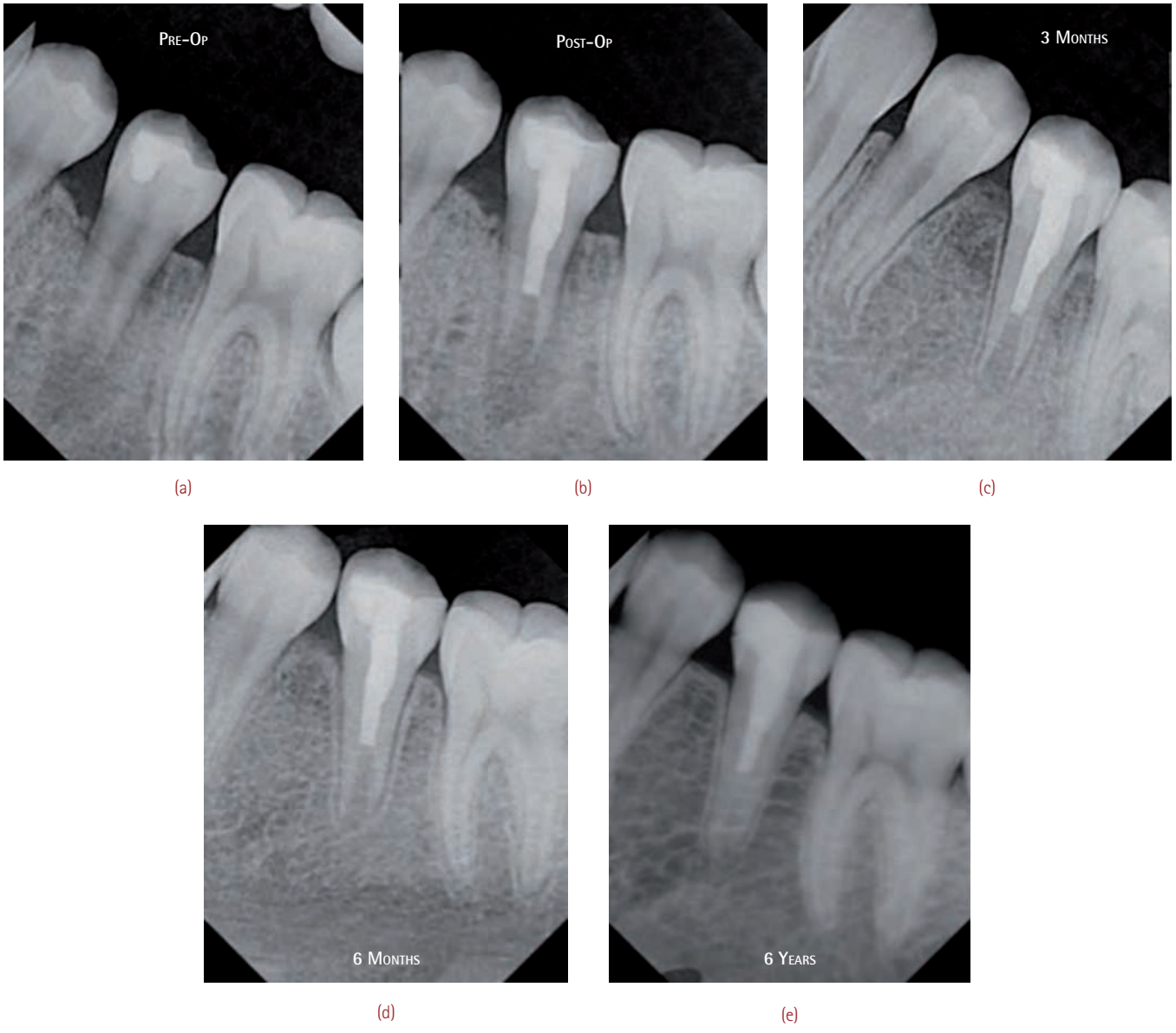


Figure 12.1 Case of regenerative endodontic treatment on an immature mandibular premolar with a 6-year follow-up. (a–e) Progressive root development can be appreciated. (*Courtesy: Jason J. Hales, USA.*)

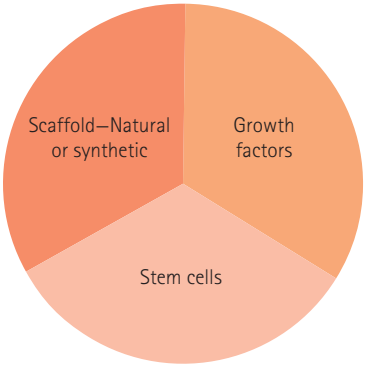


Figure 12.2 The three key elements of tissue regeneration.

Box 12.2

Types of Stem Cells

1. Stem cells of the apical papilla (SCAP)
2. Dental pulp stem cells (DPSCs)
3. Inflamed periapical progenitor cells (iPAPCs)
4. Periodontal ligament stem cells (PDLSCs)
5. Bone marrow stem cells (BMSCs)
6. Stem cells from human exfoliated deciduous teeth (SHED)
7. Tooth germ progenitor cells (TGPCs)
8. Dental follicle stem cells (DFSCs)
9. Salivary gland stem cells (SGSCs)

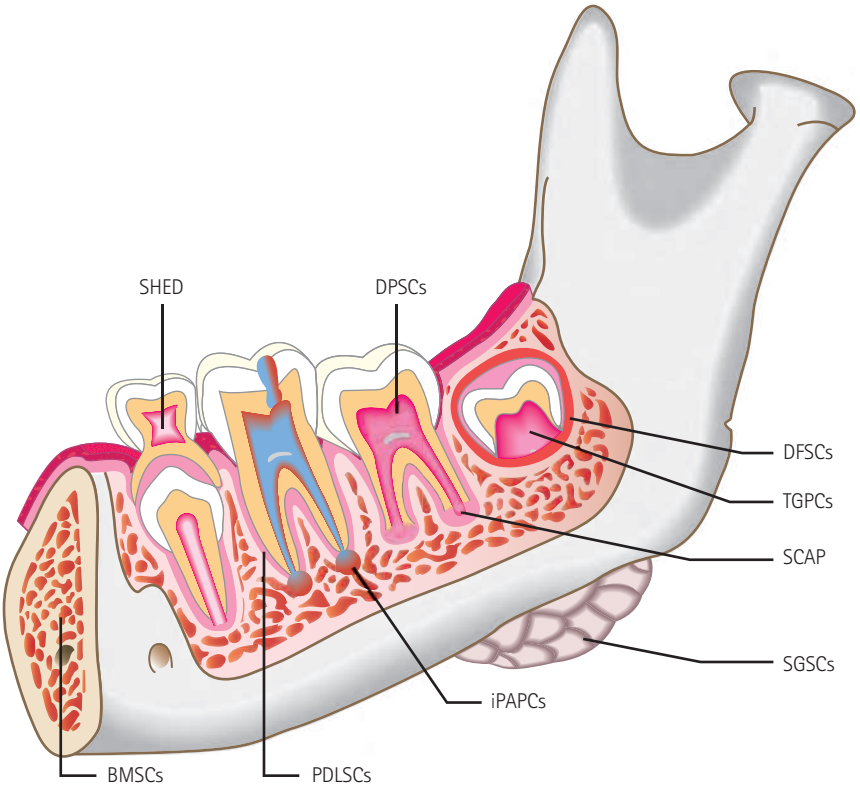


Figure 12.3 Schematic representation of the potential sources of postnatal stem cells in the oral environment. Cell types include tooth germ progenitor cells (TGPCs), dental follicle stem cells (DFSCs), salivary gland stem cells (SGSCs), stem cells of the apical papilla (SCAP), dental pulp stem cells (DPSCs), stem cells from human exfoliated deciduous teeth (SHED), periodontal ligament stem cells (PDLSCs), inflamed periapical progenitor cells (iPAPCs), and bone marrow stem cells (BMSCs). (Adapted from Hargreaves, K.M., Diogenes, A., Teixeira, F.B.: Treatment options: biological basis of regenerative endodontic procedures. *J. Endod.*, **39**(3 Suppl):S30–43, 2013.)

SCAFFOLD

Scaffold is a three-dimensional structure that contains growth factors. It has the following functions:

- Supports cell organization and vascularization
- Aids stem cell proliferation and differentiation
- Leads to improved and faster tissue development
- Contains nutrients to promote cell survival and growth
- May contain antibiotics to prevent bacterial ingrowth in the canal systems
- Mechanical and biological functions

Classification

Scaffolds can be classified as natural and synthetic:

I. *Natural:* Collagen, platelet-rich plasma, fibrin, and glycosaminoglycans
II. *Synthetic:* Polylactic acid, polyglycolic acid (PGA), and poly(lactic-*co*-glycolic) acid (PLGA)

Natural polymers offer good biocompatibility and bioactivity while synthetic polymers elaborate physiochemical features such as degradation rate, microstructure, and mechanical strength.

Platelet-Rich Fibrin

Platelet-rich fibrin (PRF), introduced by Choukroun in 2001, is one of the most commonly used scaffolds in regenerative endodontic procedures. The fibrin matrix contains a large quantity of platelet and cytokines. Fibrin helps in migration of fibroblasts and endothelial cells and is the source of growth factors that aid in revascularization. **Box 12.3** depicts the steps involved in the preparation of PRF.

MECHANISM OF REVASCULARIZATION

According to Shah et al., the possible mechanisms by which the process of revascularization takes place are as follows:

- A few *vital pulp cells* remaining at the apical end of the root canal might proliferate into the newly formed matrix and differentiate into odontoblasts. This may happen under the influence of the cells of Hertwig's epithelial root sheath, which are quite resistant to destruction, even in the presence of inflammation. Atubular dentin is laid down by the odontoblasts at the apical end of the canal and on lateral aspects of dentinal walls of the root canal. This leads to apexogenesis and reinforcing and strengthening of the root, respectively.

Box 12.3

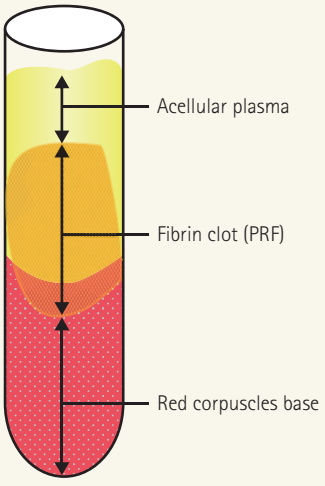
Steps Involved in the Preparation of Platelet-Rich Fibrin (PRF)

Patient's own intravenous blood collected in a sterile test tube without an anticoagulant

↓

Centrifugation performed at 3000 rpm for 10 minutes

↓



The following three layers are formed:
(1) Upper straw-colored acellular plasma
(2) Lower fraction: Red-colored, containing red blood cells (RBCs)
(3) Middle fraction containing the fibrin clot

↓

The upper straw-colored layer is then removed and the middle fraction is collected which is platelet-rich fibrin (PRF)

- Continued root development could be due to *multipotent dental pulp stem cells*, which are present abundantly in immature permanent teeth. These cells from the apical end might be seeded onto the existing dentinal walls and might differentiate into odontoblasts and deposit tertiary or atubular dentin.
- *Stem cells in the periodontal ligament* can proliferate and grow into the apical end and within the root canal. They may deposit hard tissue both at the apical end and on the lateral root walls. The evidence in support of this hypothesis is presented by documentation of cementum and Sharpey's fibers in the newly formed tissues.
- The fourth possible mechanism of root development could be attributed to stem cells of the apical papilla (*SCAP*) or to the *bone marrow*. Instrumentation beyond the confines of the root canal to induce bleeding can also transplant mesenchymal stem cells from the bone into the canal lumen. These cells have extensive proliferating capacity.
- The *blood clot* is a rich source of growth factors such as platelet-derived growth factor, vascular endothelial growth factor, platelet-derived epithelial growth factor, and tissue growth factor. These could play an important role in regeneration.

CLINICAL PROTOCOL

INDICATIONS

- Teeth with necrotic pulp and an immature apex in young patients.
- Good patient compliance
- No known allergies to antibiotics if intended for use
- Good periodontal status
- Patient with no bleeding or clotting disorders

Boxes 12.4 and **12.5** depict the protocol for regenerative endodontic procedures.

Clinical Note

A 30-G side vent needle is recommended to be placed 2 mm short of working length during all irrigation steps of regenerative endodontics.

Box 12.4

Regenerative Endodontic Therapy (First Appointment)

Informed consent obtained, local anesthesia, isolation under rubber dam, and access cavity preparation

↓

Remove loose or necrotic pulp tissue using suitable endodontic instruments and avoid mechanical instrumentation of the root canal walls.

↓

Irrigation with 20 ml of 1.5% NaOCl for 5 minutes followed by irrigation with 20 ml of Saline followed by irrigation with 20 ml of 17% EDTA for 5 minutes

↓

Dry the canal with paper points

↓

Placement of intracanal medicament

↓

Calcium hydroxide OR Low concentration (0.1–1.0 mg/ml) triple antibiotic paste

↓

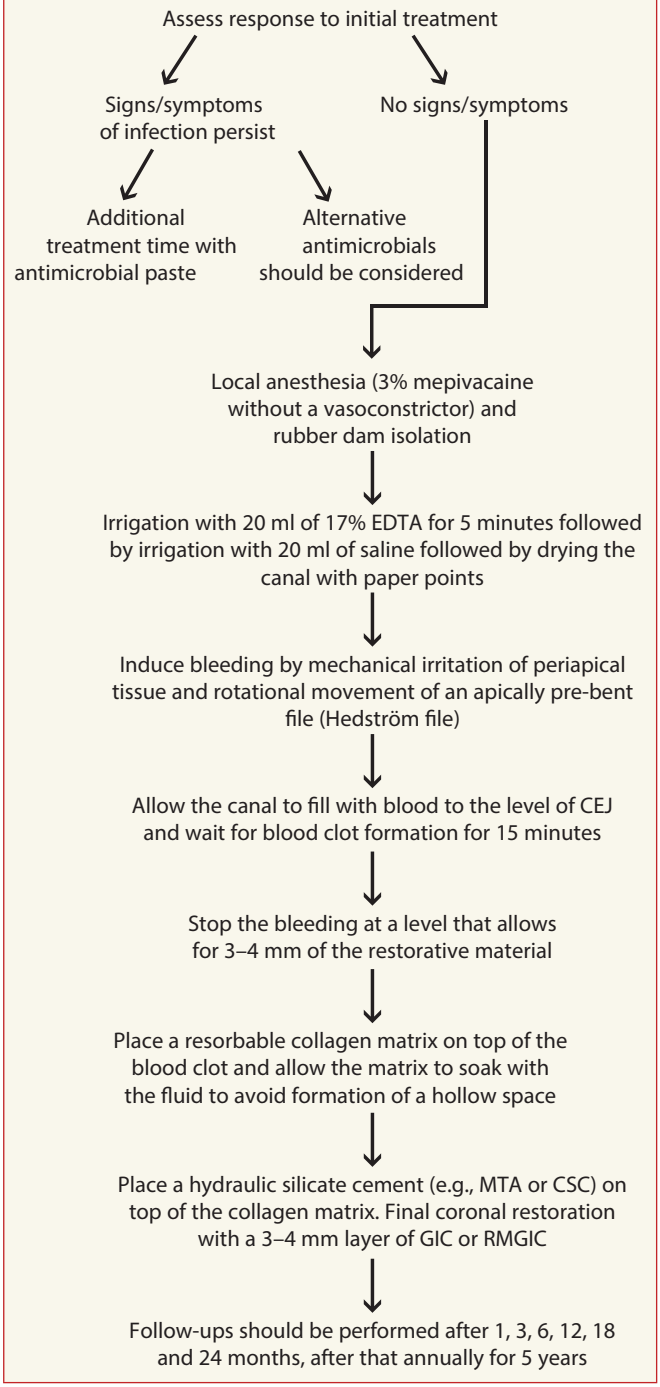
Temporary seal with 3–4 mm of Cavit/IRM/glass ionomer

↓

Recall patient after 2–4 weeks

Box 12.5

Regenerative Endodontic Therapy (Second Appointment Two to Four Weeks Later)



CONTRAINDICATIONS

- Avulsed teeth immediately after replantation (as revitalization may occur naturally).
- Impossibility of adequate tooth isolation.
- Teeth that require restoration with a post.
- Medically compromised patients.

Table 12.1 Antibiotic Pastes Employed in Regenerative Endodontics

Agent	Description
Triple antibiotic paste ("3 mix")	Ciprofloxacin, metronidazole, minocycline (1:1:1) in a macrogol/propylene glycol vehicle
Modified triple antibiotic paste	Ciprofloxacin, metronidazole, cefaclor
Double antibiotic paste	Ciprofloxacin, metronidazole
Calcium hydroxide	Calcium hydroxide paste

ROLE OF ANTIBIOTIC PASTE

The success of the regenerative endodontic procedure depends on the effective disinfection of the canal. Antibiotic pastes are a combination of more than one antibiotic mixed into a consistency of a paste (**Table 12.1**). They are advocated as an effective alternative to calcium hydroxide that has been traditionally used for intracanal disinfection.

The triple antibiotic paste is the most commonly advocated type and the following guidelines have to be ensured when employing an antibiotic paste:

- Concentration is adjusted to 0.1–1.0 mg/mL (100–1000 µg of each drug/mL).
- Deliver the paste into the canal system with a syringe.
  - It remains below cemento-enamel junction (CEJ; minimize crown staining).
  - The pulp chamber is sealed with a dentin-bonding agent to avoid the risk of staining.

Clinical Note

- Regenerative endodontic procedures rely on chemical disinfection rather than on mechanical instrumentation of the root canal space.
- Aggressive shaping and cleaning procedures could damage the fragile and relatively thin root canals walls of immature incompletely developed permanent teeth.
- Lower concentration of NaOCl is recommended for irrigation due to the cytotoxic effects of higher NaOCl concentration on stem cells.
- A final rinse with 17% ethylenediaminetetraacetic acid (EDTA) is recommended during irrigation as it is found to promote the bioavailability of growth factors such as transforming growth factor-beta (TGF-β) and dentin sialoprotein (DSP) in the dentin matrix. These stimulate stem cell proliferation and differentiation.
- Owing to the discoloration potential of MTA, alternatives should be considered in teeth where there is an esthetic concern.

FOLLOW-UP

- Clinical and radiographic examination
- There should be no pain, soft-tissue swelling, or sinus tract formation

- Resolution of periradicular radiolucency (6–12 months after treatment)
- Increase in the width of root canal walls (12–24 months after treatment)
- Increased root length
- Pulp vitality test

ADVANTAGES

- Obturation of the canal is not required unlike in calcium hydroxide–induced apexification (inherent danger of splitting the root during lateral condensation can be avoided).
- After control of infection, the procedure can be completed in a single visit.

DISADVANTAGES

- Discoloration due to use of minocycline in triple antibiotic paste (revealed by Kim et al.)
- Prolonged treatment period and more appointments (compared with one-visit MTA apical barrier technique)

SUCCESS CRITERIA

- No pain;
- No signs and symptoms of inflammation;
- Healing of pre-existing bony periapical lesion;
- Increase of root thickness and length;
- Absence of external root resorption;
- Positive response to sensibility testing;
- Patient acceptance;
- No unacceptable color changes;
- Radiographic detection of a new PDL along the inner wall of the root canal.

POTENTIAL CAUSES OF FAILURE

- Poor root development (absence of increase in root length, absence of increase in root wall thickness, or lack of formation of tooth apex)
- Insufficient bleeding during the procedure
- Root canal calcification/obliteration

In cases of regenerative endodontic procedures not showing clinical signs of success, the clinician is recommended to attempt alternative endodontic procedures as depicted in cases shown in **Figures 12.4–12.6**.

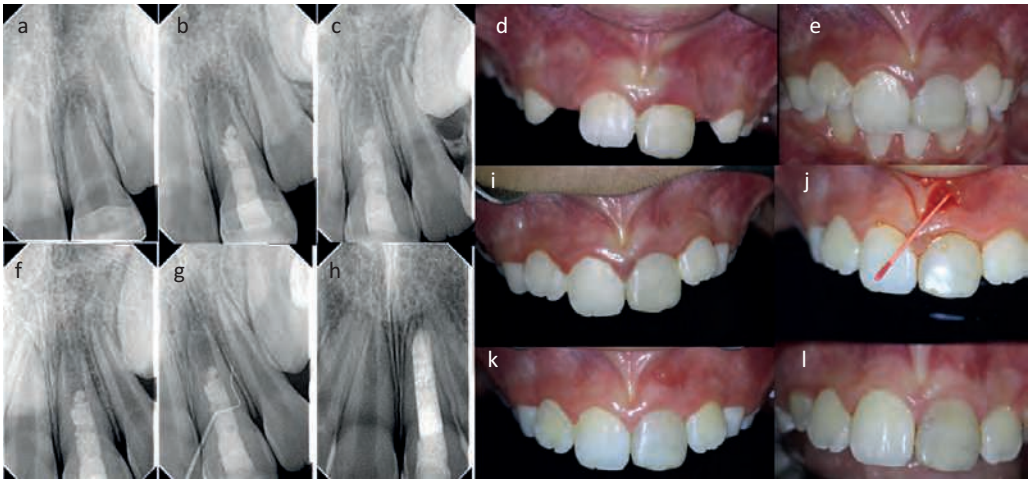


Figure 12.4 (a) Preoperative periapical radiograph of maxillary central incisor indicating the existence of periapical lesion and thin dentinal walls. (b) Postoperative radiograph of tooth 9 after single-step regenerative endodontic procedure. (c) Two-year follow-up periapical radiograph showing healing of the periapical lesion and unaltered dentinal walls. (d) Preoperative clinical image showing slight discoloration of the crown and healthy soft tissues. (e) Two-year follow-up clinical image showing increased discoloration of the crown. (f) Three-year follow-up periapical radiograph showing unaltered dentinal walls and unclear periapical tissues. (g) Four-year follow-up radiograph with sinus tract showing unaltered dentinal walls and recurrence of the periapical disease. (h) Five-year follow-up radiograph suggesting uneventful healing of the recurrent periapical disease after MTA plug placement, possible apical closure below the MTA plug, and thin dentinal walls. (i) Three-year clinical image showing healthy soft tissues. (j) Four-year clinical image with sinus tract present. (k) Four-year clinical image after 1-week dressing with calcium hydroxide showing resolution of sinus tract and healthy soft tissues. (l) Five-year follow-up clinical image showing healthy soft tissues and discolored crown. (*Courtesy: Antonis Chaniotis, Greece.*)



Figure 12.5 (a) Preoperative periapical radiograph of maxillary central incisor showing periapical lesion growing in the mesial side of the periapex and incomplete apical closure. (b) Postoperative periapical radiograph after single-step regenerative endodontic procedures. (c) Six-month follow-up radiograph demonstrating partial healing of the periapical lesion and signs of apical closure and dentinal wall thickening. (d) Preoperative clinical image showing a buccal swelling and fractured crown. (e) Postoperative clinical image after single-visit regenerative procedure and composite resin restoration. (f) Thirteen-month follow-up radiograph showing recurrence of the periapical disease, fracture of the coronal restoration, and convergent apical dentinal walls. (g) Postoperative radiograph after conventional retreatment procedures revealing a lateral canal and slight material extrusion. (h) Three years after the initial treatment follow-up radiograph suggesting almost complete healing of the periapical lesion. (i) Six-month clinical image demonstrating resolution of the initial buccal swelling and no discoloration. (j) Twelve-month clinical image demonstrating the reappearance of the sinus tract. (k) Postoperative clinical image after conventional retreatment procedures and composite resin restoration repair. (l) Three-year clinical image after the initial regenerative effort showing healthy soft tissues and no discoloration. (*Courtesy: Antonis Chaniotis, Greece.*)

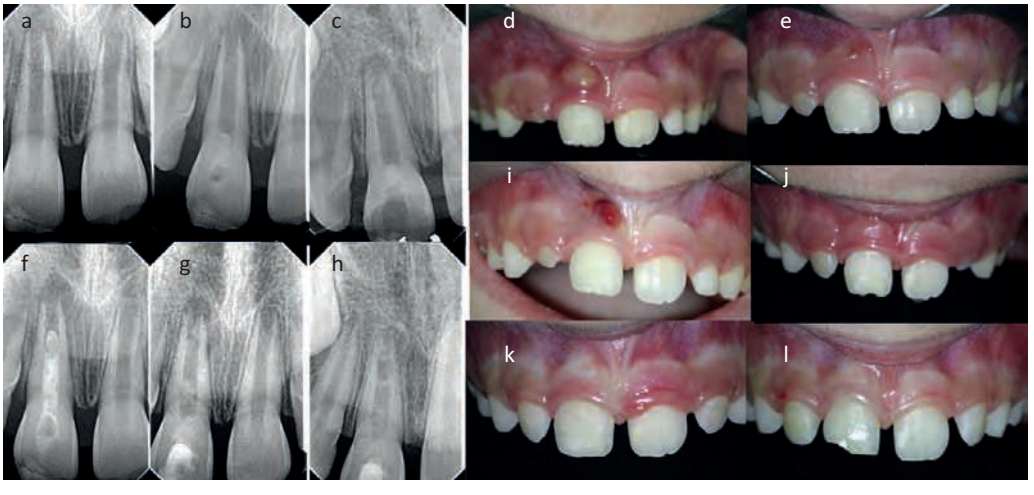


Figure 12.6 (a) Preoperative periapical radiograph of maxillary central incisor showing thin dentinal walls and periapical lesion. (b) Postoperative radiograph after single-step regenerative procedures with Biodentine coronal plug. (c) Six-month follow-up periapical radiograph showing unaltered dentinal walls and existence of periapical lesion. (d) Preoperative buccal clinical view showing buccal swelling. (e) Three-month buccal clinical view showing initial resolution of the buccal swelling. (f) Six-month follow-up radiograph after retreatment procedures and calcium hydroxide placement showing periapical lesion and unaltered walls. (g) One-year follow-up radiograph after removal of calcium hydroxide and repetition of the regenerative endodontic procedure showing unaltered walls and partial healing of the periapical lesion. (h) Three-year follow-up radiograph revealing healing of the periapical lesion, dentinal wall thickening, apical closure, and a hard tissue bridge at the middle third of the canal. (i) Six-month buccal clinical view demonstrating the reappearance of the sinus tract. (j) Twelve-month buccal clinical view showing resolution of the sinus tract after calcium hydroxide placement. (k) Twelve-month buccal clinical view after repetition of the regenerative endodontic procedure and composite resin restoration. (l) Three-year follow-up buccal clinical view after the repetition of the regenerative endodontic procedure. (*Courtesy: Antonis Chaniotis, Greece.*)

CONCLUSION

Regenerative endodontics holds promise of restoring pulp–dentin complex in teeth with immature roots and necrotic pulps. This procedure has potential advantages versus traditional treatment procedures of increasing root wall thickness and root length while maintaining immune competency. Still, significant scientific hurdles need to be overcome with continued growth in knowledge and armamentarium.

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13 Anatomy of Pulp Cavity and its Access Opening

Of all the phases of anatomic study in the human system, one of the most complex is the pulp cavity morphology.
—M.T. Barrett

The external morphologic features of the crowns of teeth vary according to the shape and size of the head. The length of the crown differs with the size and gender of the person and is generally shorter in females than in males. As the external morphology of the tooth varies from person to person, so does the internal morphology of the crown and root. Changes in pulp cavity anatomy result from age, disease, and trauma. Although morphologic variations occur, clinical experience indicates that these changes usually follow a general pattern, and thus the study of pulp cavity morphology is an important undertaking.

PULP SPACE

The pulp space is the central cavity within a tooth and is entirely enclosed by dentin except at the apical foramen (**Fig. 13.1**). The pulp space may be divided into the following:

- A coronal portion → *Pulp chamber*
- A radicular portion → *Root canal*

PULP CHAMBER

In anterior teeth, the pulp chamber gradually merges into the root canal, and this division becomes indistinct. In multirooted teeth, the pulp space consists of a single pulp chamber and usually three root canals, although the number of canals can vary from one to four or more.

- *Roof* of the pulp chamber consists of dentin covering the pulp chamber occlusally or incisally (**Fig. 13.1**).
- *Pulp horn* is an accentuation of the roof of the pulp chamber directly under a cusp or developmental lobe. The term refers more commonly to the prolongation of the pulp itself directly under a cusp.
- *Floor* of the pulp chamber runs parallel to the *roof* and consists of dentin bounding the pulp chamber near the cervical area of the tooth, particularly dentin forming the furcation area.
- The *canal orifices* are openings in the floor of the pulp chamber leading into the root canals. The canal orifices are not separate structures, but are continuous with both the pulp chamber and the root canals. The walls of the

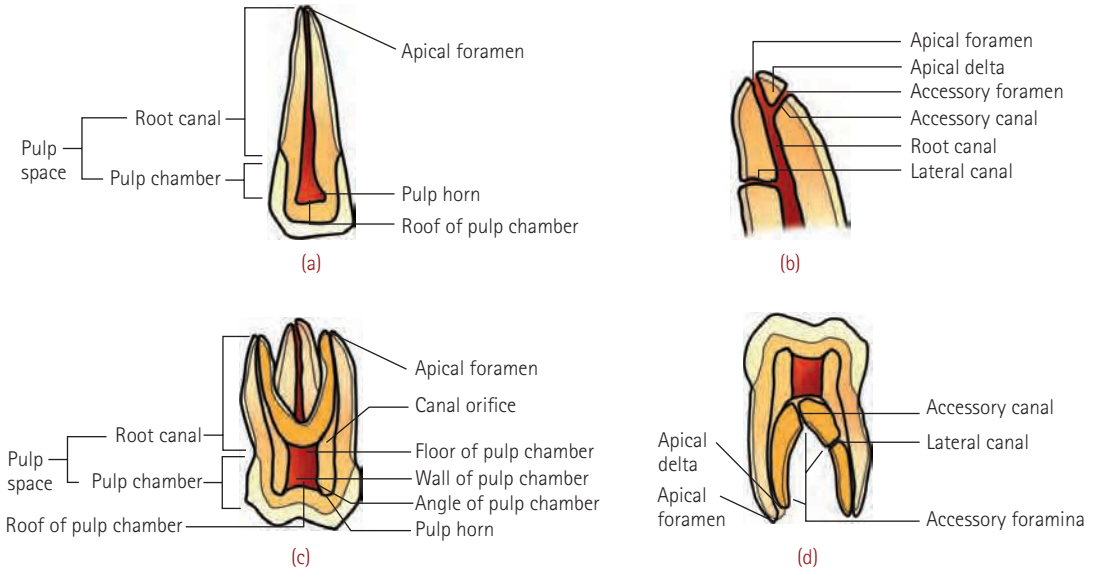


Figure 13.1 Various views of the root canal system: (a) Labial view of a central incisor. (b) Apical third of a root. (c) Buccal view of a maxillary first molar. (d) Buccal view of a mandibular first molar.

pulp chamber derive their names from the corresponding walls of the tooth surface, such as the buccal wall of a pulp chamber. The angles of a pulp chamber derive their names from the walls forming the angle, such as the mesiobuccal (MB) angle of a pulp chamber (**Fig. 13.1**).

ROOT CANALS

The root canal is the portion of the pulp space from the canal orifice to the apical foramen. For convenience, it may be divided into three sections, namely: *coronal*, *middle*, and *apical* thirds.

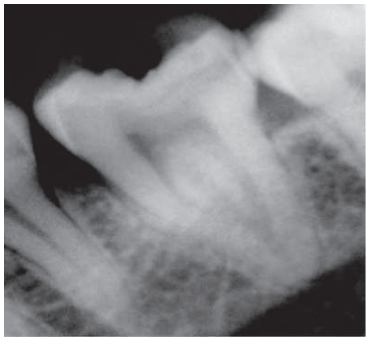
- *Accessory canals*, or *lateral canals*, are lateral branching of the main root canal generally occurring in the apical third or furcation area of a root (**Fig. 13.1**).
- *Lateral canal* is an accessory canal that branches to the lateral surface of the root and may be visible on a radiograph.
- *Apical foramen* is an aperture at or near the apex of a root through which the blood vessels and nerves of the pulp enter or leave the pulp cavity.
- *Accessory foramina* are the openings of the accessory and lateral canals in the root surface (**Fig. 13.1**).

A straight root canal extending the entire length of the root is uncommon. Either a constriction is present before the apex is reached or, as is often the case, a curvature is present. The curvature may be:

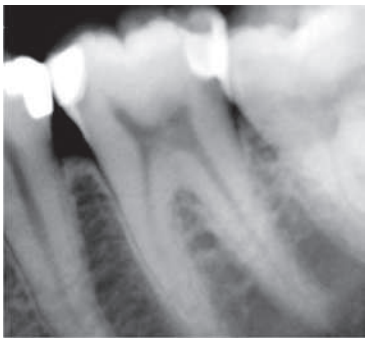
- A straight canal extending with minimal apical curvature



- A gradual curvature of the canal with a straight apical ending



- A gradual curvature of the entire canal



- A sharp curvature of the canal near the apex





A curvature of about 20° in a narrow root canal may be difficult or even impossible to negotiate with endodontic instruments, whereas a curvature of even 30° may be negotiated if the root canal is wide. Success in negotiating a narrow, curved canal depends on the following:

- Degree of curvature
- Size and constriction of the root canal
- Size and flexibility of the endodontic instrument blade
- Skill of the operator

Clinical Note

In most cases, the number of root canals corresponds with the number of roots, but a root may have more than one canal.

- Mesial root of the mandibular first molar almost always has two canals, which sometimes meet in a common foramen.

- Distal root of the mandibular first molar occasionally has two canals.
- Mesiobuccal root of the maxillary first molar frequently has two canals.
- Pulp chamber of a mandibular anterior or premolar tooth may be bifurcated to present two separate root canals.

Although variations are the norm in root canal configurations, various researchers have classified them according to the number of canals, intracanal branching and fusion, and exit from the canal. The various classifications proposed are as give in the subsequent text.

I. VERTUCCI'S CLASSIFICATION (Fig. 13.2)

- *Type I:* **(1)** Single canal extends from the pulp chamber to the apex.
- *Type II:* **(2–1)** Two separate canals leave the pulp chamber and join short of the apex to form one canal.
- *Type III:* **(1–2–1)** One canal leaves the pulp chamber and divides into two in the root; the two then merge to exit as one canal.
- *Type IV:* **(2)** Two separate distinct canals extend from the pulp chamber to the apex.
- *Type V:* **(1–2)** One canal leaves the pulp chamber and divides short of the apex into two separate distinct canals with separate apical foramina.
- *Type VI:* **(2–1–2)** Two separate canals leave the pulp chamber, merge in the body of the root, and redivide short of the apex to exit as two distinct canals.
- *Type VII:* **(1–2–1–2)** One canal leaves the pulp chamber, divides and then rejoins in the body of the root, and finally redivides into two distinct canals short of the apex.
- *Type VIII:* **(3)** Three separate distinct canals extend from the pulp chamber to the apex.

II. WEINE'S CLASSIFICATION (Fig. 13.3)

- *Type I:* Single canal from the pulp chamber to the apex
- *Type II:* Two canals leaving the chamber and merging to form a single canal short of the apex
- *Type III:* Two separate and distinct canals from the chamber to the apex
- *Type IV:* One canal leaving the chamber and dividing into two separate and distinct canals

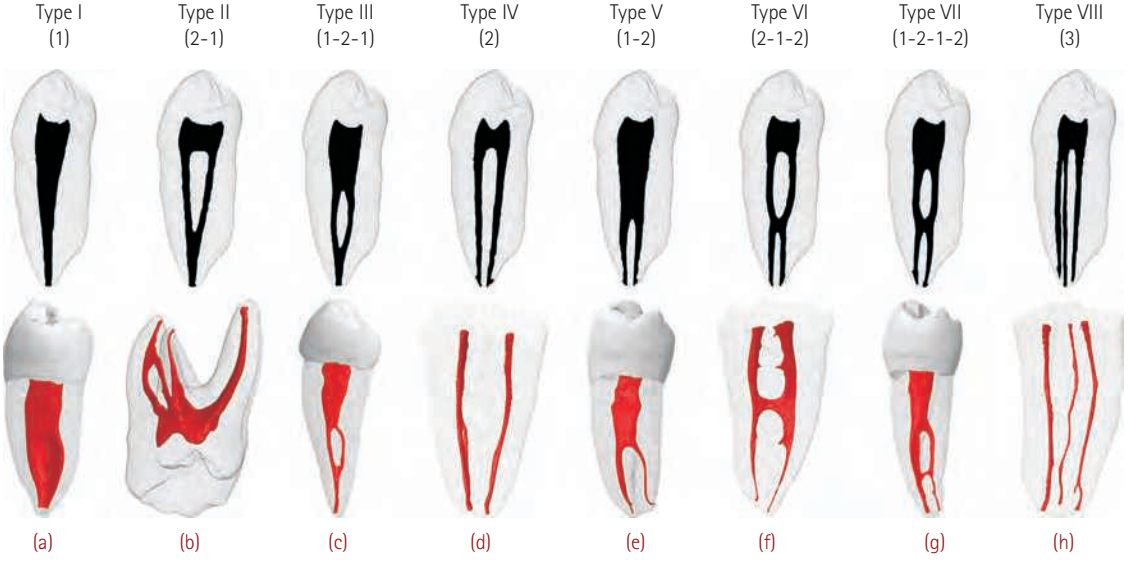


Figure 13.2 Vertucci's root canal configurations. Above: diagrammatic representation of 8 different root canal configurations found by Vertucci et al. (1974) using 200 cleared maxillary second premolars, which had their pulp cavities stained with dye. Below: three-dimensional micro-computed tomographic models of different teeth representing the Vertucci's root canal configurations. (a) Type I (1 configuration): mandibular second premolar presenting a single canal from the pulp chamber to the apex. (b) Type II (2–1 configuration): mesiobuccal root of a maxillary first molar showing two separate canals leaving the chamber, but merging short of the apex to form a single canal. (c) Type III (1–2–1 configuration): mandibular first premolar showing a single canal that divides into two, and subsequently merges to exit as one. (d) Type IV (2 configuration): mesial root of a mandibular second molar showing two distinct canals from the pulp chamber to the apex. (e) Type V (1–2 configuration): mandibular first premolar showing a single canal leaving the chamber and dividing into two separate canals at the apex. (f) Type VI (2–1–2 configuration): mesial root of a mandibular first molar showing two separate canals leaving the pulp chamber, merging in the body of the root, and dividing again into two distinct canals short from the apex. (g) Type VII (1–2–1–2 configuration): mandibular first premolar showing a single canal that divides, merges, and exits into two distinct canals short from the apex. (h) Type VIII (3 configuration): mesial root of a mandibular first molar showing three distinct canals from the pulp chamber to the apex. (*Courtesy: Marco Versiani, Pecora, and Sousa-Neto, Brazil.*)

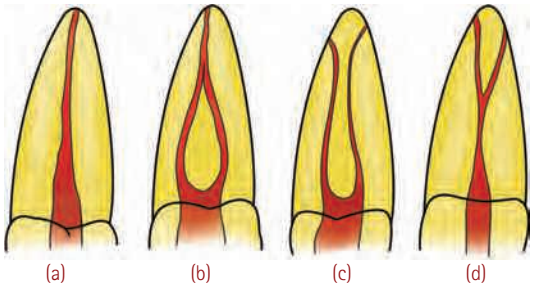


Figure 13.3 Weine's classification of root canal anatomy: (a) Type I. (b) Type II. (c) Type III. (d) Type IV.

III. CLASSIFICATION BASED ON CANAL CROSS-SECTION

According to Jou et al., canals can vary based on their anatomy cross-sectionally:

- Round (circular)
- Oval
- Long oval
- Flattened (flat/ribbon)
- Irregular

ISTHMUS

Kim et al. have classified the isthmus into the following categories (**Fig. 13.4**):

- *Type I:* Faint communication between two canals
- *Type II:* Complete isthmus with a definite connection between two canals
- *Type III:* A complete but very short isthmus between two canals
- *Type IV:* Complete or incomplete isthmus between three or more canals
- *Type V:* Two or three canal openings without visible connections

APICAL FORAMEN

- In young, incompletely developed teeth, the apical foramen is funnel shaped, with the wider portion extending outward. The mouth of the funnel is filled with periodontal tissue that is later replaced by dentin and cementum.
- As the root develops, the apical foramen becomes narrower (**Fig. 13.5**).
- The inner surface of the root apex becomes lined with cementum, which may even extend for a short distance (1 mm or so) into the root canal. The *cementodentinal junction* (CDJ), therefore, does not necessarily occur at the extreme end of the root, but may occur within the main root canal.
- ***Apical constrictions are found 0.5–1.0 mm away from the root apex.***
- The apical foramen is ***not*** *always the most constricted portion of the root canal.* Constrictions can and do occur before the extremity of the root is reached.
- The apical foramen is *not always located in the center of the root apex.* It may exit on the mesial, distal, labial, or lingual surface of the root, usually slightly eccentrically (**Fig. 13.6**).
- Anatomic studies have shown that the apical foramen coincides within the anatomic apex in only 17–46% of cases and it is located at an average of 0.4–0.7 mm away from the anatomic apex. In a few cases, the apical foramen has been found as much as 2–3 mm away from the anatomic apex.

Clinical Note

- Studies have led to the recommendation that root canal obturation should end approximately *0.5–1.0 mm short of the anatomic root apex* as seen in the radiograph.
- *It is not necessary to shape, clean, or fill root canals to their anatomic apices, but rather to the cementodentinal junction, which usually lies within the canal just short of the apex.*

Knowledge of the age at which calcification of the root apex occurs is essential for endodontic practice, particularly when dealing with pulp-involved or pulpless teeth of children and young persons. As a general rule, a root apex is completely formed about 2–3 years after eruption of the tooth. **Table 13.1** gives the approximate time (in years) of eruption of the teeth and calcification of the root apices. Endodontic treatment of young teeth does not affect normal eruption.

LATERAL CANALS AND ACCESSORY FORAMINA

- Lateral canals and accessory foramina have been found with enough regularity to prove that they are integral parts of a normal pulp space rather than exceptions (**Fig. 13.7**).
- The periodontal vessels curve around the root apex of a developing tooth and often become entrapped in Hertwig's epithelial root sheath, resulting in the formation of lateral canals and accessory foramina during calcification.

Table 13.1 Age of Tooth Eruption and Calcification of Root Apices

	Central Incisor	Lateral Incisor	Cuspid	First Premolar	Second Premolar	First Molar	Second Molar
Eruption	6–8	7–9	10–12	9–11	11–12	5–7	12–13
Calcification	10–12	11–12	13–14	12–14	13–14	10–11	15–16

Note: The values are in years.

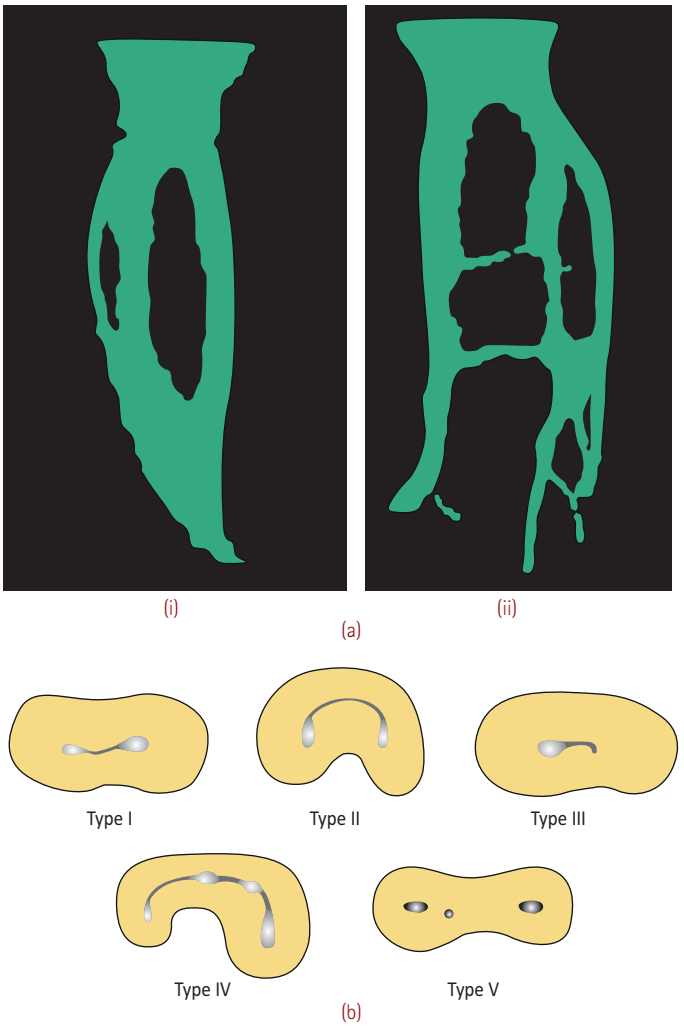


Figure 13.4 (a) (i) Two dentin fusion areas in C-shaped canal system. Partial dentin fusion area may appear in the coronal and/or middle portion of the canal system. (ii) Two canal interconnections between mesial canal and distal canal in C-shaped canal system. Canal interconnections may exist between mesial canal and distal canal. (*Courtesy: Prof. Bing Fan China.*) (b) Schematic representation of isthmus classification described by Kim et al.

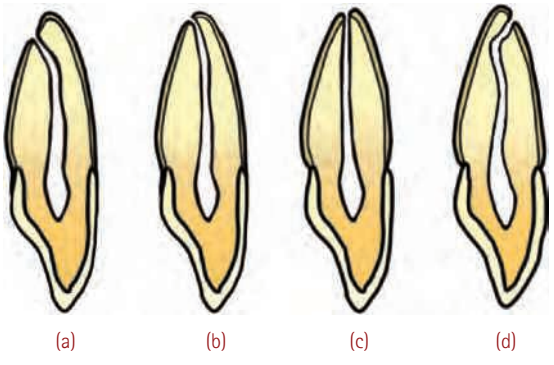


Figure 13.5 Various courses taken by root canals and locations of apical foramina: (a) Curved root canal with the apical foramen distant from the root apex. (b) Curved root canal with the foramen near the apex. (c) Constricted root canal as the apical foramen is approached. (d) Double curvature of the root canal with the foramen at a distance from the root apex.



Figure 13.6 Scanning electron micrograph of the apex of the mesial root of a maxillary first molar, showing the apical foramen (arrow) and multiple accessory foramina. (*Courtesy: J.M. Brady, USA.*)

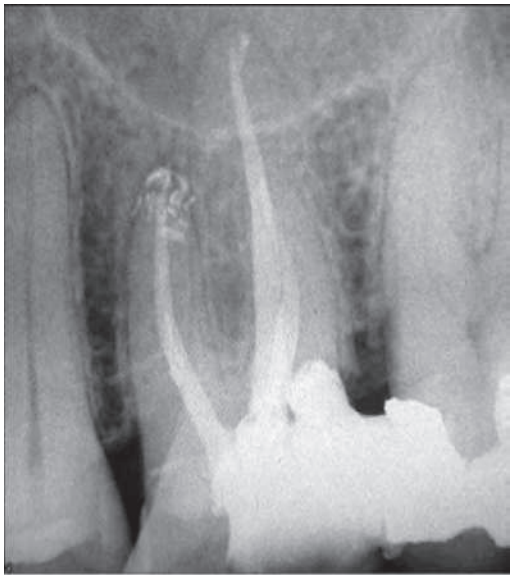


Figure 13.7 Accessory canals filled in a maxillary molar.

Box 13.1

Comparative Assessment of Pulp Space Changes due to Aging

Pulp Space in Young Person	Pulp Space Changes due to Aging
• Pulp horns are long.	• Pulp horns recede.
• Pulp chambers are large.	• Pulp chambers become smaller in height rather than in width.
• Root canals are wide.	• Root canals become narrower by deposition of secondary and reparative dentin.
• Apical foramina are broad.	• Apical foramina deviate from the exact anatomic apex. Their minor diameter becomes narrower, while their major diameter becomes wider from the deposition of dentin and cementum.
• Dentinal tubules are wide, regular, and filled with protoplasmic fluid.	

- This phenomenon frequently occurs in the apical third of the root which explains the *high incidence of lateral canals and accessory foramina in the apical third.*
- Lateral canals may also occur in the *area of bifurcation or trifurcation of multirooted teeth*. These canals result from the entrapment of the periodontal vessels during the fusion of the parts of the diaphragm that become the floor of the pulp chamber. The reported incidence of lateral canals ranges from 27.4 to 35.5%.
- Pulp tissue lies within a dentinal enclosure of the accessory or lateral canal. When the pulp is removed, the blood vessels lying within the accessory or lateral canals are sealed or obliterated by cementum, unless injury occurs, whether mechanical, chemical, or bacterial. With increasing age, the accessory foramina diminish in number because of calcification of their contained soft tissue.

INFLUENCE OF AGING ON PULP SPACE

The size and shape of the pulp space are influenced by age (**Box 13.1**).

TOOTH ANATOMY AND ITS RELATION TO THE PREPARATION OF ACCESS OPENING

Micro-CT images of the most common root canal configurations in all groups of teeth are depicted in **Figure 13.8**.

GOALS OF ACCESS CAVITY PREPARATION

According to Vertucci, the following are the objectives of access cavity preparation:

- Removal of all carious tooth structure
- Conservation of sound tooth structure
- Complete deroofing of the pulp chamber
- Removal of coronal pulp tissue (vital and necrotic)
- Location of all root canal orifices
- Straight line access to the root canal

CLINICAL GUIDELINES FOR ACCESS CAVITY PREPARATION

I. PREOPERATIVE CONSIDERATIONS

A. Armamentarium for Access Cavity Preparation

- Front surface mouth mirrors
- Airotor and slow-speed rotary handpieces
- Burs: These include the following:
  - Round carbide burs (No. 2, No. 4, and No. 6) for caries removal and defining the external outline shape
  - Diamond burs with round cutting ends for axial wall extensions (**Fig. 13.9**)
  - Fissure carbide burs and diamond burs with safety tips (**Fig. 13.10**)
  - Round diamond burs for entry into teeth with porcelain or ceramometal restorations and transmetal burs for teeth with metal restorations
  - Extended long shank burs such as Mueller burs (Brasseler, USA) and LN burs (Dentsply Maillefer, USA) for calcified teeth
- Endodontic spoon excavator (**Fig. 13.11a**)
- Endodontic explorers, e.g., DG-16 (**Fig. 13.11b**)
- Additional aids
  - Magnification and illumination aids
  - Ultrasonic tips (**Fig. 13.12**)
  - Micro-openers and microdebriders

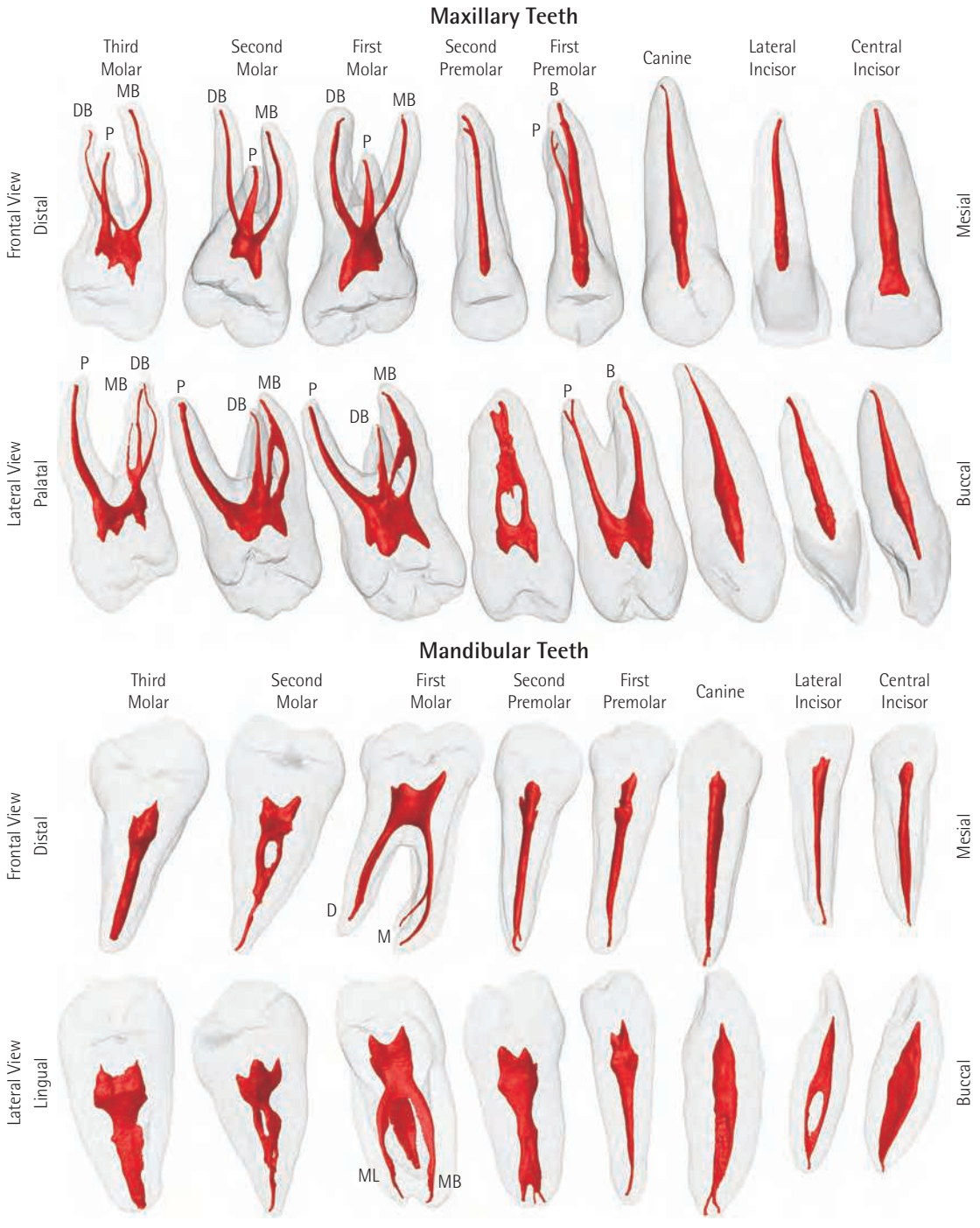


Figure 13.8 Micro-computed tomographic three-dimensional models of the most common root canal configurations in all groups of teeth. In most of the teeth, the common root canal morphology is the presence of one canal per root with the exception of the mandibular incisors, the maxillary premolars, the mesiobuccal root of the maxillary first molar, and the mesial root of mandibular molars, which have two root canals. B, buccal; D, distal; DB, distobuccal; M, mesial; MB, mesiobuccal; P, palatal; ML, mesiolingual. (*Courtesy: Marco Versiani, Pecora, and Sousa-Neto, Brazil.*)



Figure 13.9 Diamond burs with rounded cutting ends. (*Courtesy: Dentsply Sirona.*)



Figure 13.10 Fissure carbide burs with non-end cutting safety tips. (*Courtesy: Dentsply Sirona.*)

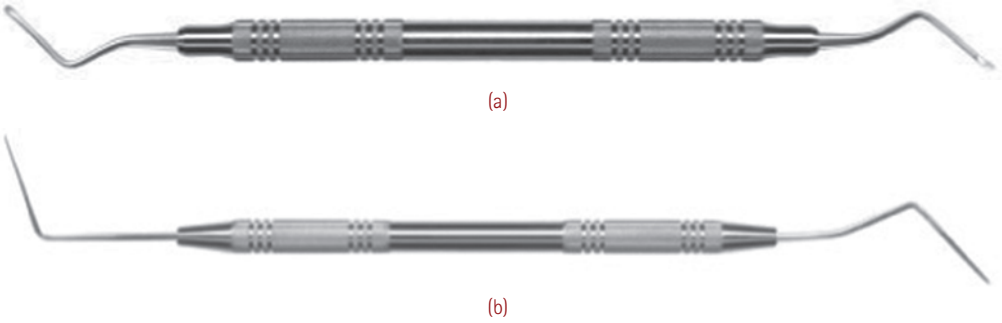


Figure 13.11 (a) Endodontic excavator. (b) DG-16 endodontic explorer. (*Courtesy: Hu-Friedy Mfg. Co., USA.*)



Figure 13.12 Start X ultrasonic tips 1, 2, 3, and 5 for access refinement. (*Courtesy: Dentsply Sirona.*)

B. Assessment of Occlusal Tooth Anatomy

The following clinical observations are indicative of an unusual root canal anatomy (**Fig. 13.13**):

- Presence of an additional cusp
- Abnormality in the size and shape of the tooth

Major principle of the endodontic cavity outline form: *The internal anatomy of the tooth (pulp) dictates the external outline form.* This is accomplished by extending preparation from the inside of the tooth to the outside surface, that is, working from inside to outside.

Size and shape of endodontic coronal preparations relates to the size and shape of the pulp and chamber.

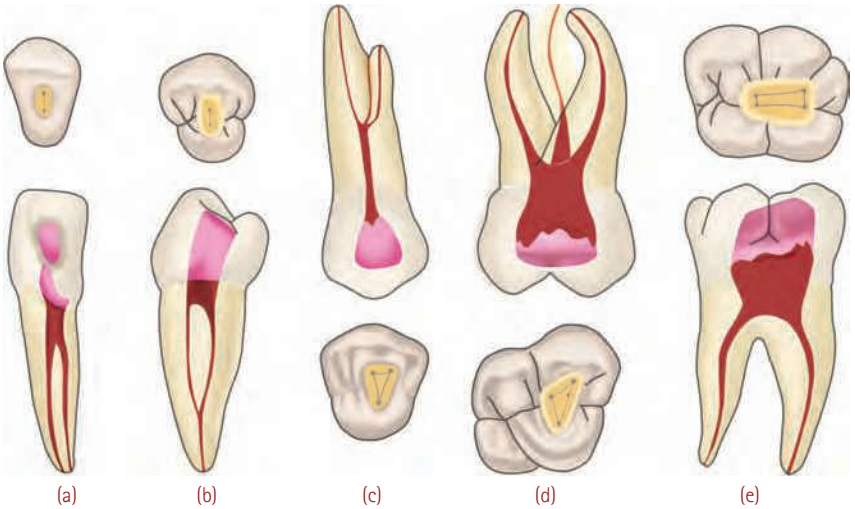
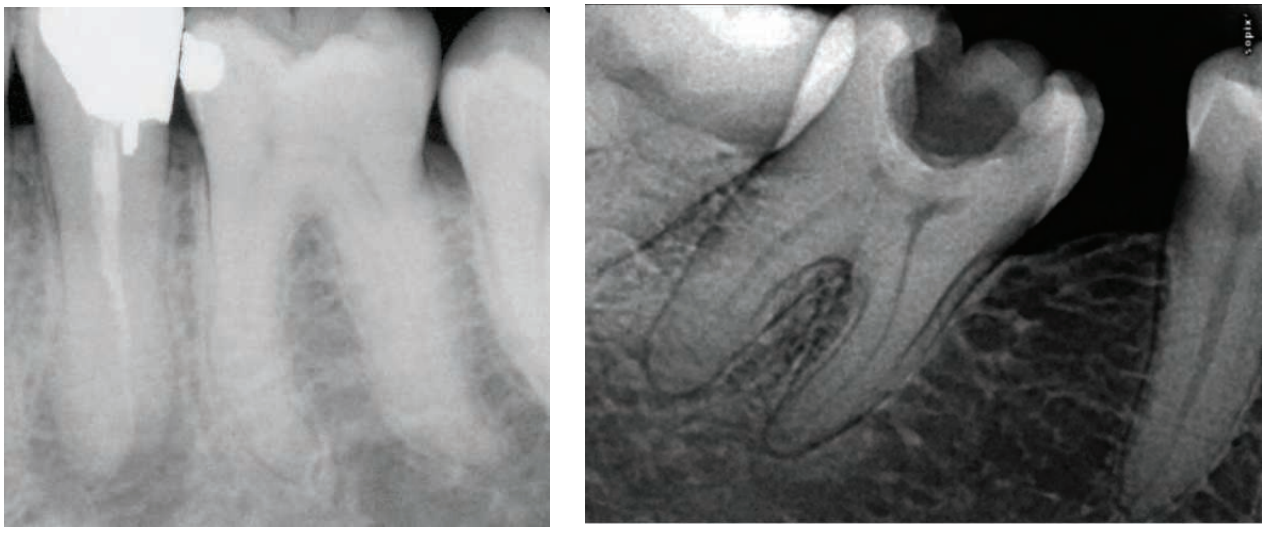


Figure 13.13 Clues in locating extra root canals: (a) Prominent cingulum of a mandibular incisor; an extra canal may be found lingually. (b) Prominent lingual cusp of a mandibular bicuspid; extra canal may be found lingually. (c) Prominent buccal cusp and wide crown mesiodistally; a mesiobuccal canal or root may be found in the maxillary first premolar. (d) Prominent buccal cusp and wide crown buccolingually on the mesial half in the maxillary molar; a second mesiobuccal canal may frequently be found. (e) Where unusually small canals are seen, an extra canal may be found, as in the distal root of a mandibular molar.



(a) (b)

Figure 13.14 (a) Mandibular second premolar with unusual root canal anatomy. (b) Mesial tilting of mandibular second molar in a patient with a history of extraction of the first molar 6 years back.

C. Complicating Factors

Access cavity preparation would be challenging and has to be prepared carefully in the following conditions:

- Rotated teeth/malpositioned teeth
- Tipping/mesial tilting of the tooth (**Fig. 13.14b**)
- Grossly decayed teeth
- Teeth with full-coverage restorations
- Abutment teeth of fixed prostheses
- Teeth with extensive calcifications

D. Radiographic Assessment

The most important prerequisite for successful access cavity preparation is having a sound knowledge of the root canal anatomy and its variations. Visualization of the internal anatomy of the tooth can be done using preoperative periapical radiographs. **Box 13.2** presents some of the features that can be visualized using periapical radiographs.

Box 13.2

Preoperative Radiographic Assessment (Fig. 13.14)

- Mesiodistal tilt of the tooth
- Size and shape of the pulp chamber
- Thickness of the roof of the pulp chamber
- Presence of pulp stones
- Variations in the number of canals and/or roots
- Extent of root and canal curvature
- Radiographic changes in the furcation and/or periradicular region

II. CLINICAL CONSIDERATIONS

A. Complete Removal of Carious Tooth Structure and Other Restorative Material

- While preparing the access cavity in a cariously involved tooth, start removing the carious tooth structure *irrespective of the location of the carious lesion*. This would invariably lead into the pulp chamber.
- Hence, in case of a tooth with distal carious tooth structure, the access opening commences from the distal side toward the mesial pulp chamber.

B. Complete Deroofing and Removal of Dentinal Shoulders

- The overhanging roof of the pulp chamber misdirects the instrument, which results in ledge formation in the canal. Hence, *complete deroofing* must be done to obtain unrestricted access to the canals. Removing the roof completely from the pulp chamber will bring canal orifices into view and allow immediate access to each orifice. Using a round bur and working from inside out will accomplish this end. *Removal of the dentinal shoulders* present *between* root canal orifices will help in achieving *straight line access* and improve the clinical access to the root canals (**Fig. 13.15**).

C. Evaluation of the Cementoenamel Junction (CEJ) and Root Canal Orifices

Krasner and *Rankow* in a study of 500 pulp chambers determined that the *CEJ is the most important anatomic landmark for determining the location of pulp chambers and root canal orifices.*

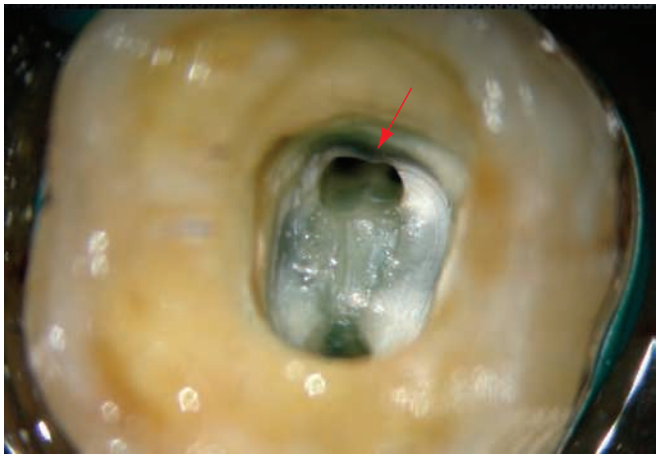


Figure 13.15 Complete deroofing and removal of mesial shoulder in a mandibular molar would facilitate straight line access during the shaping procedure.

Clinical Note

- On entering the roof of the pulp chamber, the operator has to change to a *lateral cutting motion* instead of proceeding in an apical cutting direction.
- The following dentinal shoulders should be taken into consideration to achieve straight line access:
  - Mandibular anteriors → Lingual shoulder
  - Maxillary anteriors → Palatal shoulder
  - Premolars → Mesial and distal shoulders
  - Mandibular molars → Mesial and distal shoulders
  - Maxillary molars → Mesial and buccal shoulders

They demonstrated that specific and consistent pulp chamber floor and wall anatomy exist and proposed laws for assisting clinicians to identify canal morphology. The relationships expressed in these laws are particularly helpful in locating calcified canal orifices. These laws are given in **Box 13.3**.

Clinical Note

- *Champagne bubble test:* When sodium hypochlorite irrigant is allowed to remain within the pulp chamber following access cavity preparation, the appearance of bubbles frothing out from a point in the floor of the pulp chamber is indicative of the presence of a root canal orifice.

D. Significance of Straight Line Access

Removal of the coronal tooth structure is necessary to allow complete freedom of endodontic instruments in the coronal cavity and direct access to the apical canal. This is especially true when the root is severely curved or leaves the chamber at an obtuse angle. Walls are generally reduced with burs or long, thin diamond points and with endodontic files, Gates-Glidden drills, or orifice openers. Burs are rarely used in the floor or immediate orifice area. In the event that a second canal is suspected in the MB root of the maxillary molar, the cavity outline would be extended in both these directions to broaden the search. Depending on the technique used to fill the canal, the outline form may also be expanded to some extent to accommodate pluggers used in obturation.

One of the practical guides for a clinician is to keep looking for distinct color changes (**Box 13.4**) that take place as one goes through various stages of access preparation.

Box 13.3

Krasner and Rankow's Laws of Access Opening

- *Law of centrality:* The floor of the pulp chamber is always located in the center of the tooth at the level of the CEJ.
- *Law of concentricity:* The walls of the pulp chamber are always concentric to the external surface of the tooth at the level of the CEJ.
- *Law of the CEJ:* The distance from the external surface of the clinical crown to the wall of the pulp chamber is the same throughout the circumference of the tooth at the level of the CEJ. The CEJ is the most consistent, repeatable landmark for locating the position of the pulp chamber.
- *Law of symmetry 1:* Except for maxillary molars, the orifices of the canals are equidistant from a line drawn in a mesiodistal direction through the pulp chamber floor.
- *Law of symmetry 2:* Except for maxillary molars, the orifices of the canals lie on a line perpendicular to a line drawn in a mesiodistal direction across the center of the floor of the pulp chamber.
- *Law of color change:* The color of the pulp chamber floor is always darker than the walls.
- *Law of orifices location 1:* The orifices of the root canals are always located at the junction of the walls and the floor.
- *Law of orifices location 2:* The orifices of the root canals are located at angles in the floor–wall junction.
- *Law of orifices location 3:* The orifices of the root canals are located at the terminus of the root developmental fusion lines.

Box 13.4

Law of Color Change

- Enamel → White
- Dentin → Yellow
- Floor of the pulp chamber → Gray
- Root canal orifice → Dark gray or black
- Pulp stone → Pearly white/dark yellow

Clinical Note

- Complete deroofing of the pulp chamber and elimination of dentinal shoulders between root canal orifices will aid in the achievement of straight-line access.
- *Mouse hole effect:* If the lateral wall of the cavity has not been sufficiently extended and the pulpal horn portion of the orifice still remains in the wall, the orifice will have the appearance of a tiny "mouse hole." This feature occurs due to the extension of the canal orifice into the axial wall. By extending the lateral wall of the cavity, thus removing all intervening dentin from the orifice, the "mouse hole" in the wall will be eliminated and the orifice will appear completely on the floor (**Fig. 13.15**).

These changes are much more distinct when the operator employs some form of magnification in the form of either a magnification loupe or a dental operating microscope

The clinically significant features that a clinician should take into consideration before preparing the endodontic access in maxillary teeth are given in **Table 13.2.**

Table 13.2 Clinically Significant Features During Access Preparation of Maxillary Teeth

Tooth	Average Tooth Length	Shape of Pulp Chamber	Roots and Root Canals	Clinically Significant Attributes	Shape of Access Preparation	Most Common Anomalies
Maxillary central incisors	• 22.5–24 mm (average: 23.5 mm)	• Ovoid mesiodistally • Three pulp horns	• One root • One root canal • Broad labiopalatally, large, conical, centrally located	• Majority of roots are straight • Labial perforation most common iatrogenic error	• Rounded triangular shape (base of triangle toward incisal edge)	• Talon Cusp (Dens evaginatus) • Two roots and two canals
Maxillary lateral incisors	• 21.5–23 mm (average: 22 mm)	• Similar to maxillary central incisor • Two pulp horns	• Conical • Finer diameter than that of maxillary central incisor	• Majority of roots have distal curve (53%); others have straight (30%) • Labial perforation most common iatrogenic error	• Similar to central incisors	• Dens invaginatus • Talon cusp (Dens evaginatus) • Palatogingival groove
Maxillary canine	• 26–28 mm (average: 27 mm)	• Largest of any single-rooted tooth • Labiopalatally triangular, mesiodistally narrower	• Single root large • Wider labiopalatally than mesiodistally	• Straight root • Lateral canal present	• Circular to ovoid	• Two roots in rare cases
Maxillary first premolar	• 21.5–23 mm (average: 22.5 mm)	• Narrower mesiodistally • Wider buccopalatally • Pulp horn under each cusp	• Two roots and two canals	• Two distinct canals	• Ovoid buccopalatal diameter wider while mesiodistal diameter narrower	• Three roots and three canals
		• Floor pulp chamber convex • Two canal orifices (buccal and palatal)				
Maxillary second premolar	• 21.5–23 mm (average: 22.5 mm)	• Narrow mesiodistally • Wider buccopalatally	• Single root with two canals in most cases • Rarely two roots	• If one root, one orifice but 50% cases will have two canals and 46% cases have single canal • If two roots, two orifices	• Ovoid buccopalatal diameter wider while mesiodistal diameter narrower	• Three roots and three canals

(*continued*)

Table 13.2 Clinically Significant Features During Access Preparation of Maxillary Teeth (*continued*)

Tooth	Average Tooth Length	Shape of Pulp Chamber	Roots and Root Canals	Clinically Significant Attributes	Shape of Access Preparation	Most Common Anomalies
Maxillary first molar	• Buccal canals: 18–20 mm (average: 19 mm) • Palatal canal: 19–21 mm (average: 20.5 mm)	• Largest in dental arch • Four pulp horns	• Three roots with three to four root canals – Mesiobuccal canal 1 (MB1) – Meisobuccal canal 2 (MB2) – Distobuccal canal (DB1) – Palatal Canal (P)	• Tooth with highest anatomical canal variations • Tooth with highest incidence of missed canals seen clinically during retreatment	• Rhomboid shape • Floor triangular in shape in cross-section	• Three roots and four canals • One root, one canal • Two distal canals • Two palatal roots • Three mesiobuccal canals
Maxillary second molar	• Buccal canals: 17.5–19 mm (average: 18 mm) • Palatal canal: 18.5–19.5 mm (average: 19 mm)	• Similar to maxillary first molar • Narrow mesiodistally	• Three root canal orifices closely grouped	• Distobuccal canal has high incidence of asymmetrical location	• Rhomboid shape. Floor obtuse. Triangular in cross-section • Smaller in dimension than maxillary first molar	• Four rooted molar with two palatal roots
Maxillary third molar	• 16.5–18 mm (average: 17.5 mm)	• Resembles second molar • C-shaped pulp chamber	• Three root canal orifices closely grouped	• Tooth that is most challenging to access and work on clinically	• Rhomboid shape • Smaller in dimension than maxillary second molar	• Anomalies are common

MAXILLARY CENTRAL INCISOR

Average Tooth Length: The average length of this tooth is 23.5 mm.

Pulp Chamber: The pulp chamber of the maxillary central incisor is located in the center of the crown equidistant from the dentinal walls. It is broad mesiodistally, with its broadest part incisally aligned. The pulp chamber usually follows the contours of the crown and has three pulp horns that correspond to the developmental mamelons in a young tooth. The chamber is ovoid mesiodistally. The division between the root canal and the pulp chamber is indistinct.

Root and Root Canal: The maxillary central incisor has one root with one root canal. The root canal is broad labiopalatally, large and simple in outline, conical in shape, and centrally located. A definite apical constriction is present in the mature root canal. In cross-section, the canal is ovoid mesiodistally in the cervical third, ovoid to almost round in the middle third, and round in the apical third.

Clinical Significance:

- Although the majority of the roots are straight (75%), some may curve labially or palatally (17%). The root canal usually follows the direction of the curved root. The palatal and labial curvatures *may not be seen* in a routine radiograph unless taken at different horizontal angulations.
- Lateral canals may be present (24% of specimens), usually in the apical third.
- The labial surface of the root of the maxillary central incisor lies under the labial cortical plate of the maxilla and may fuse with it. Because of the proximity of the labial root surface to the cortical plate, fenestrations and dehiscence may be present, and *abscesses may perforate the labial cortical plate.*
- The relationship between the apex of the maxillary central incisor and the osseous plate in the floor of the nasal cavity depends on the height of the face and the length of the root. Usually, the nasal fossa and the root apex are separated sufficiently so that curettage of granulomatous tissue within the surrounding cancellous bone does not result in perforation of the floor of the nasal fossa. In some patients, the apex of the root is close to the nasal floor and hence an abscess may drain into the nasal fossa or a cyst may bulge into the inferior nasal meatus.
- Labial perforations are the most common iatrogenic errors committed during access preparation.

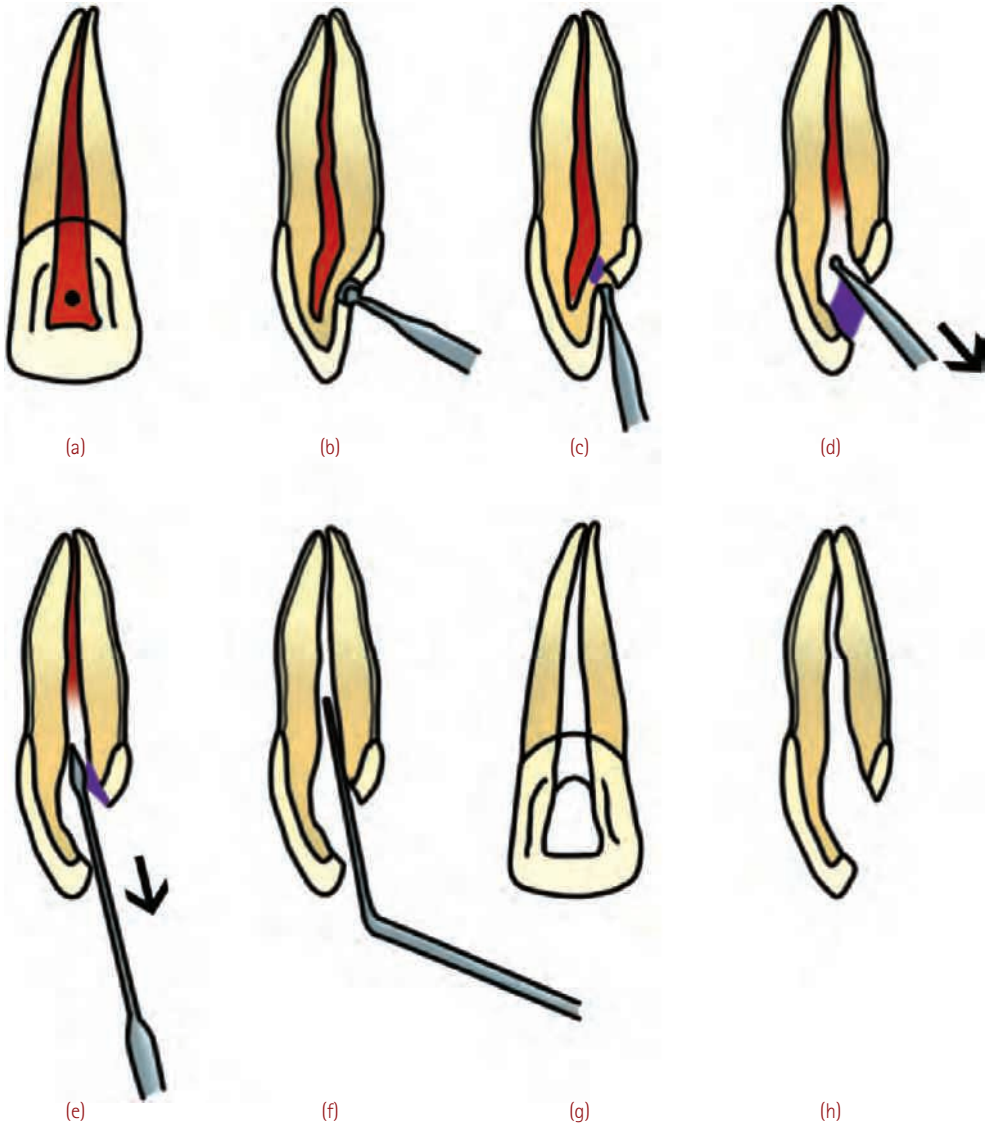


Figure 13.16 Steps in the access opening of a maxillary central incisor. (See text for details.)

Access Opening: The shape, size, and coronal extension of the pulp chamber are estimated from a diagnostic radiograph. The internal anatomic structure of the pulp chamber of the maxillary central incisor dictates the shape and size of the access opening (**Figs 13.16** and **13.17**).

The enamel is penetrated in the center of the lingual surface at an angle perpendicular to it with a No. 4 round bur in a high-speed contra-angle (**Fig. 13.16a** and **13.16b**). After penetration of the enamel, the bur is directed along the long axis of the tooth until the pulp chamber is reached (**Fig. 13.16c**). A "drop" of the bur into the chamber may be felt if the chamber is large enough. The overhanging enamel and dentin of the palatal roof of the pulp chamber are removed, including the pulp horns, with a No. 4 round bur in a slow-speed contra-angle by working from the inside to the outside following the internal anatomy (**Fig. 13.16d**). This procedure makes the access cavity walls confluent with the



Figure 13.17 Clinical access opening in a maxillary central incisor.

lateral and incisal walls of the pulp chamber and renders the access cavity a lingual extension of the pulp chamber, with a *"straight line" penetration* to the apical root canal.

A Gates-Glidden drill of appropriate size (usually No. 3) or any other suitable orifice enlarger is used to remove the palatal shoulder by working from inside to outside with light strokes. The *palatal shoulder* is not an anatomic entity itself, but rather is a prominence of dentin created when the palatal roof is removed (**Fig. 13.16e**). One gains direct access to the apical area of the root canal by removing the palatal roof and the palatal shoulder of the pulp chamber in an anterior tooth (**Fig. 13.16f**). Direct access can be verified by placing the straight end of the endodontic explorer into the canal orifice. The explorer should follow the path of the canal without impedance from the walls of the surrounding access preparation.

Clinical Note

- The shape of the access outline form for all anterior teeth should reflect the shape of the internal anatomic structure of the coronal pulp chamber of each tooth.
- In maxillary incisors, the access shape is *slightly triangular*, with the base of the triangle toward the incisal edge (**Fig. 13.16g** and **13.16h**).
- The usual anatomic structure of the chamber and root canal in any tooth can be altered by the deposition of reparative or secondary dentin, a response often associated with trauma, caries, restorative procedures, or aging. The pulp chambers of these teeth may be reduced in size or completely calcified. **Figure 13.18** depicts the retreatment of a maxillary central incisor and the significance of root canal anatomy on endodontic treatment.

MAXILLARY LATERAL INCISOR

Average Tooth Length: The average length of this tooth is 22 mm.

Pulp Chamber: The shape of the pulp chamber of the maxillary lateral incisor is similar to that of the maxillary central incisor but smaller. It has only two pulp horns, corresponding to the developmental mamelons. It is broad mesiodistally, with its broadest part incisally aligned. The division between the root canal and the pulp chamber is indistinct.

Root and Root Canal: The configuration of the root canal of the maxillary lateral incisor is also conical, but it has a finer diameter than the maxillary central incisor, and occasionally may have a fine constriction in its course toward the apex. In cross-section, the canal is ovoid labiopalatally in the cervical third because of the flatness of the root, ovoid in the middle third, and round in the apical third.

Clinical Note

- Lateral canals occur more frequently in these teeth (26%) than in maxillary central incisors.
- The majority of roots have a distal curve (53%), whereas others are straight (30%).
- As with the central incisor, the labial surface of the root of the maxillary lateral incisor lies under the labial cortical plate of the maxilla; therefore, fenestrations and dehiscence may be present. As this root curves distally, it may be in the center of the cancellous bone pointing toward the palate, and abscesses arising in this area may drain palatally as well as labially.
- The access opening should be more conservative than that of the central incisor. Labial perforation is the most common iatrogenic access opening error.

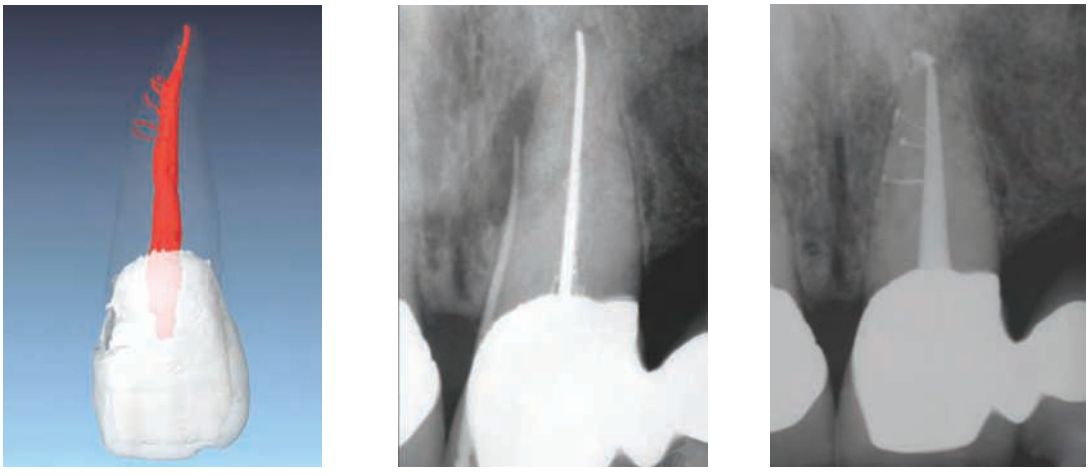


Figure 13.18 Root canal anatomy of a maxillary central incisor: (a) Micro-CT image of a maxillary central incisor. (*Courtesy: Frank Paque, Switzerland.*) (b) Preoperative view of an endodontically failing maxillary central incisor with a lateral periradicular lesion traced with a gutta-percha point. (c) Endodontic retreatment with sealing of lateral canals leading to complete periradicular healing and clinical success. (*Courtesy: Clifford Ruddle, USA.*)

Access Opening: The access opening for the maxillary lateral incisor is similar to that for the maxillary central incisor, but it is smaller and usually more ovoid. The technique for entry is the same as that for the maxillary central incisor, except that a No. 2 round bur may be used instead of a No. 4.

MAXILLARY CANINE

Average Tooth Length: The average length of this tooth is 27 mm, the longest of human teeth. A specimen 33.5 mm in length has been reported.

Pulp Chamber: The pulp chambers of the maxillary canines are the largest of any single-rooted teeth. Labiopalatally, the chamber is triangular in shape, with the apex toward the single cusp and a broad base in the cervical third of the crown. Mesiodistally, it is narrow, resembling a flame. In cross-section, the chamber is ovoid in shape, with a greater diameter labiopalatally. Only one pulp horn is present, corresponding to one cusp. The division between the pulp chamber and the root canal is indistinct.

Root and Root Canal: The single root canal of the maxillary canine is larger than that of the maxillary incisor. It is wider in labiopalatal than in mesiodistal dimension, and on reaching the middle third, it tapers gradually to an apical constriction.

Access Opening: The access opening for the maxillary canine is basically the same as that for the maxillary central and lateral incisors. The only variation is that the shape of the access opening is circular to ovoid, as dictated by pulp chamber anatomy. The technique for entry is the same as that for the maxillary central and lateral incisors (**Fig. 13.19**).

Anomalies: The maxillary canine has two roots in rare cases.

The common access opening errors in maxillary anterior teeth are illustrated in **Figure 13.20.**

Clinical Note

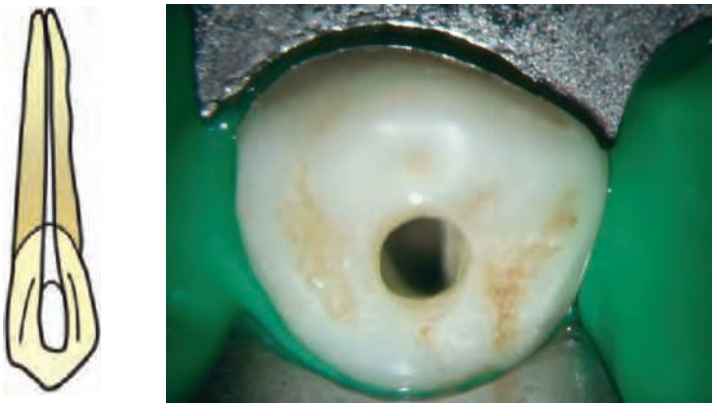
- One report noted straight roots in 39% of cases, whereas in 32% the roots curved distally.
- Lateral canals are present in 30% of cases.
- The root of the maxillary canine is positioned in the cancellous bone of the maxilla between the nasal cavity and the maxillary sinus, called the canine pillar. The labial surface of the root lies under the labial cortical plate and may fuse with it. Because of its great size, it causes the most prominent bulge in the maxilla, called the *alveolar* or *canine eminence*. The size and proximity of the root to the cortical plate may produce fenestrations and dehiscences in that plate.
- An abscess originating in the maxillary canine usually perforates the labial cortical plate below the insertion of the levator muscles of the upper lip and drains into the buccal vestibule. If the perforation occurs above this insertion, the abscess will drain into the canine space and will cause *cellulitis*.
- Apical curettage may be difficult during periradicular procedures because of the length of the tooth.

MAXILLARY FIRST PREMOLAR

Average Tooth Length: The average length of this tooth is 22.5 mm.

Pulp Chamber: The pulp chamber of the maxillary first premolar is narrow mesiodistally. It has a pulp horn under each cusp, but both may be missed in routine radiographic projections because of superimposition of one over the other. It is wide buccopalatally, and the buccal pulp horn is more prominent than the palatal in young teeth. The floor of the pulp chamber is convex, usually with two canal orifices, one buccal and the other palatal, and it lies deep in the coronal third of the root below the cervical line. In cross-section, the pulp chamber is wide and ovoid in a buccopalatal dimension.

Roots and Root Canals: The maxillary first premolar has two roots in 54.6% of cases. In 21.9% of the double-rooted



(a) (b)

Figure 13.19 (a and b) Access opening in a maxillary canine tooth.

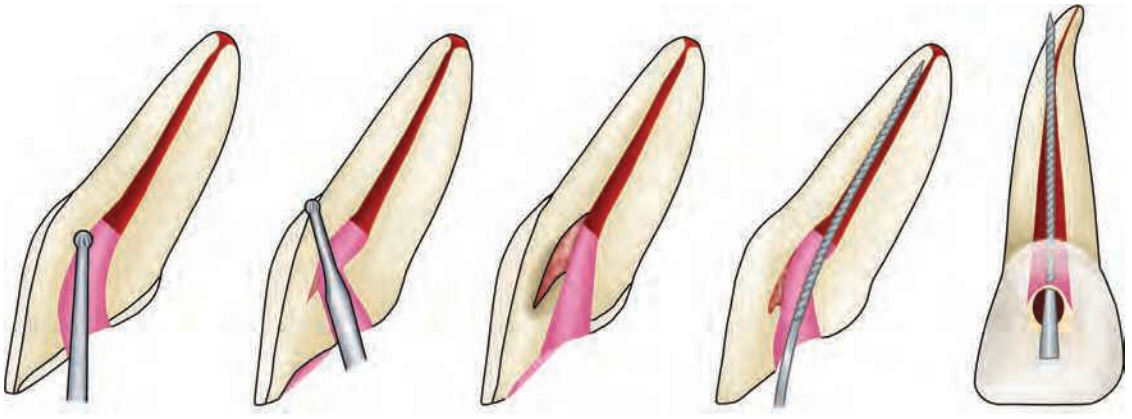


Figure 13.20 Common errors in access openings of maxillary anterior teeth: (a) Gouging. (b) Perforation of crown. (a) and (b) are caused by not directing the bur parallel to the long axis of the tooth after initial penetration. (c) Discoloration. (d) Ledge with inadequate cleaning and shaping of canal. (e) Perforation of root.

Table 13.3 Root Canals and Apical Foramina in Maxillary First Premolars

Investigators	One Canal and One Foramen (%)	One Canal and Two Foramina (%)	Two Canals and One Foramen (%)	Two Canals and Two Foramina (%)	Three Canals (%)
Pineda and Kuttler	26.2	7.7	23.9	41.7	0.5
Green	8.0	–	26.0	66.0	–
Cams and Skidmore	9.0	–	13.0	72.0	6.0
Vertucci and Gegauff	8.0	7.0	18.0	62.0	5.0
Bellizzi and Hartwell	6.2	–	–	90.5	3.3

cases, the roots are separated, whereas in 32.7%, the roots are partially fused (**Table 13.3**).

When fused roots occur, a groove running in an occlusoapical direction divides the root into buccal and palatal portions, each containing a single root canal. The maxillary first premolar lies in its alveolar socket below the maxillary sinus and is separated from it by a thin layer of spongy and compact bone. The buccal surface of a single- or double-rooted maxillary first premolar is in close proximity to the buccal cortical plate. The proximity of these roots to the cortical plate may produce a fenestration or a dehiscence in that plate.

Clinical Note

- The buccal canal is directly under the buccal cusp, and its orifice can be penetrated by following the buccal wall of the pulp chamber.
- The palatal canal is generally the larger of the two canals; it is directly under the palatal cusp, and its orifice can be penetrated by following the palatal wall of the pulp chamber.
- In teeth with single roots, majority of the roots are straight (38.4%) and an almost equal number have a distal curve (36.8%).
- Regardless of whether maxillary first premolars have one or two roots, they have two root canals at the apex in 69% of cases.

Access Opening: By measuring the shape, size, and extension of the pulp chamber mesially, distally, and coronally in the diagnostic radiograph, one can determine the approximate size, shape, depth, and location of the coronal access cavity to be prepared. The internal anatomic structure of the pulp chamber of the maxillary first premolar dictates the shape and size of the access opening (**Fig. 13.21a**).

Using a No. 2 round carbide bur in a high-speed contra-angle, one penetrates the enamel in the center of the occlusal surface between the buccal and lingual cusps, and the bur is directed into the long axis of the tooth (**Fig. 13.21b**). Then a bur aligned to the long axis of the tooth is used to penetrate through the dentin into the pulp chamber (**Fig. 13.21c**). The operator frequently feels the bur "drop" into the pulp chamber when the chamber is large. Using the radiographic measurement, one penetrates deep enough to remove the roof of the pulp chamber without cutting into the chamber floor; one should avoid an access opening that is too shallow and exposes only the pulp horn tips, which may appear to be root canal orifices (**Fig. 13.21h** and **13.21i**).

To remove the roof of the pulp chamber, one should place the bur alongside the walls of the chamber and cut occlusally (**Fig. 13.21d**). A tapered cylinder, self-limiting diamond bur is used to remove the remaining roof of the pulp chamber

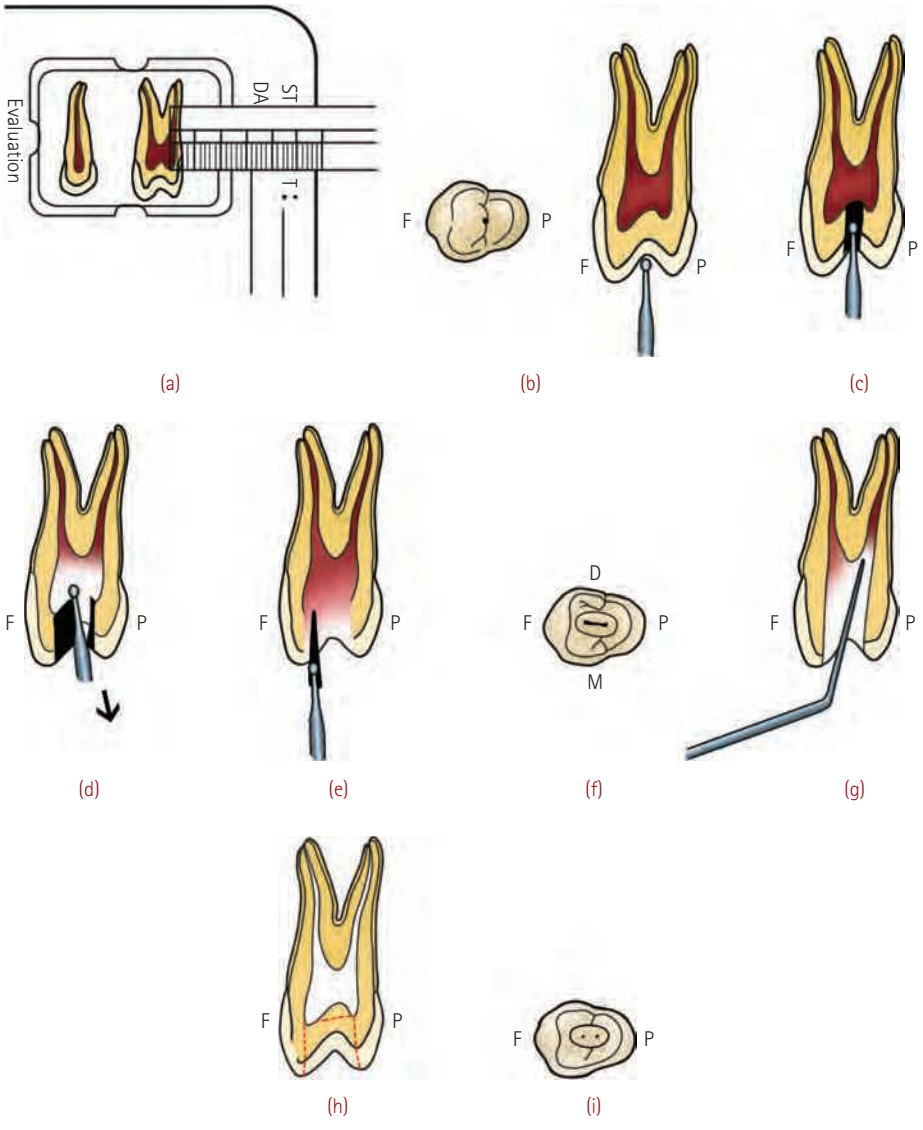


Figure 13.21 Steps in the access opening of a maxillary first premolar. (See text for more details.) D, distal; F, facial; M, mesial; P, palatal.

(**Fig. 13.21e**). The walls of the access cavity are smoothened and are sloped slightly toward the occlusal surface with this diamond. The divergence of the access cavity walls creates a positive seat for the entrance filling.

Clinical Note

The border of the ovoid access cavity of a maxillary premolar should not extend beyond half the lingual incline of the facial cusp and half the facial incline of the palatal cusp (**Fig. 13.21f**).

The access cavity preparation for endodontic treatment of a premolar differs from Black's cavity preparation for an occlusal restoration (class I). In Black's preparation, the ovoid shape runs mesiodistally and encompasses all pits and fissures, whereas the endodontic preparation runs ovoid in a buccolingual direction (**Fig. 13.22**) and permits direct access

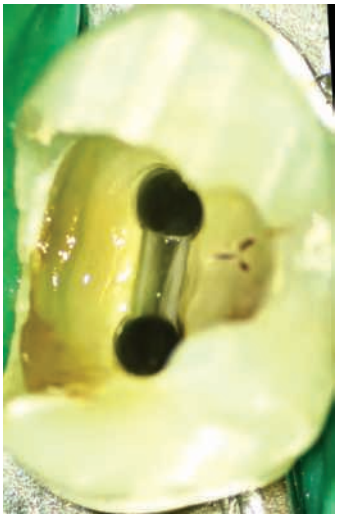


Figure 13.22 Access opening of a maxillary premolar.

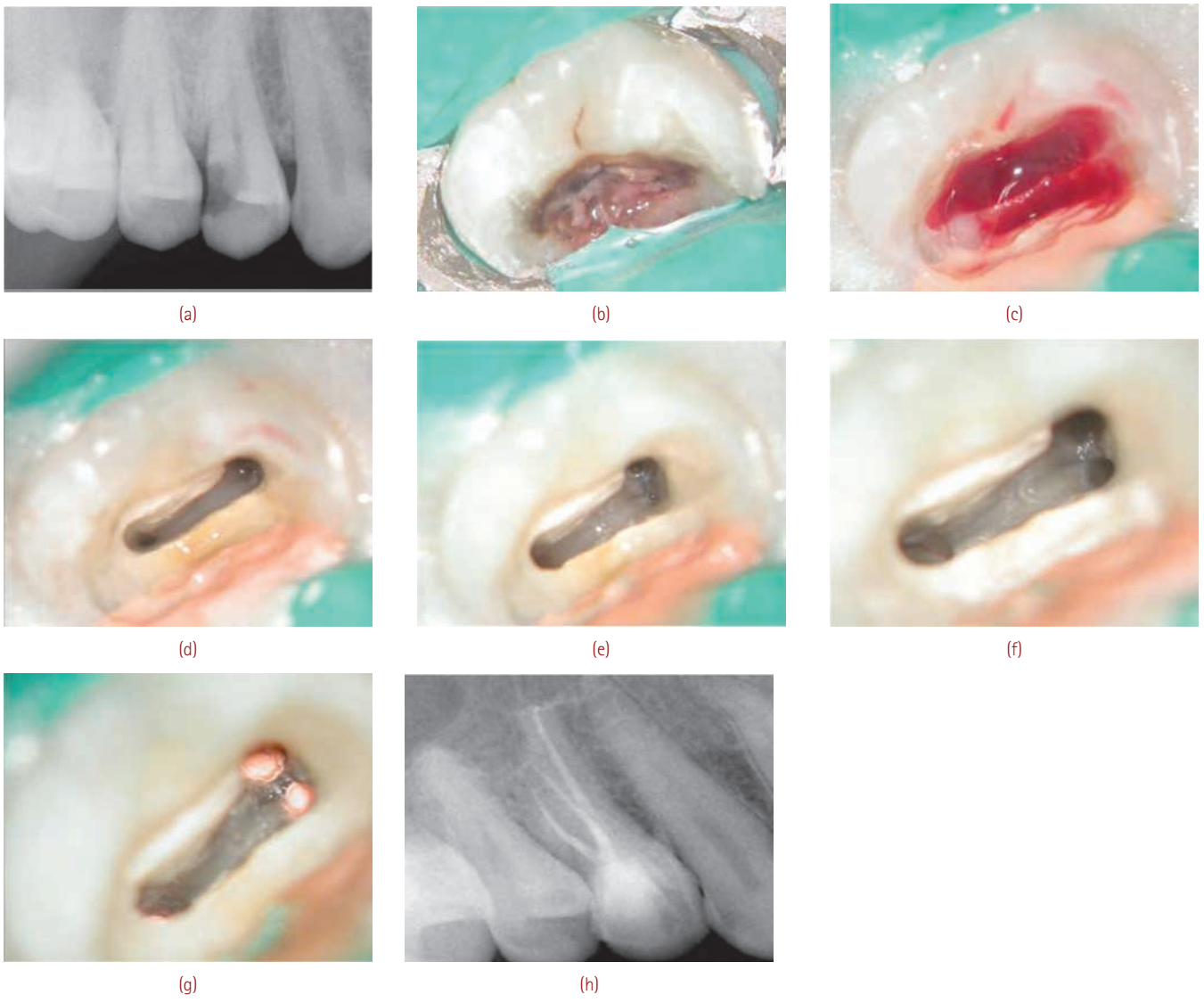


Figure 13.23 Clinical tracing and obturation of a maxillary first premolar with three canals. (*Courtesy: Siju Jacob, India.*)

to the root canal, especially the buccal and lingual canal orifices when more than one canal is present (**Fig. 13.21g**).

Any loose debris is removed by irrigating the access cavity with a 5.2% sodium hypochlorite solution. Excess sodium hypochlorite is removed by suction or is absorbed with 2 × 2 gauze sponges. The pulp chamber should be suctioned dry to permit unimpeded observation of the pulpal floor. The anatomic dark lines in the pulpal floor (dentinal map) should be examined and followed with an endodontic explorer to identify the orifices. The orifice of the buccal canal lies beneath the buccal cusp, and the orifice of the palatal canal lies beneath the palatal cusp.

Anomalies: The maxillary first premolar in rare cases has three root canals (**Fig. 13.23**).

MAXILLARY SECOND PREMOLAR

Average Tooth Length: The average length of this tooth is 22.5 mm.

Pulp Chamber: The maxillary second premolar, like the maxillary first premolar, has a narrow chamber mesiodistally showing one pulp horn superimposed over another when it is viewed in this projection. It is wider buccopalatally than the maxillary first premolar and shows two pulp horns in this projection, a buccal and a palatal. The roof of the pulp chamber is similar to that of the maxillary first premolar, but the pulp floor is deeper if two canals are present.

Roots and Root Canals: Maxillary second premolars have only a single root in 90.3% of patients. Only 2% have two

Table 13.4 Root Canals and Apical Foramina in Maxillary Second Premolars

Investigators	One Canal and One Foramen (%)	One Canal and Two Foramina (%)	Two Canals and One Foramen (%)	Two Canals and Two Foramina (%)	Three Canals (%)
Pineda and Kuttler	62.8	8.9	19.0	9.3	–
Green	72.0	–	24.0	4.0	–
Vertucci and colleagues	48.0	–	27.0	24.0	1.0
Bellizzi and Hartwell	40.3	–	–	58.6	1.1



Figure 13.24 Maxillary second premolar with two canals.

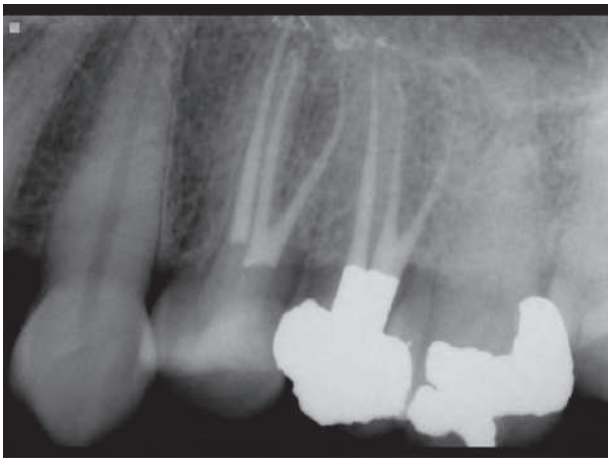


Figure 13.25 Maxillary first and second premolars with three canals each. (*Courtesy: Sashi Nallapati, Jamaica.*)

well-developed roots, whereas 7.7% have two roots that are partially fused (**Table 13.4**).

When two canals occur, they may be distinct and separated along the entire length of the root, or they may converge to form a common canal as they approach the apex. The majority of canals are curved.

Clinical Significance

- If one root canal is present, the root canal orifices will be indistinct, but if two canals are present, two distinct orifices will be visible (**Fig. 13.24**).
- The root(s) of the maxillary second premolar are situated below and therefore closer to the maxillary sinus than the maxillary canine. The sinus may dip down and surround the tip of the root(s) forming prominences in the sinus floor.

Access Opening: The access opening for the maxillary second premolar is basically the same as that for the maxillary first premolar. It is varied only as dictated by the anatomic structure of the pulp chamber.

Anomalies: The maxillary second premolar in rare cases has three root canals (**Fig. 13.25**). **Figure 13.26** depicts the common errors in access opening in maxillary premolars.

MAXILLARY FIRST MOLAR

Average Tooth Length: The average length of the buccal canals in this tooth is 19 mm and that of the palatal canal is 20.5 mm.

Pulp Chamber: The pulp chamber of the maxillary first molar is the largest in the dental arch, with four pulp horns: MB, distobuccal, mesiopalatal, and distopalatal. The arrangement of the horns gives the pulpal roof a *rhomboidal shape* in cross-section. The four walls forming the roof converge toward the floor where the lingual wall almost disappears; the floor of the pulp chamber thus has a triangular form in cross-section. The orifices of the root canals are located in the three angles of the floor. Anatomic dark lines in the floor of the pulp chamber connect the orifices.

- The *palatal orifice* is the largest, round or oval in shape, and easily accessible for exploration.
- The *MB orifice* is under the MB cusp, is long buccopalatally, and may have a depression at the palatal end in which the orifice of a fourth canal may be present. This orifice is located by insinuating the tip of a long-shank explorer in a mesiobuccoapical inclination into the point angle created at the juncture of the buccal wall, mesial wall, and subpulpal floor of the pulp chamber.

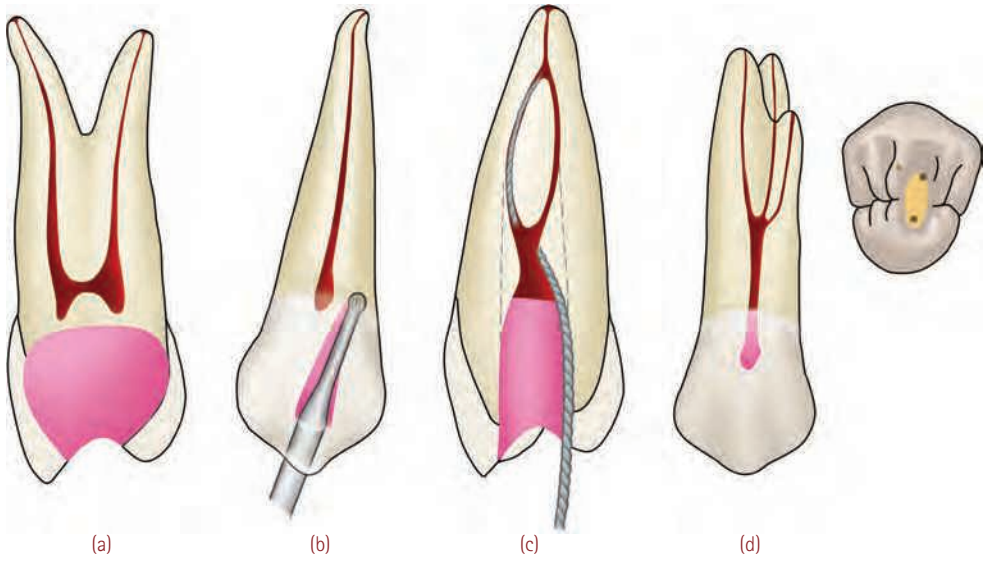


Figure 13.26 Common errors in access openings of maxillary premolars: (a) Gouging. (b) Perforation. (a) and (b) are caused by not directing the bur parallel to the long axis of the tooth. (c) Broken instrument. Caused by failure to remove the dentinal shoulders before placing instruments in the canals. (d) Missing extra canals. Caused by failure to funnel access openings and not following the outline of the pulp chamber.

Table 13.5 Root Canals and Apical Foramina in Maxillary First Molars: Mesiobuccal Root

Investigators	One Canal and One Foramen (%)	One Canal and Two Foramina (%)	Two Canals and One Foramen (%)	Two Canals and Two Foramina (%)
Weine	48.5	–	37.5	14.0
Pineda and Kuttler	39.0	–	12.5	48.5
Pineda	41.0	–	17.0	42.0
Seidberg and colleagues	38.0	–	37.0	25.0
Pomeranz and Fishelberg	72.0	–	17.0	11.0
Vertucci	45.0	–	37.0	18.0

- The *distobuccal orifice* is located slightly distal and palatal to the MB orifice and is accessible from the mesial side for exploration. The floor of the pulp chamber is in the cervical third of the root, and the roof is in the cervical third of the crown.

Roots and Root Canals: The maxillary first molar has three roots with, usually, three canals situated mesiobuccally, distobuccally, and palatally. The MB canal is not always patent along its entire length and is divided to form a second root canal known as the *MB-2 canal*. The distobuccal root is small and is more or less round in shape. It usually has a single root canal, which is a narrow and tapering canal (**Table 13.5**).

The palatal root has the largest diameter and is the longest root of the maxillary first molar. It is straight in only 40% of cases and may curve buccally (55%).

Access Opening: The internal anatomy of the pulp chamber of the maxillary first molar dictates the shape and size of the access opening. By determining the shape and size of the chamber, by measuring the extension of the pulp chamber mesially, distally, and coronally on the diagnostic radiograph, and by transposing these measurements to the tooth, one can estimate the approximate size, shape, depth, and location of the coronal access cavity to be prepared (**Fig. 13.27a**).

The enamel is penetrated with a high-speed bur by positioning the instrument in the central fossa and angling it toward the palatal root (**Fig. 13.27b**). The bur is directed toward the palatal canal, where the pulp chamber of this tooth is largest (**Fig. 13.27c**).

After penetration into the enamel, one uses the bur to penetrate the dentin; the bur is angled toward the palatal root until the pulp chamber is reached (**Fig. 13.27d**). A "drop" of the bur into the pulp chamber may be felt if the chamber is large. In partially calcified chambers, the drop of the bur is not felt, and the operator has to rely on the measurements made from the radiograph to avoid penetration beyond the chamber roof.

Cutting occlusally from within the pulp chamber, one removes the bulk of the roof of the pulp chamber (**Fig. 13.27e**).

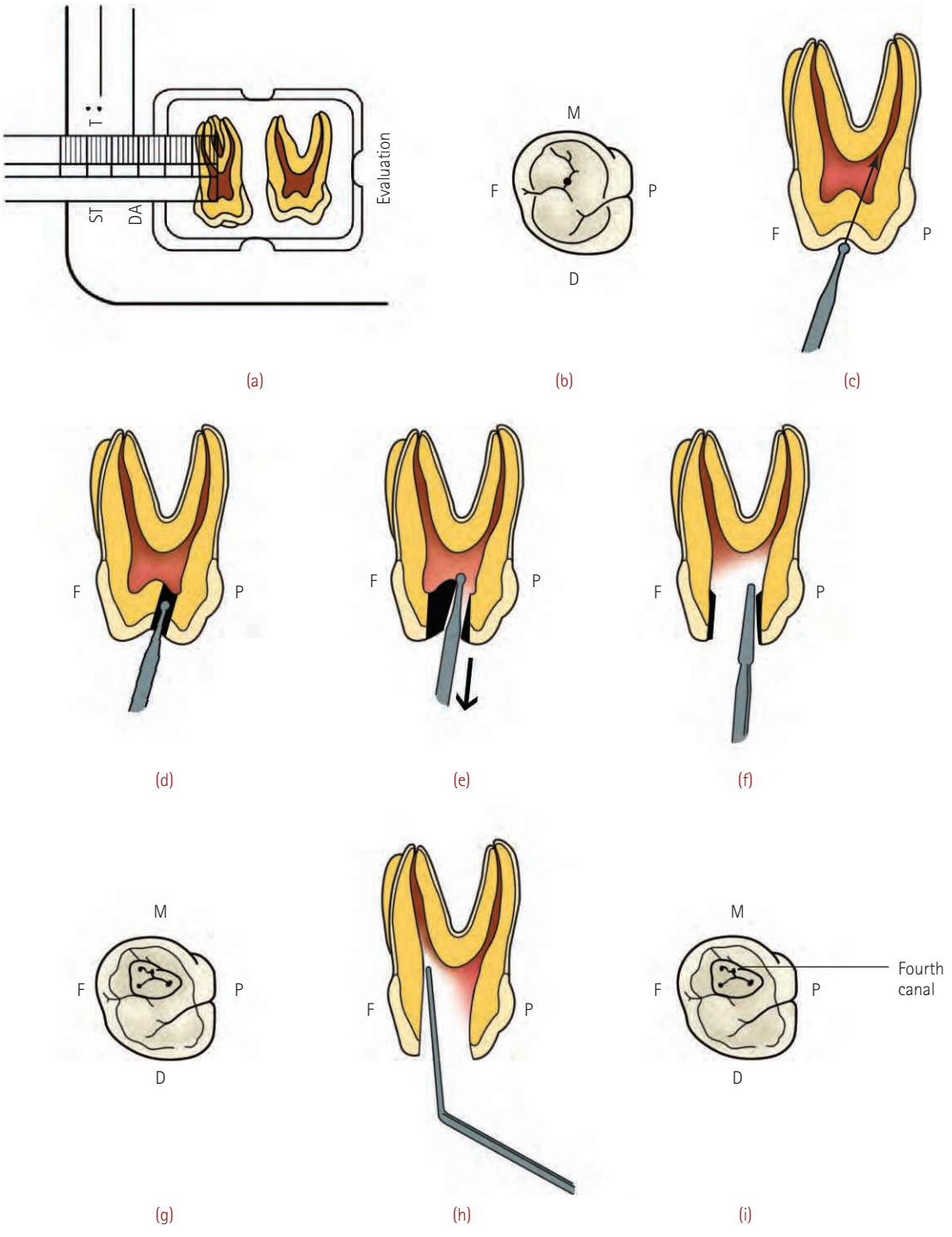


Figure 13.27 Steps in the access opening of a maxillary first molar. (See text for more details.) D, distal; F, facial; M, mesial; P, palatal.

The shape and size of the internal anatomy of the pulp chamber guide the cutting. A tapered-cylinder, self-limiting diamond bur is used to remove the remaining roof of the pulp chamber (**Fig. 13.27f**). The walls of the access cavity are refined with this diamond to be divergent toward the occlusal surface, and this divergence creates a positive seat for the temporary filling that prevents its displacement by occlusal forces.

The walls of the access cavity should be confluent with the walls of the pulp chamber and slightly divergent toward the occlusal surface. The access opening is usually triangular, with round corners extending toward, but not including, the MB cusp tip, marginal ridge, and oblique ridge (**Fig. 13.27g**). This triangular preparation permits direct access to the root canal orifices (**Fig. 13.27h**).

Loose debris is removed by irrigation with a 5.2% solution of sodium hypochlorite. Excess sodium hypochlorite solution is removed by suction or is absorbed with a 2 × 2 gauze. The pulp chamber should be suctioned dry for unimpeded examination of the floor. The anatomic dark lines in the pulpal floor (dentinal map) should be examined and followed with an endodontic explorer to identify the orifices, as described previously. One should routinely search for a fourth orifice and canal that may be present in the MB root (**Fig. 13.27i**).

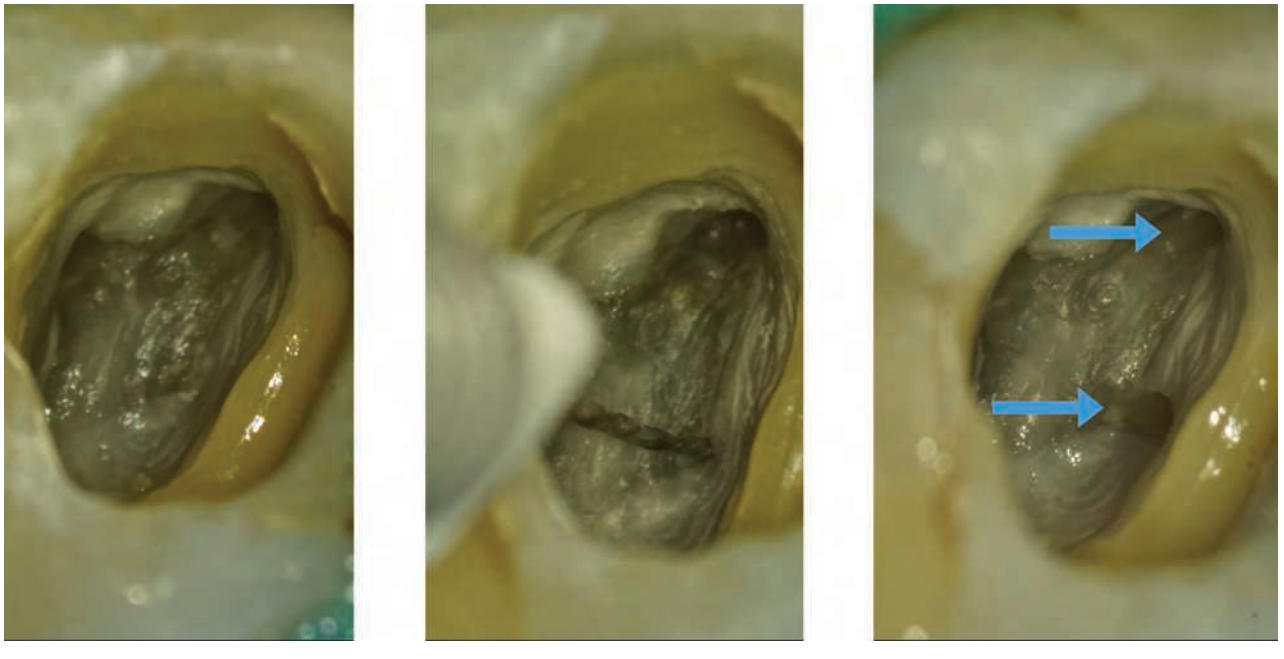
The maxillary first molar lies under the maxillary sinus. The fundus of the alveolar socket containing the root may protrude into the sinus and may produce a small, bony prominence in the floor of the sinus.

As in the maxillary second premolar, bony defects in these small prominences may leave only the periodontal ligament and the mucoperiosteal lining of the sinus to separate the roots from the sinus cavity. This close relationship may produce soreness in the maxillary teeth due to maxillary sinusitis; conversely, infection of the sinus may result from pulpal disease.

Clinical Note

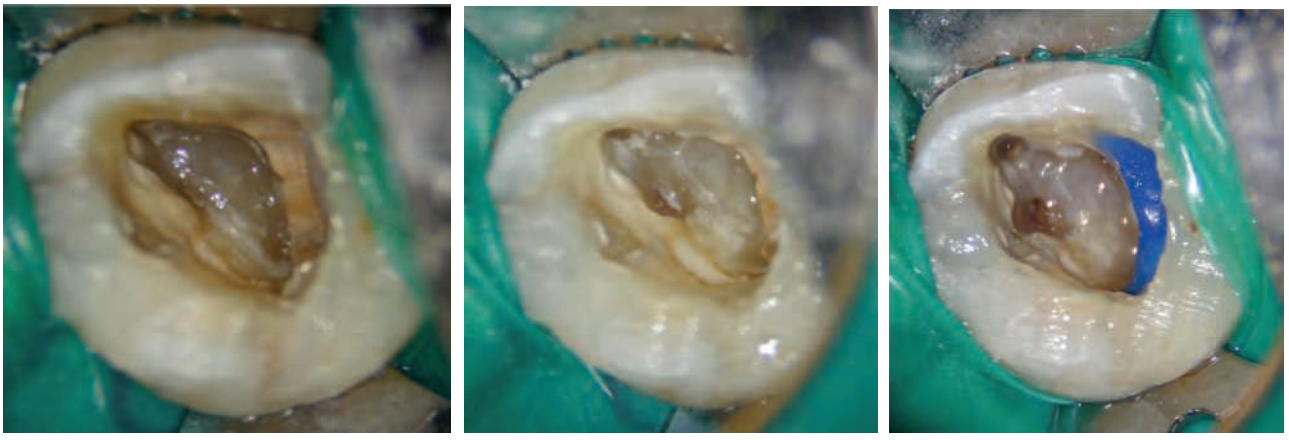
- The triangular access preparation in a maxillary molar is modified into a *rhomboidal shape* whenever the MB-2 canal is suspected or traced.

- Clinically, the orifice of the MB-2 canal is often difficult to find. The common area where a clinician should search is 2–3 mm palatal to the MB-1 canal, in the direction of an imaginary line connecting the MB-1 canal to the palatal canal. Modify the mesial wall of the access cavity and trough or countersink with the help of ultrasonic tips mesially and apically along the mesiobuccal pulpal groove (**Fig. 13.28a–13.28c**).
- Two separate and distinct mesiobuccal canals occur in 84% of teeth in which two separate orifices are traced (**Fig. 13.29**).
- According to Nallapati, the following are the possible locations of the MB-2 canal in the maxillary first molar:
  - Present on the developmental line that connects the MB-1 and the palatal canal (**Fig. 13.29a**)
  - Present mesial to the developmental line that connects the MB-1 and the palatal canal (**Fig. 13.29b**)
  - Appears as a groove on the palatal wall of the MB-1 canal (**Fig. 13.29c**)
  - Splits off the MB-1 canal in the middle third of the canal (**Fig. 3.29d**)
  - Splits off the MB-1 canal in the apical third of the canal (**Fig. 13.29e**)
  - Comes off the buccal wall of the palatal canal (**Fig. 13.29f**)
- The clinician should always suspect the presence of unusual anatomy and modify the access preparation accordingly (**Fig. 13.30**).
- The operator must be aware that the palatal root may curve in the apical third in a buccal curvature (55% of cases) and this curvature will not be apparent radiographically.



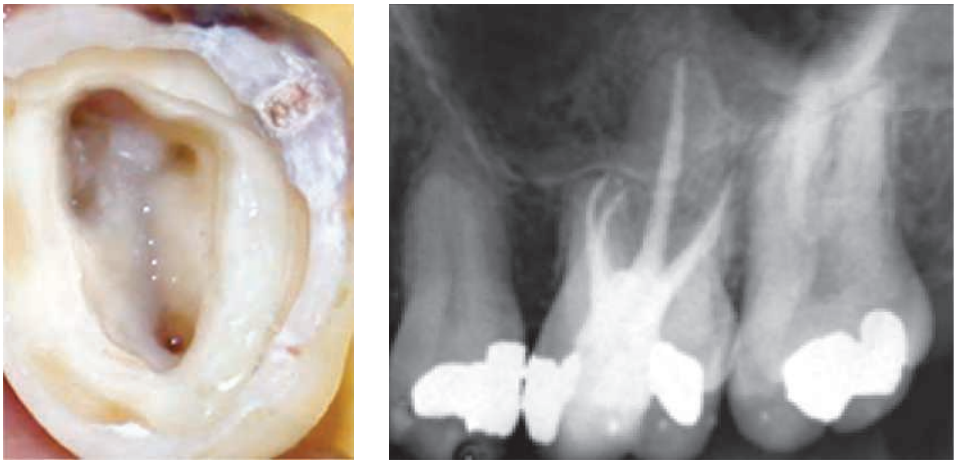
(a) (b) (c)

Figure 13.28 Clinical tracing of the MB-2 canal: (a) MB-1 canal traced. and Ultrasonic tip used to trough the developmental groove below the MB-1 canal to visualize the orifice of the MB 2 canal. (b) Canal traced using an ISO size 8 K-file. (c) MB-1 and MB-2 under higher magnifications.



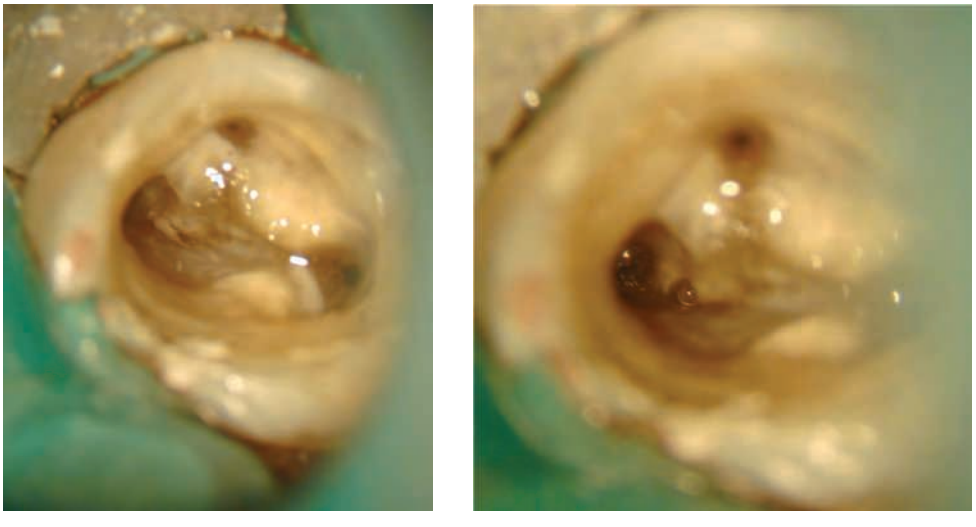
(i) (ii) (iii)

(a)



(i) (ii)

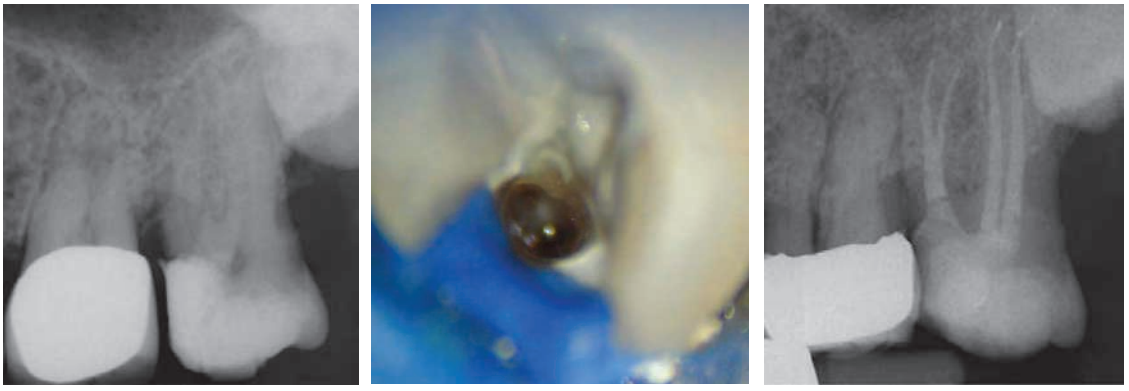
(b)



(i) (ii)

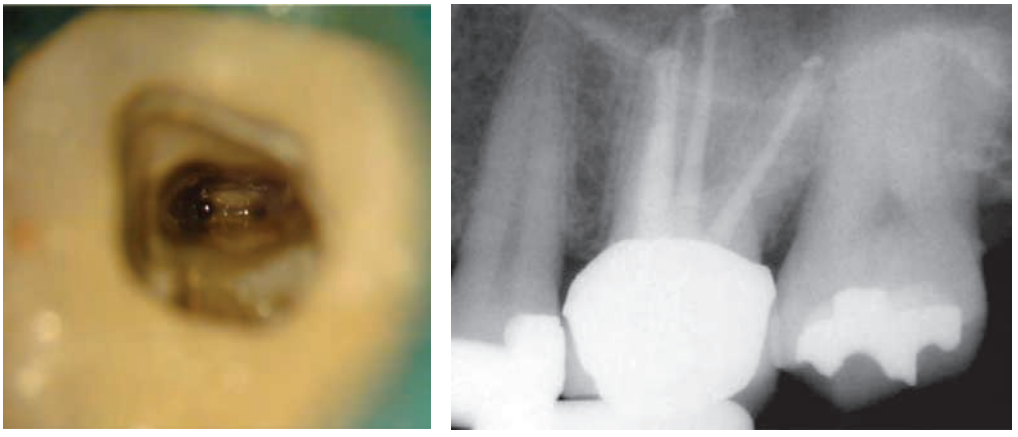
(c)

Figure 13.29 (a) MB-2 canal on the developmental line that connects MB-1 and palatal canal. (b) MB-2 canal mesial to the developmental line that connects MB-1 and palatal canal. (c) MB-2 appears as a groove on the palatal wall of the MB-1 canal. *(continued)*



(i) (ii) (iii)

(d)



(i) (ii)

(e)



(i) (ii) (iii)

(f)

Figure 13.29 *(continued)* (d) MB-2 splits off the MB-1 canal in the middle third of the canal. (e) MB-2 splits off the MB-1 canal in the apical third of the canal. (f) MB-2 comes off the buccal wall of the palatal canal. (*Courtesy: Sashi Nallapati, Jamaica.*)

Anomalies

- Maxillary first molar with a single root and a single canal (**Fig. 13.30**)
- Maxillary first molar with two distal canals (**Fig. 13.31**)
- Maxillary first molar with two palatal roots (**Fig. 13.32**)
- **Figure 13.33** depicts variations in maxillary first molar anatomy
- Maxillary molar with three MB canals (**Fig. 13.34**)

MAXILLARY SECOND MOLAR

Average Root Canal Length: The average buccal canal length is 18 mm and the average palatal canal length is 19 mm.

Pulp Chamber: The pulp chamber of the maxillary second molar is similar to that of the maxillary first molar, except that it is narrower mesiodistally. Because of this narrower dimension, the roof of the pulp chamber is more rhomboidal

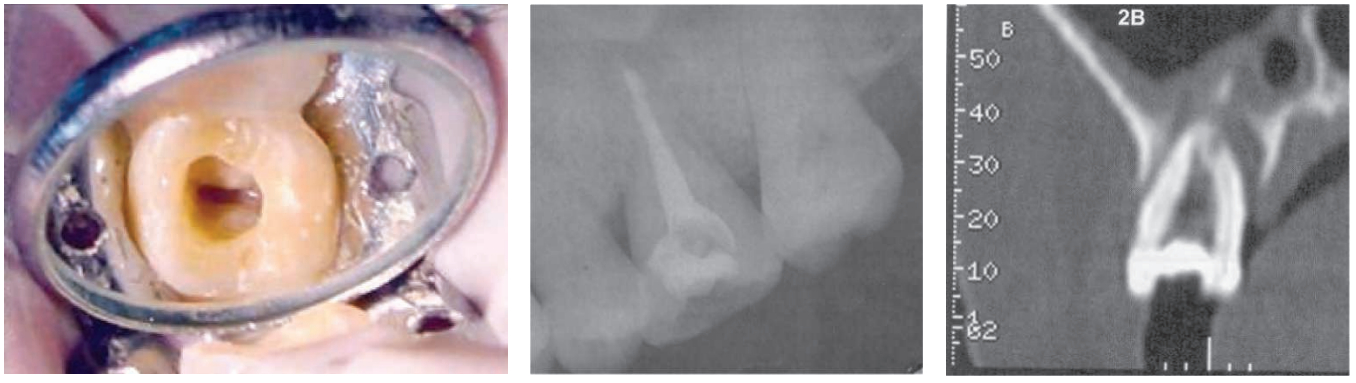
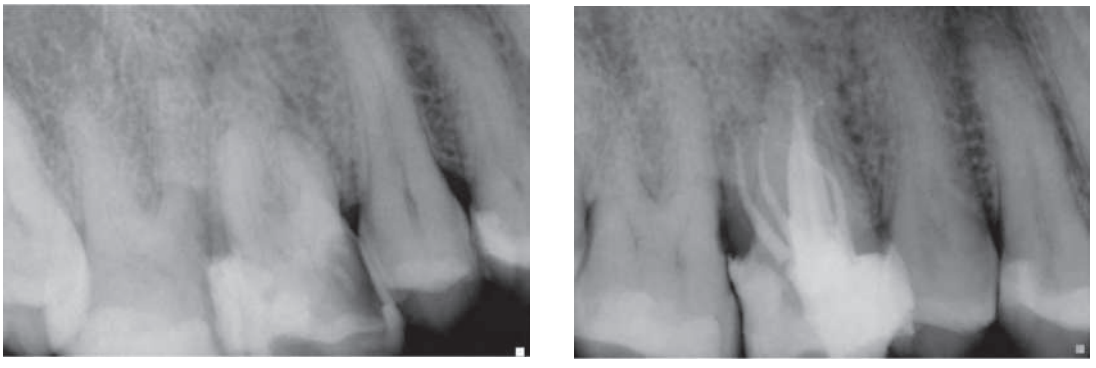


Figure 13.30 Maxillary first molar with a single root and a single canal. (Adapted from Gopikrishna, V., et al.: Endodontic management of a maxillary first molar with a single root and single canal diagnosed with spiral CT—a case report. *J. Endod.*, 32:687–91, 2006.)



(a) (b)

Figure 13.31 Maxillary first molar with two separate mesiobuccal canals as well as two separate distobuccal canals: (a) Preoperative radiograph indicating complex and unusual root canal anatomy. (b) Postobturation radiograph showing two distinct distal canals. (*Courtesy: Sashi Nallapati, Jamaica.*)

in cross-section, the floor of the pulp chamber is an obtuse triangle in cross-section, and the MB and distobuccal canals are closer together and may appear to have a common opening, but they are readily distinguishable from each other. Sometimes, all three canal orifices may be almost in a straight line.

Roots and Root Canals: The maxillary second molar usually has three roots, which are closely grouped. Because of this close grouping, the buccal roots may fuse, and occasionally all three roots fuse to form a single conical root. Studies have reported this characteristic in 46% of cases.

If the buccal roots fuse to form one buccal root, the tooth may have only two canals, one buccal and one palatal, although it is not unusual to find three canals (**Table 13.6**). A tooth with only one root usually has only one conical root canal.

Clinical Note

- The maxillary second molar is usually more closely related to the maxillary sinus than the maxillary first molar.
- The distobuccal canal will be located more closer to the mesiobuccal canal compared to its location in the maxillary first molar.

Access Opening: The maxillary second molar access opening is basically the same as that for the maxillary first molar, with the variations that anatomic structure dictates.

Table 13.6 Root Canals and Apical Foramina in Maxillary Second Molars: Mesiobuccal Root

Investigators	One Canal and One Foramen (%)	One Canal and Two Foramina (%)	Two Canals and One Foramen (%)	Two Canals and Two Foramina (%)
Pineda and Kuttler	64.6	14.4	8.2	12.8
Pomeranz and Fishelberg	62.1	–	13.8	24.1
Vertucci	71.0	–	17.0	12.0

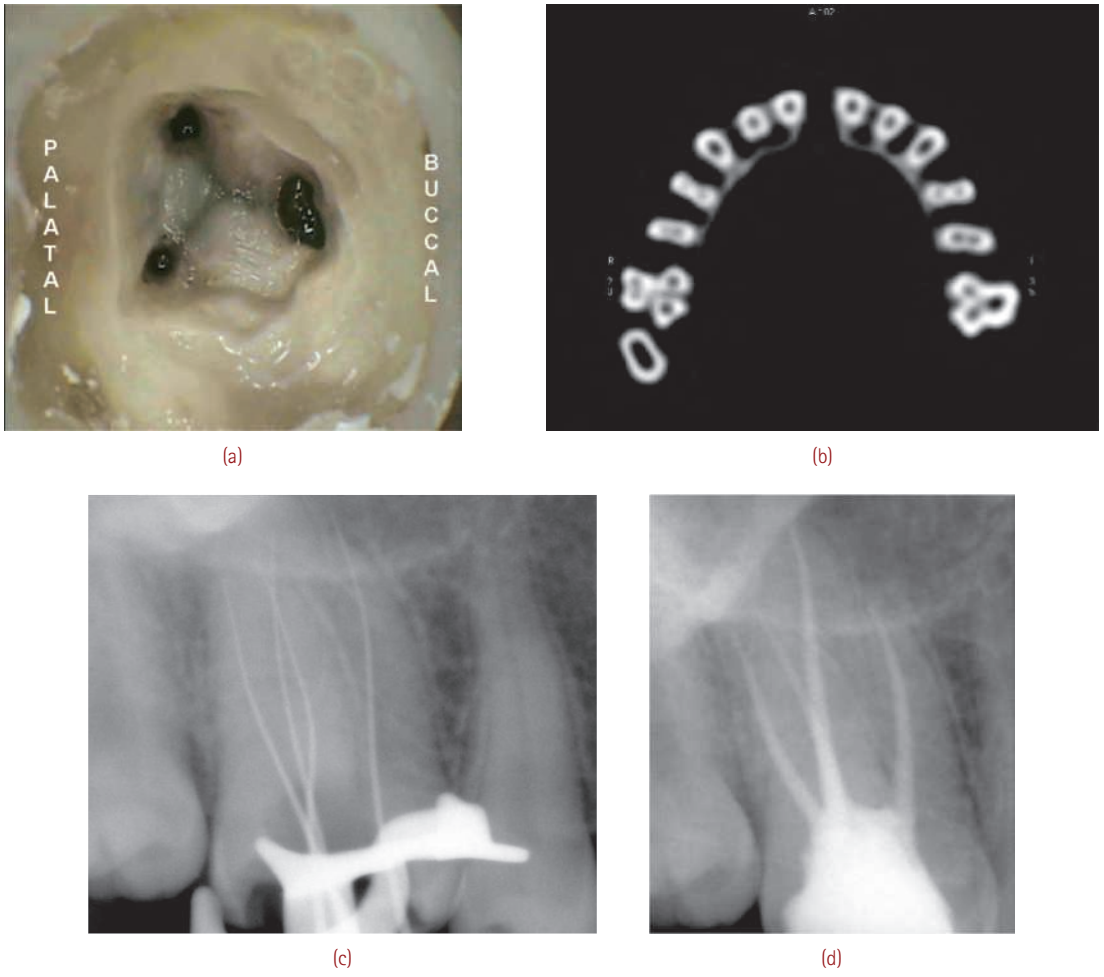


Figure 13.32 Maxillary first molar with two palatal roots: (a) Access opening showing two distinct palatal orifices and a single buccal orifice. (b) Spiral CT confirming the unusual anatomy. (c) Working length radiograph of the tooth. (d) Postobturation view. (Adapted from Gopikrishna, V., et al.: Endodontic management of a maxillary first molar with two palatal roots and a single fused buccal root diagnosed with spiral computed tomography—a case report. *Oral Surg. Oral Med. Oral Pathol. Oral Radiol. Endod.*, **105**:e74–78, 2008.)

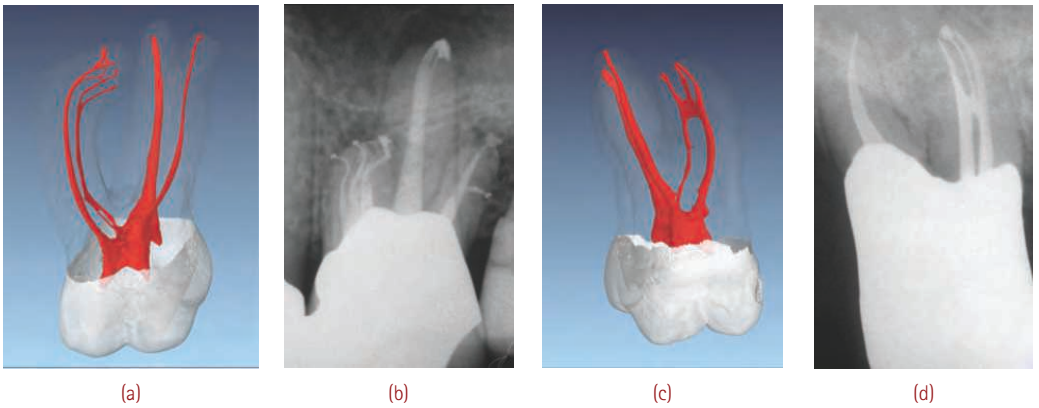


Figure 13.33 (a–d) Demonstrating variations in the maxillary first molar anatomy. (*Courtesy: Frank Paque, Switzerland, and Clifford Ruddle, USA.*)



Figure 13.34 Maxillary molar with three mesiobuccal canals.

Anomalies: The two most frequent anomalies in the maxillary second molar are the presence of only one root and one canal and the incidence of pulp stones in the pulp chamber. The unusual anatomy that has been reported includes:

- Maxillary second molar with five roots and five canals
- Maxillary second molar with three MB canals

MAXILLARY THIRD MOLAR

Average Tooth Length: The average length of this tooth is 17.5 mm.

Pulp Chamber: The maxillary third molar anatomically resembles the second molar. The pulp chamber can be similar to that of the maxillary second molar with three canal orifices, but it may also have an oddly shaped chamber with four or five root canal orifices or a conical chamber with only one root canal.

Roots and Root Canals: The maxillary third molar may have three well-developed roots that are closely grouped. It may also have fused roots, one conical root, or four or more independent roots. The roots may be straight, curved, or dilacerated, and may be fully or partially developed.

Root canals vary from one to four or even five in number, depending on the number of roots. One may find *a "C-shaped" pulp chamber with a "C-shaped" root canal.*

Clinical Note

The maxillary third molar is closely related to the maxillary sinus and the maxillary tuberosity.

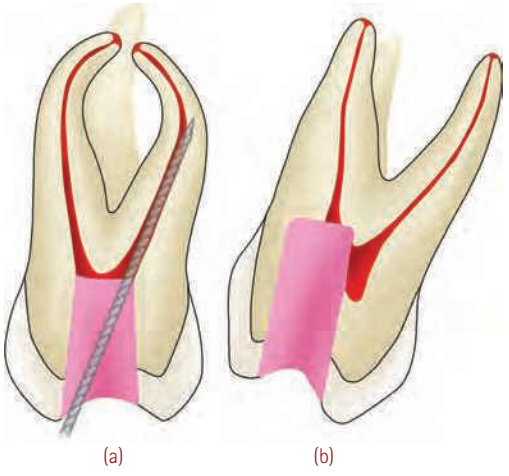


Figure 13.35 Common errors in access openings of maxillary molars: (a) Ledging. Caused by failure to remove dentinal shoulder. Another cause is using a large straight instrument in a curved canal. (b) Gouging. Failure to direct the bur parallel with the long axis of the tooth on penetration.

Access Opening: The access opening is similar to that for the maxillary second molar, with modifications for variations in anatomic structure.

Anomalies: The maxillary third molar is a tooth in which anomalies are common, not exceptions. **Figure 13.35** depicts the common errors in access opening of maxillary molars.

The clinically significant features that a clinician should take into consideration before preparing the endodontic access in mandibular teeth are given in **Table 13.7**.

MANDIBULAR CENTRAL INCISOR

Average Tooth Length: The average length of this tooth is 21.5 mm.

Pulp Chamber: The mandibular central incisor is the *smallest tooth in the arch*. The pulp chamber is small and flat mesiodistally. The three distinct pulp horns present in a recently erupted tooth become calcified and disappear early in life because of constant masticatory stimulus. Labiolingually, the pulp chamber is wide and ovoid in cross-section in the cervical third of the crown and tapers incisally.

Roots and Root Canals: The mandibular central incisor has one root, which is flat and narrow mesiodistally but wide labiolingually. The root is straight in 60% of cases. The canal configuration varies from:

- One canal exiting in one apical foramen, as in 70% of these teeth, to
- One canal bifurcating into two canals, coming together, and exiting into one apical foramen (22%)

From the labiolingual dimension, the canal is broad in the cervical and middle thirds of the root, tapers gradually toward the apex, and forms a constriction in the apical third of the root (**Table 13.8**).

Table 13.7 Clinically Significant Features During Access Preparation of Mandibular Teeth

	Average Tooth Length	Shape of Pulp Chamber	Roots and Root Canals	Clinical Significance	Shape of Access Preparation	Most Common Anomalies
Mandibular central incisors	• 21–22 mm (Average 21.5 mm)	• Smallest tooth of the arch • Small and flat mesiodistally • Wide and ovoid labiolingually • Three distinct pulp horns (disappear early in life because of constant masticatory stimulus)	• One root, which is flat and narrow mesiodistally but wide labiolingually	• 60% of roots are straight • Buccal perforation is the most common iatrogenic error. • Second canal normally located lingual to primary canal	• Long and oval	• Two root canals • Talon cusp (Dens evaginatus)
Mandibular lateral incisors	• 22.5–24 mm (Average 23.5 mm)	• Similar to mandibular central incisor, but the lateral incisor has larger dimensions	• Similar to mandibular central incisors, but slightly larger	• Majority of roots are straight or distally or labially curved (more of distal curvature)	• Long and oval	• Two root canals • Talons cusp (Dens evaginatus)
Mandibular canine	• 26–28 mm (Average 27 mm)	• Pulp chamber narrow mesiodistally • Labiolingually tapers to the incisal third and wide at the cervical third • Only one pulp horn	• Single root	• Straight roots (68%) • Distal curvature (20%)	• Circular to ovoid	• Two root canals
Mandibular first premolar	• 21.5–23 mm (Average 22.5 mm)	• Narrow mesiodistally • Wide buccopalatally • Prominent buccal pulp horn • Prominent buccal cusp and smaller lingual cusp give 30° lingual tilt	• Usually short and conical root • Usually straight (48%), distal curve (35%)	• Mental foramen mimic periradicular pathology radiographically	• Ovoid buccolingually	• Bifurcation and trifurcations of the roots or root canals are most common anomalies
Mandibular second premolar	• 21.5–23 mm (Average 22.5 mm)	• Similar to mandibular first premolar, except that the lingual horn is more prominent	• Single root • Rarely two or three roots • Straight (39%), distal curve (40%)	• Usually exits in one apical foramen (97.5%), in some may exit in two foramina (2.5%)	• Ovoid access opening wider mesiodistally (similar to mandibular first premolar)	• Bifurcation and trifurcations of the roots or root canals are most common anomalies
Mandibular first molar	• 21–22 mm (Average 21.5 mm)	• Roof of pulp chamber rectangular in shape • Rhomboidal floor • Four pulp horns • Three distinct orifices: mesiobuccal, mesiolingual, distal	• Two well-differentiated roots (one mesial and one distal) • Both roots are wide and flat buccolingually • Third root found either mesially or distally in 5.3% cases called radix entomolaris	• The distal canal has more clinical variations than the mesial canal	• Trapezoidal with round corners	• Radix entomolaris • Middle mesial canal

(*continued*)

Table 13.7 Clinically Significant Features During Access Preparation of Mandibular Teeth (*continued*)

	Average Tooth Length	Shape of Pulp Chamber	Roots and Root Canals	Clinical Significance	Shape of Access Preparation	Most Common Anomalies
Mandibular second molar	• 19–21 mm (Average 20 mm)	• Similar, but smaller than mandibular first molar	• Majority have two roots (71%), but with one root (27%) and three roots (2%) also seen	• C-shaped canal significantly higher • C-shaped canal system classified into: merging, symmetrical, asymmetrical	• Similar to mandibular first molar	• C-shaped canal significantly higher
Mandibular third molar	• 17.5–19.5 mm (Average 18 mm)	• Resembles mandibular first and second molar • C-shaped root canal orifices	• Usually two roots and two canals; occasionally, one root and one canal or three roots and three canals may be present	• Apex of root in close proximity to mandibular canal	• Similar to mandibular first and second molar	• Frequently has complex anatomic structure

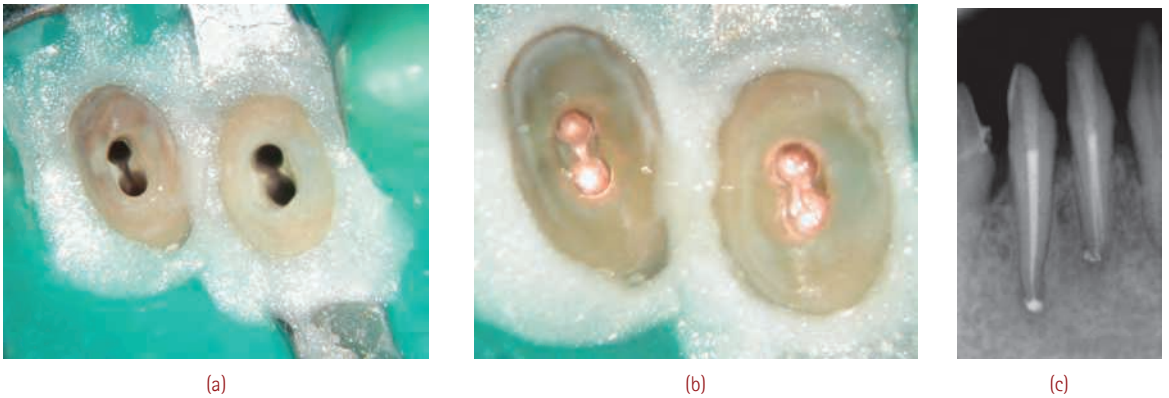
Table 13.8 Root Canals and Apical Foramina in Mandibular Incisors

Investigators	One Canal and One Foramen (%)	One Canal and Two Foramina (%)	Two Canals and One Foramen (%)	Two Canals and Two Foramina (%)
Green	80.0	–	7.0	13.0
Rankine-Wilson and Henry	60.0	–	35.0	5.0
Madeira and Hetem	88.5	–	11.0	0.5
Benjamin and Dowson	59.0	–	40.0	1.0
Vertucci	92.5	–	5.0	2.5

Clinical Note

- The second canal is normally located lingual to the primary canal (**Fig. 13.36**).
- Care should be taken during access opening in order to avoid buccal perforations.

Access Opening: The access opening of the mandibular central incisor is made in a similar manner as for the maxillary anterior teeth, with the variations that its smaller size demands. The shape of the access opening of the mandibular incisor is long and oval, with its greatest dimension oriented incisogingivally. Proper access enables one to explore the



(a) (b) (c)

Figure 13.36 Endodontic management of mandibular incisors with two canals. (*Courtesy: Siju Jacob, India.*)

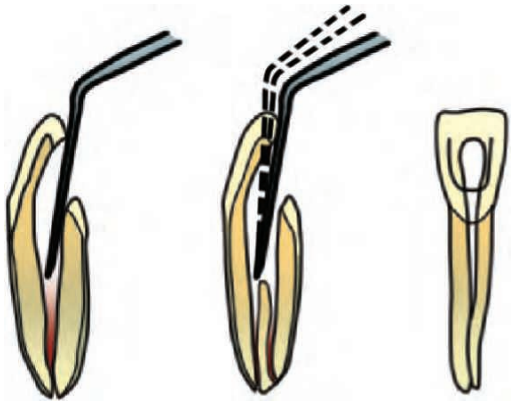


Figure 13.37 Access opening of a mandibular incisor followed by exploration to assess for the presence of the second lingual canal.



Figure 13.38 Access opening of a mandibular incisor followed by exploration to assess for the presence of the second lingual canal.

cervical third of the root to determine whether a second root canal is present (**Fig. 13.37**).

MANDIBULAR LATERAL INCISOR

Average Tooth Length: This tooth averages 23.5 mm in length.

Pulp Chamber: The configuration of the pulp chamber of the mandibular lateral incisor is similar to that of the mandibular central incisor, but the lateral incisor has larger dimensions.

Roots and Root Canals: Although the root of the mandibular lateral incisor is larger than that of the mandibular central incisor, it has basically the same configuration. The majority of the roots are straight or distally or labially curved, as they are in the central incisor, but the distal curve of the lateral incisors is sharper.

The incidence of double-root canals at the apex is about the same as in the central incisor, and their anatomy in cross-section is also similar.

Access Opening: The access opening is made in the same manner as for the mandibular central incisor (**Fig. 13.38**).

Anomalies: Gemination and fusion can occur in mandibular anterior teeth.

MANDIBULAR CANINE

Average Tooth Length: The average length of this tooth is 27 mm.

Pulp Chamber: The mandibular canine resembles the maxillary canine, but it is smaller in all dimensions. The pulp chamber is narrow mesiodistally. When viewed labiolingually, the chamber tapers to a point in the incisal third of the crown, but it is wide in the cervical third. Only one pulp horn is present in the adult tooth. In cross-section, the chamber is ovoid in the cervical third. No distinct demarcation exists between the pulp chamber and the root canal.

Roots and Root Canals: Although the tooth usually has a single root, it may have two (2.3%). Most of these teeth have a straight root (68%), but some have distal curvatures (20%).

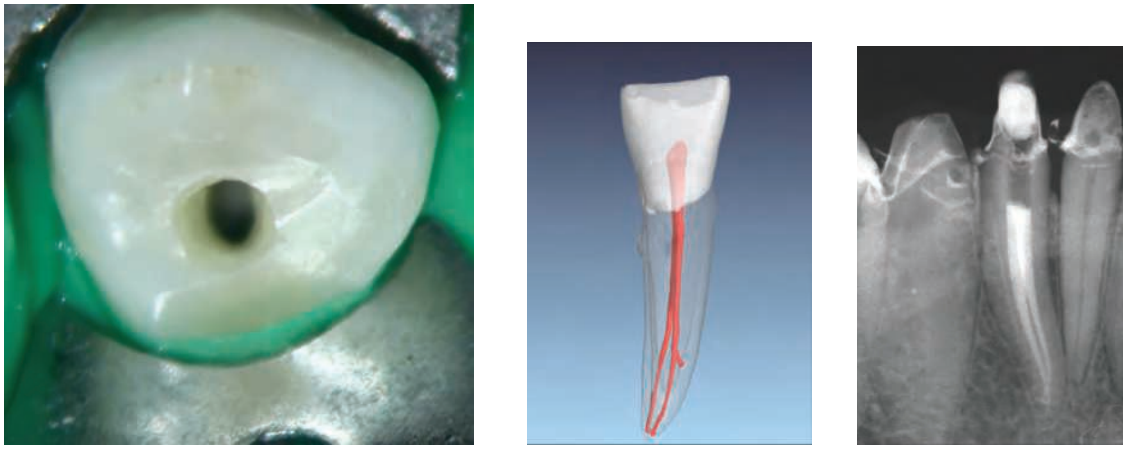
The mandibular canine usually has one canal exiting in one apical foramen (78%). When one root canal is present, a labiolingual view of the root shows a canal that is broad in the middle third and tapers to a constriction in the apical third. It is ovoid in cross-section in the cervical and middle thirds of the root and round in the apical third (**Table 13.9**).

Access Opening: The access opening of the mandibular canine is made in a similar manner as for the maxillary canine, with the variations dictated by a smaller anatomic dimension (**Fig. 13.39**).

Anomalies: The mandibular canine on rare occasions has more than one canal (**Fig. 13.39b** and **13.39c**) and more than

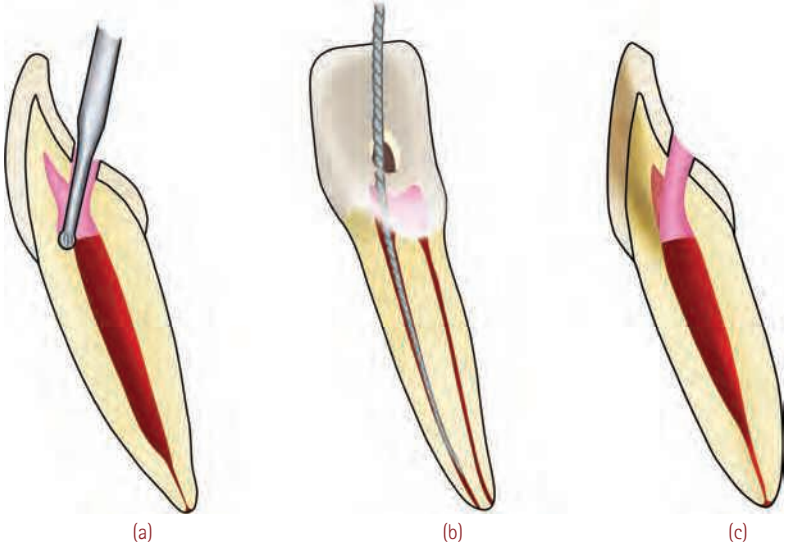
Table 13.9 Root Canals and Apical Foramina in Mandibular Canine

Investigators	One Canal and One Foramen (%)	One Canal and Two Foramina (%)	Two Canals and One Foramen (%)	Two Canals and Two Foramina (%)
Pineda and Kuttler	81.5	–	13.5	5.0
Green	87.0	–	10.0	3.0
Vertucci	80.0	–	14.0	6.0



(a) (b) (c)

Figure 13.39 (a) Access opening of a mandibular canine. (b) Micro-CT image of a mandibular canine with two canals. (*Courtesy: Frank Paque, Switzerland.*) (c) Mandibular canine with two canals. (*Courtesy: Clifford Ruddle, USA.*)



(a) (b) (c)

Figure 13.40 Common errors in access openings of mandibular anterior teeth: (a) Gouging. Caused by not directing the bur parallel to the long axis of the tooth after initial penetration. (b) Missed lingual canal. (c) Discoloration due to incomplete deroofing of the pulp chamber.

one root. **Figure 13.40** presents the common errors encountered in access opening of mandibular anterior teeth.

MANDIBULAR FIRST PREMOLAR

Average Tooth Length: This tooth averages 22.5 mm.

Pulp Chamber: The mandibular first premolar is the transitional tooth between anterior and posterior teeth, and in anatomic structure, it resembles both types of teeth. The mesiodistal width of the pulp chamber is narrow. Buccolingually, the pulp chamber is wide, with a prominent buccal pulp horn that extends under a well-developed buccal cusp. In the young tooth, one sees a small lingual pulp horn that may disappear with age and may give the pulp chamber an appearance similar to that of a mandibular canine. The prominent buccal cusp and the smaller lingual cusp give the crown of the mandibular first premolar about a 30° lingual tilt (**Fig. 13.41**). In cross-section, the chamber is ovoid, with the greater diameter present in a buccolingual direction. If only one canal is present, no distinct division will be seen between the pulp chamber and the root canal.

Roots and Root Canals: The mandibular first premolar usually has a short, conical root. This root may divide in the apical third into two or three roots. The root is usually straight (48%), but some roots curve distally (35%).

- One canal and one foramen are present in 70% of cases.
- One canal bifurcates into two canals and exits in two foramina in 24% of cases.

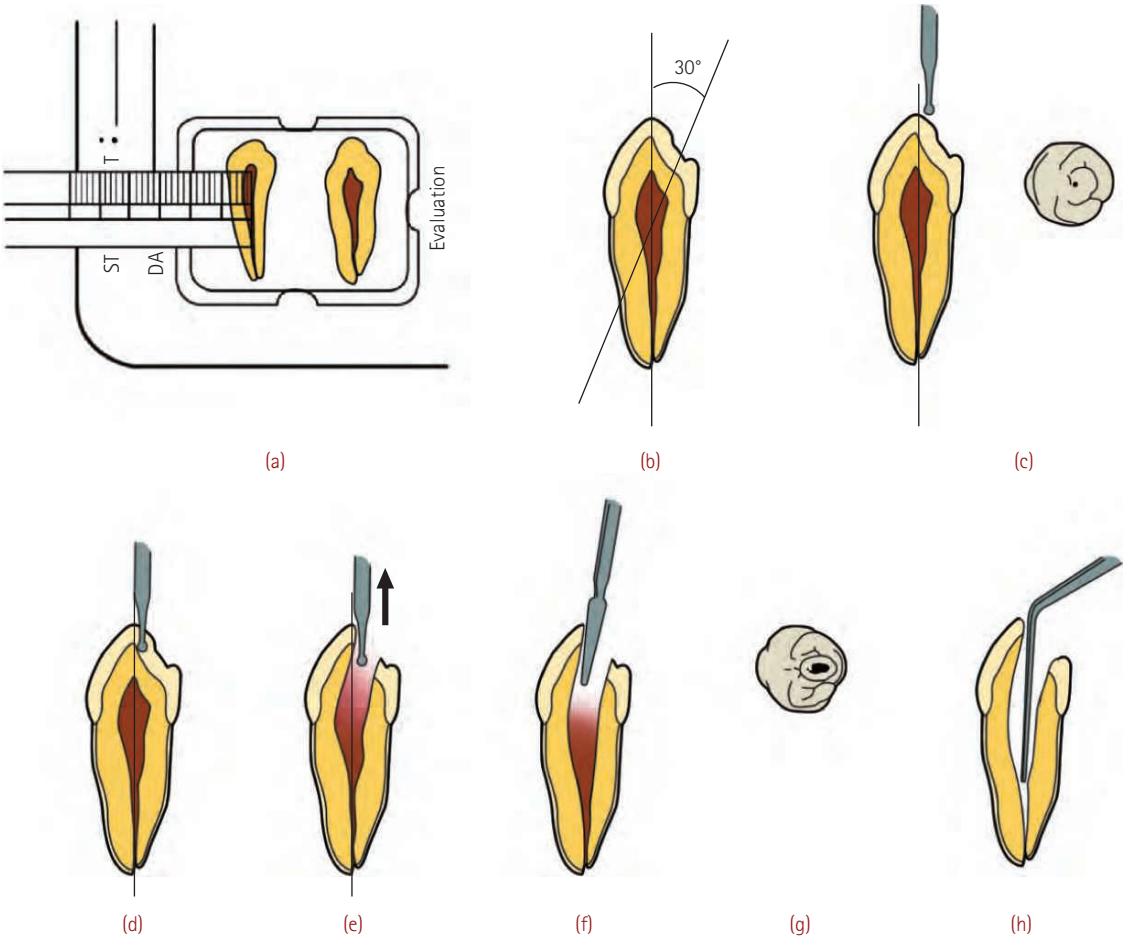


Figure 13.41 Steps in the access opening of a mandibular first premolar. (See text for more details.)

Table 13.10 Root Canals and Apical Foramina in Mandibular First Premolars

Investigators	One Canal and One Foramen (%)	One Canal and Two Foramina (%)	Two Canals and One Foramen (%)	Two Canals and Two Foramina (%)	Three Canals (%)
Pineda and Kuttler	74.2	23.4	–	1.5	0.9
Green	86.0	–	4.0	10.0	–
Zillich and Dowson	76.9	–	5.2	17.5	0.4
Vertucci	74.0	24.0	–	1.5	0.5

- Two canals exit in two foramina in 1.5% of cases.
- One canal bifurcates into two canals, uniting into one canal in the apical third and then exiting in one foramen in 4% of cases.
- Three canals exit in three foramina in 0.5% of cases.

If one canal is present, it will be cone shaped and simple in outline. Mesiodistally, such a root canal is narrow; buccolingually, it is broad and tapers toward the apical third. In cross-section, the cervical and middle thirds are ovoid, and the apical third is round (**Table 13.10**).

Clinical Note

The mental canal and foramen are sometimes close to the root apex of the mandibular first premolar; the radiographic appearance may mimic periradicular pathology.

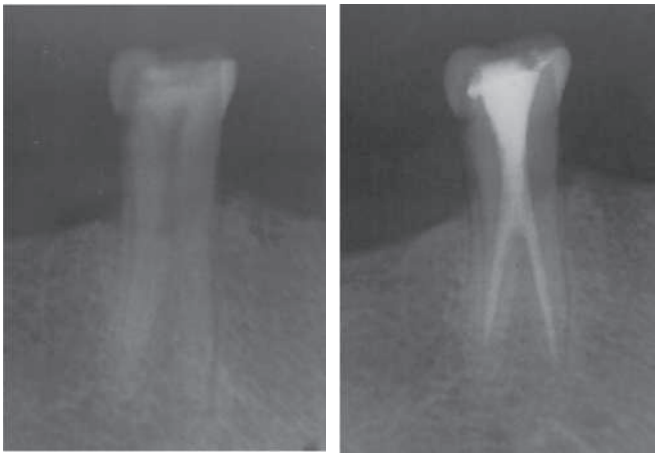
Access Opening: By determining the shape and size and measuring the extension of the pulp chamber mesially, distally, and coronally in the diagnostic radiograph and by transposing these measurements to the tooth, one can

estimate the approximate size, shape, depth, and location of the coronal access cavity to be prepared (**Fig. 13.41a**). The internal anatomy of the pulp chamber dictates the shape and size of the access opening.

The mandibular first premolar has about a 30° lingual tilt of the crown to the long axis of the root (**Fig. 13.41b**). To compensate for the tilt and prevent perforations, the enamel is penetrated at the upper third of the lingual incline of the facial cusp with a bur in a high-speed contra-angle centered mesiodistally and directed along the long axis of the root (**Fig. 13.41c**).

The procedure is the same as for the maxillary premolars (**Fig. 13.41d–13.41f**). The resulting access cavity is ovoid, with the walls of the pulp chamber confluent with the access cavity and divergent occlusally. The ovoid preparation should extend buccally and lingually enough to allow the complete removal of the roof of the pulp chamber (**Fig. 13.41g**). This ovoid access preparation permits exploration for bifurcations or trifurcations in the middle and apical thirds (**Fig. 13.41h**).

Anomalies: Bifurcations and trifurcations of the roots or root canals are the most common anomalies. They present a challenge during shaping, cleaning, and obturation (**Figs 13.42** and **13.43**).



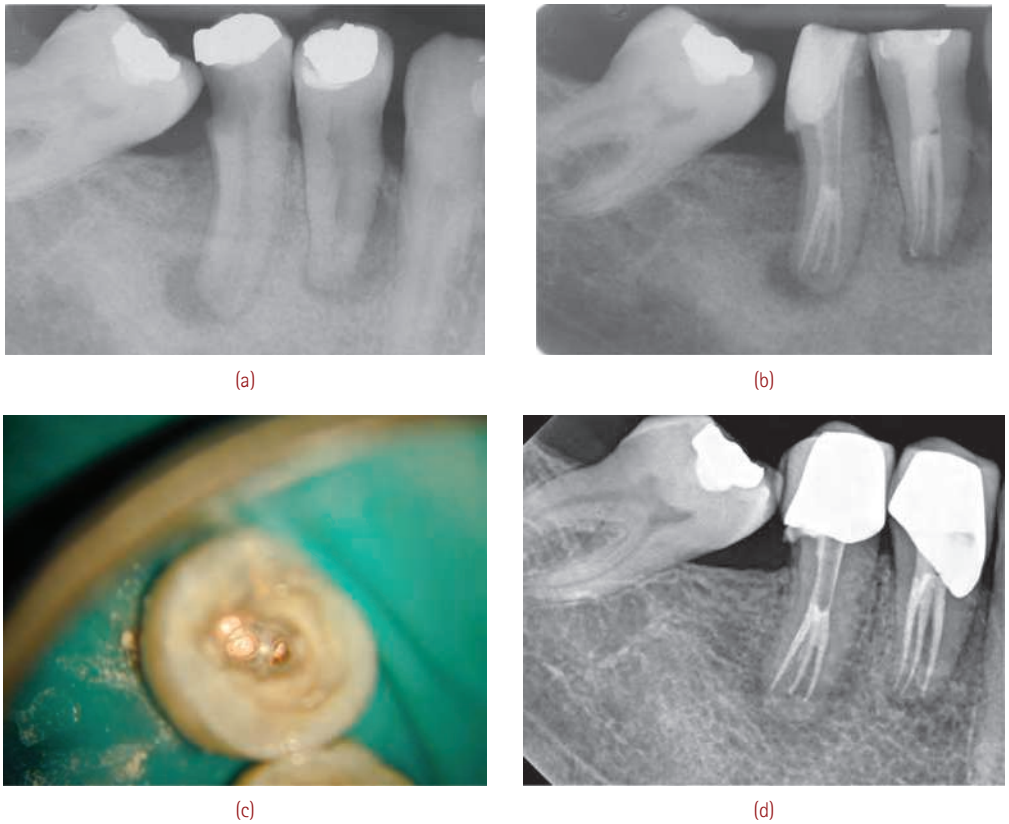
(a) (b)

Figure 13.42 Endodontic management of a two-rooted mandibular first premolar.

MANDIBULAR SECOND PREMOLAR

Average Tooth Length: The length of this tooth averages 22.5 mm.

Pulp Chamber: The pulp chamber of the mandibular second premolar is similar to that of the mandibular first premolar,



(a) (b)

(c) (d)

Figure 13.43 (a) Mandibular premolars with periradicular changes, requiring endodontic intervention. (b) Postobturation radiograph indicating trifurcations in mandibular first and second premolars. (c) Access opening view showing the obturated canal orifices. (d) Follow-up radiograph showing complete healing of the primary endodontic lesions. (*Courtesy: Sashi Nallapati, Jamaica.*)

except that the lingual horn is more prominent under a well-developed lingual cusp.

Roots and Root Canals: The mandibular second premolar usually has a single root, but on rare occasions two to three roots are present. The root has a greater girth and is wider buccolingually than that of the mandibular first premolar. The root of the mandibular second premolar may curve distally (40%), although in 39% of cases it is straight.

Usually, one canal exits in one apical foramen (97.5%), but in some roots (2.5%), a single canal may bifurcate exiting in two foramina. When one canal is present, its configuration is similar to that of the mandibular first premolar (**Table 13.11**).

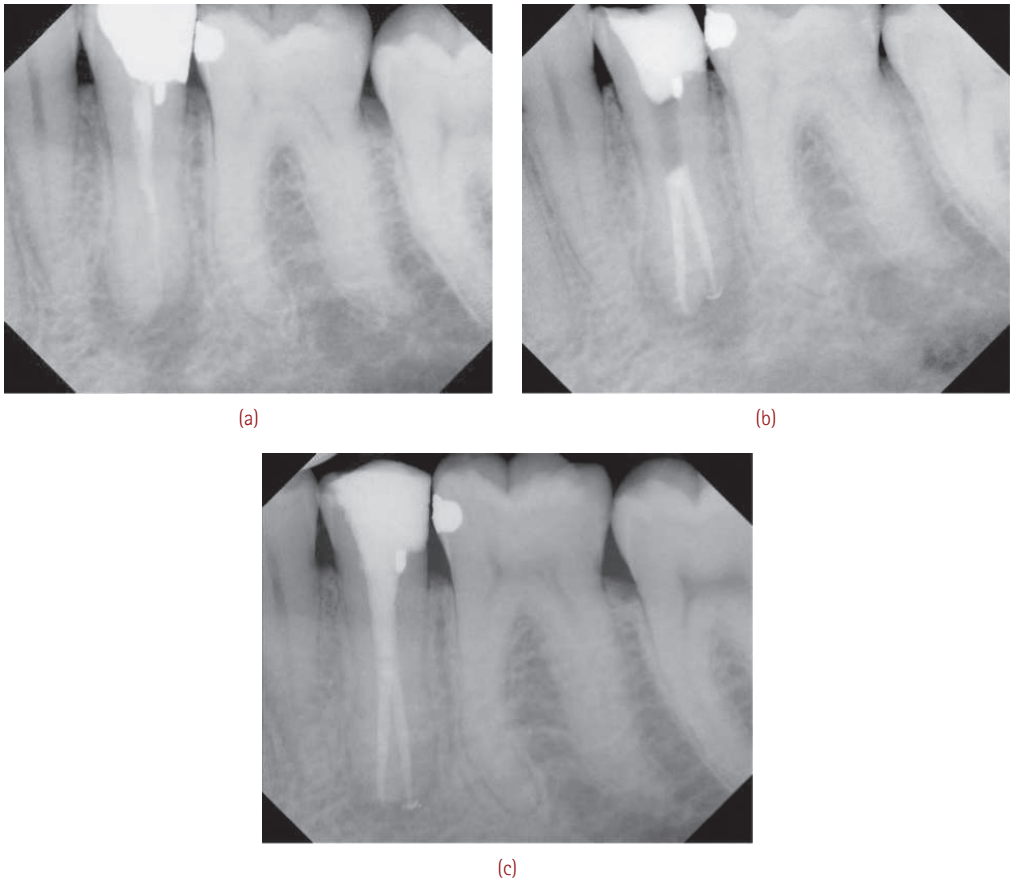
Access Opening: The access opening for the mandibular second premolar is basically the same as for the mandibular first premolar, except that the enamel penetration is initiated in the central fossa, and the ovoid access opening is wider mesiodistally, as dictated by the wider pulp chamber.

Anomalies: The mandibular second premolar has two or more roots in rare cases (**Figs 13.44–13.47**).

Figure 13.48 depicts the common errors in access opening in mandibular premolars.

Table 13.11 Root Canals and Apical Foramina in Mandibular Second Premolars

Investigators	One Canal and One Foramen (%)	One Canal and Two Foramina (%)	Two Canals and One Foramen (%)	Two Canals and Two Foramina (%)	Three Canals (%)
Pineda and Kuttler	98.8	1.2	–	–	–
Green	92.0	–	4.0	4.0	–
Zillich and Dowson	87.9	–	0.9	10.8	0.4
Vertucci	97.5	2.5	–	–	–



(a) (b) (c)

Figure 13.44 Mandibular second premolar with midroot bifurcation: (a) Periradicular radiolucency in a failing endodontically treated mandibular second premolar. (b) Two canals traced and obturation completed. (c) Follow-up radiograph showing good periradicular healing. (*Courtesy: Julian Webber, England.*)

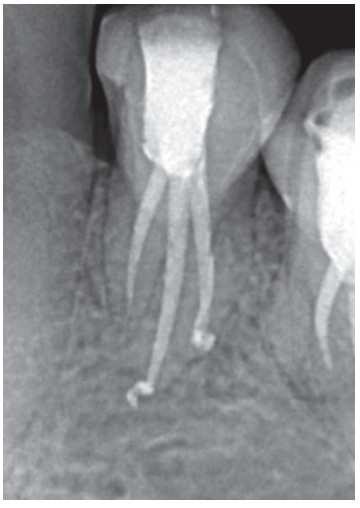


Figure 13.45 Mandibular second premolar with three roots and three canals.

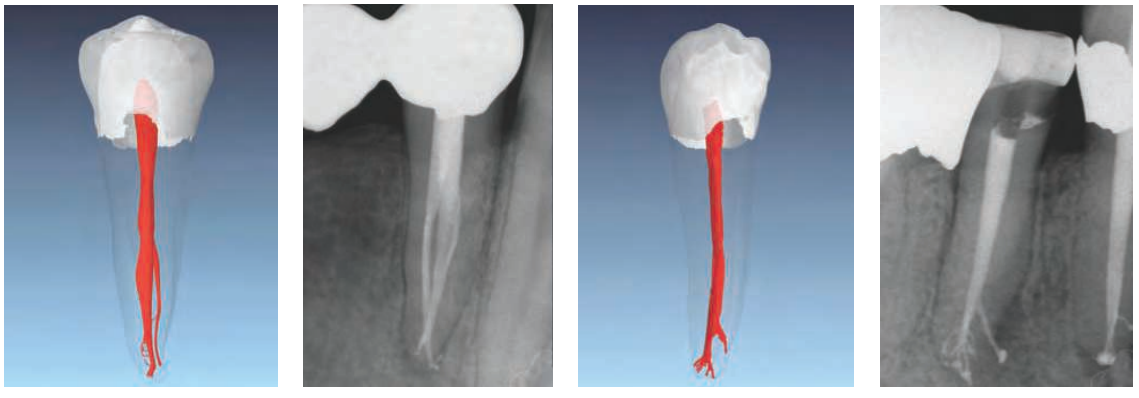
MANDIBULAR FIRST MOLAR

Average Tooth Length: The average length of this tooth is 21.5 mm.

Pulp Chamber: The roof of the pulp chamber of the mandibular first molar is often rectangular in shape. The mesial wall is straight, the distal wall round, and the buccal and lingual walls converge to meet the mesial and distal walls and form a rhomboidal floor. The roof of the pulp chamber has four pulp horns: MB, mesiolingual, distobuccal, and distolingual. These four pulp horns recede with age, with a resulting decrease in the size of the pulp chamber. The roof of the pulp chamber is located in the cervical third of the crown just above the cervix of the tooth, and the floor is located in the cervical third of the root.

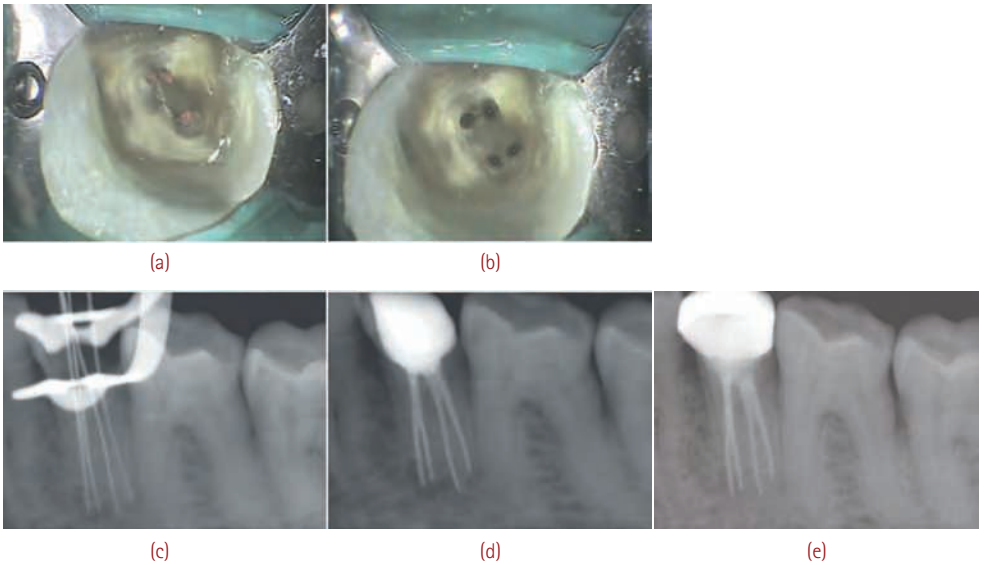
Three distinct orifices are present in the pulpal floor: MB, mesiolingual, and distal.

- The *MB orifice* is under the MB cusp and is usually difficult to find and to enter if not enough tooth structure is removed. To penetrate this orifice, insert a long-shank



(a) (b) (c) (d)

Figure 13.46 (a–d) Variations in the mandibular second premolar. (*Courtesy: (a and c) Frank Paque, Switzerland; (b and d) Clifford Ruddle, USA.*)



(a) (b)

(c) (d) (e)

Figure 13.47 (a) Initial access opening. (b) Access opening showing orifices of the four root canals. (c) Working length determination. (d) Immediate post-treatment radiograph. (e) Recall radiograph 1 year post-treatment. (From Sachdeva GS, Ballal S, Gopikrishna V, Kandaswamy D: *J. Endod.*, 34:104, 2008.)

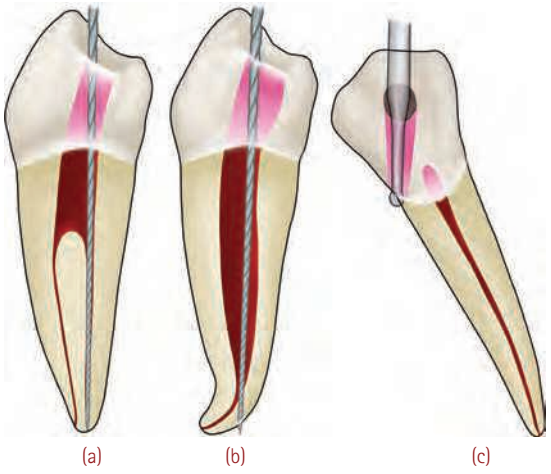


Figure 13.48 Common errors in access openings of mandibular premolars: (a) Missing extra canal. (b) Perforation of root. (a) and (b) are caused by inadequate deroofing of access opening. (c) Perforation of crown. Caused by not directing the bur parallel to the long axis of the tooth.

explorer in a mesiobuccoapical inclination into the point angle created at the juncture of the mesial wall, buccal wall, and subpulpal floor of the pulp chamber (**Fig. 13.49**).

- The *mesiolingual orifice* is located in a depression formed by the mesial and lingual walls. This orifice can be explored from a distobuccal direction. A groove usually connects the orifices of the MB and mesiolingual canals. The MB and mesiolingual orifices may be close together under the MB cusp.
- The *distal orifice*, which is oval in shape, with the widest diameter present in a buccolingual direction, can be explored by starting from a mesial direction. If the distal orifice is penetrated in a marked distobuccal or distolingual direction, one should seek an additional orifice and canal in the distal root. The multiple orifices in the distal root are usually found in the buccal and lingual portion of the ovoid coronal root canal (see **Fig. 13.51**).

Roots and Root Canals: Usually, two well-differentiated roots are present in the mandibular first molar, one mesial and one distal. Both roots are wide and flat buccolingually,

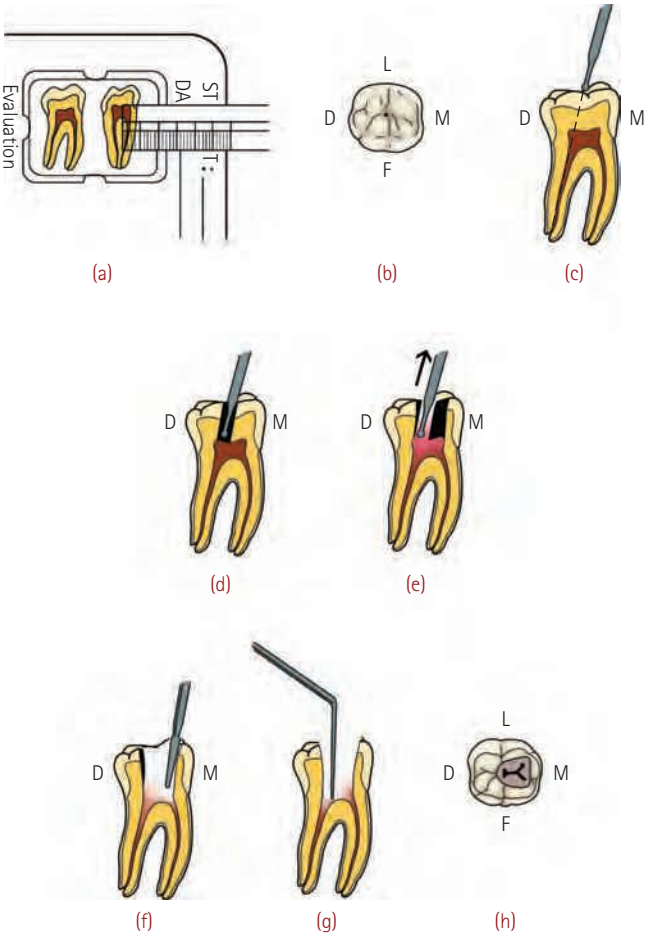


Figure 13.49 Steps in the access opening of a mandibular first molar. D, distal; F, facial; L, lingual; M, mesial.

with a depression in the middle of the root buccolingually. This anatomic characteristic may be accentuated in the mesial root. A third root is found in some cases, either distally or mesially (5.3%), and is often referred to as the *radix entomolaris*. The mesial root curves distally in 84% of cases and is straight in 16%. The distal root is straight in 74% of cases, curves to the distal in 21%, and curves to the mesial in 5%. Although the mandibular first molar has two roots, three canals are usually present (**Table 13.12**).

Table 13.12 Root Canals and Apical Foramina in Mandibular First Molars

Investigators	Roots	One Canal and One Foramen (%)	One Canal and Two Foramina (%)	Two Canals and One Foramen (%)	Two Canals and Two Foramina (%)	Three Canals (%)
Skidmore and Bjorndahl	Mesial	6.7	–	37.8	55.5	–
	Distal	71.1	–	17.7	11.2	–
Pineda and Kuttler	Mesial	12.8	–	–	30.2	57.0
	Distal	73.0	–	–	12.7	14.3
Vertucci	Mesial	12.0	8.0	28.0	51.0	1.0
	Distal	70.0	8.0	15.0	7.0	–



Figure 13.50 Middle mesial canal in mesial root of mandibular first molar.

Mesial Root

The mesial root has:

- Two canals that exit in two foramina in 41% of cases
- Two canals that coalesce to exit in one foramen in 28% of cases
- Two canals that coalesce to form one canal and bifurcate and exit in two foramina in 13% of cases
- One canal that exits in one foramen in 12% of cases
- One canal that bifurcates and exits in two foramina in 8% of cases
- In rare cases, three canals exit in three foramina and this third canal which is present between the MB and mesiolingual canal orifices is referred to as the *middle mesial canal* (**Fig. 13.50**)

*Distal Root (**Fig. 13.51**)*

The distal root has:

- One canal exiting in one foramen in 70% of cases
- Two canals coalescing and exiting in one foramen in 15% of cases
- One canal bifurcating and exiting in two foramina in 8% of cases
- Two canals exiting in two foramina in 5% of cases
- Two canals coalescing to form one canal and later bifurcating to exit in two foramina in 2% of cases

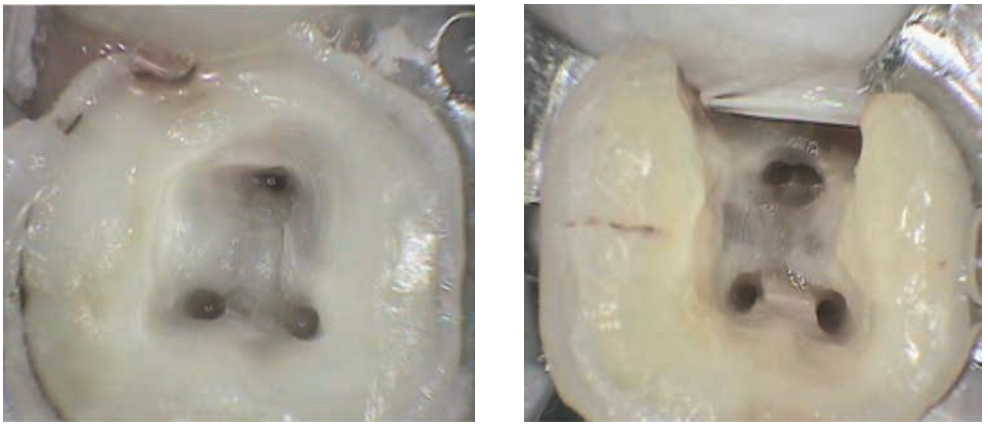
In cross-section, all three canals are ovoid in the cervical and middle thirds and round in the apical third. Two canals present in the distal root are usually round in cross-section from the cervical third to the apical third.

Clinical Note

The mesial root of the mandibular first molar is in close proximity to the buccal cortical plate, whereas the distal root is centrally located. The apex of the roots of mandibular first molars may be close to the mandibular canal, or they may be at some distance from it, depending on the length of the roots and the height of the body of the mandible.

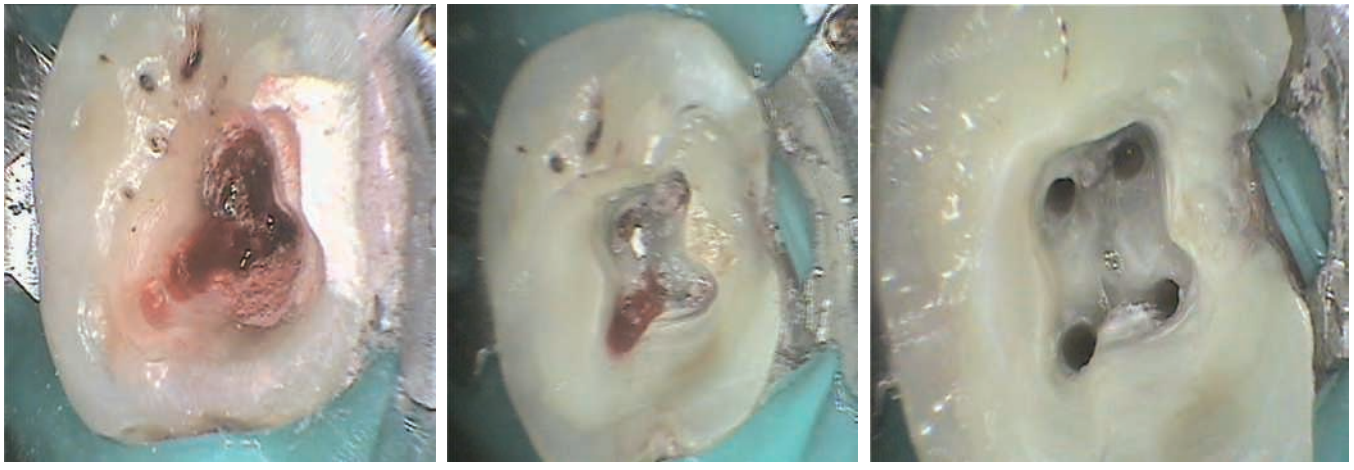
Access Opening: The access opening for the mandibular first molar follows the anatomic features of the pulp chamber. The enamel and dentin are penetrated in the central fossa with the bur angled toward the distal root, where the pulp chamber is largest (**Fig. 13.51**). The preparation follows the procedures outlined for the maxillary molar. The access opening is usually trapezoidal with round corners or rectangular if a second distal canal is present (**Figs 13.49h** and **13.52**). The access opening extends toward the MB cusp to uncover the MB canal, lingually slightly beyond the central groove and distally slightly beyond the buccal groove.

Figure 13.53 presents the micro-CT image of a mandibular first molar root canal anatomy.



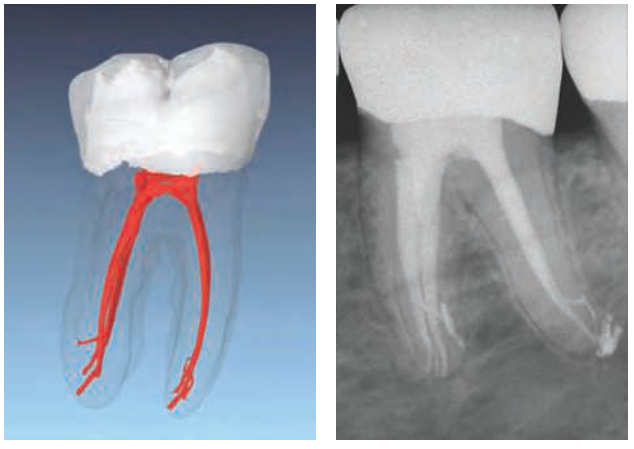
(a) (b)

Figure 13.51 Variations in distal root of mandibular first molar: (a) Distal root of a mandibular first molar with one canal and one orifice. (b) Distal root of a mandibular first molar with one canal and two orifices. Refer to **Figure 13.52c** for distal root of a mandibular first molar with two canals and two orifices.



(a) (b) (c)

Figure 13.52 Clinical access opening in a mandibular first molar: (a) Triangular access opening in a mandibular molar might lead to missing the second distal canal. (b) Complete removal of caries from the buccal wall. (c) Access refined and canals enlarged with orifice enlargers.



(a) (b)

Figure 13.53 Canal anatomy of the mandibular first molar. (*Courtesy: Frank Paque, Switzerland, and Clifford Ruddle, USA.*)

Anomalies: The mandibular first molar may have three roots and this extra root is often termed *radix entomolaris* (**Figs 13.54 and 13.55**).

MANDIBULAR SECOND MOLAR

Average Tooth Length: This tooth averages 20 mm in length.

Pulp Chamber: The pulp chamber of the mandibular second molar is smaller than that of the mandibular first molar, and the root canal orifices are smaller and closer together.

Roots and Root Canals: The majority of the mandibular second molars have two roots (71%), but teeth with one root (27%) and teeth with three roots (2%) are also seen.

Three root canals are usually present in the mandibular second molar. The most frequent variation is the presence of only two canals (**Table 13.13**).

Clinical Note

- The relationship between the apex of the root and the mandibular canal may be closer than that of the mandibular first molar.
- There is a significant incidence of this tooth having two canals only: one mesial and one distal (**Fig. 13.56**).
- The incidence of C-shaped canals is also significantly higher in this tooth compared to in others (**Fig. 13.57**).
- On the basis of the 3D reconstructed canal images, the C-shaped canal system can be classified into following three types:
  - Merging type (**Fig. 13.58a**)
  - Symmetrical type (**Fig. 13.58b**)
  - Asymmetrical type (**Fig. 13.58c**)

Access Opening: The access opening for the mandibular second molar is created as for the mandibular first molar, with the variations that a smaller tooth demands. Because of the buccoaxial inclination, it is sometimes necessary to reduce a large portion of the MB cusp to clean and shape the MB canal.

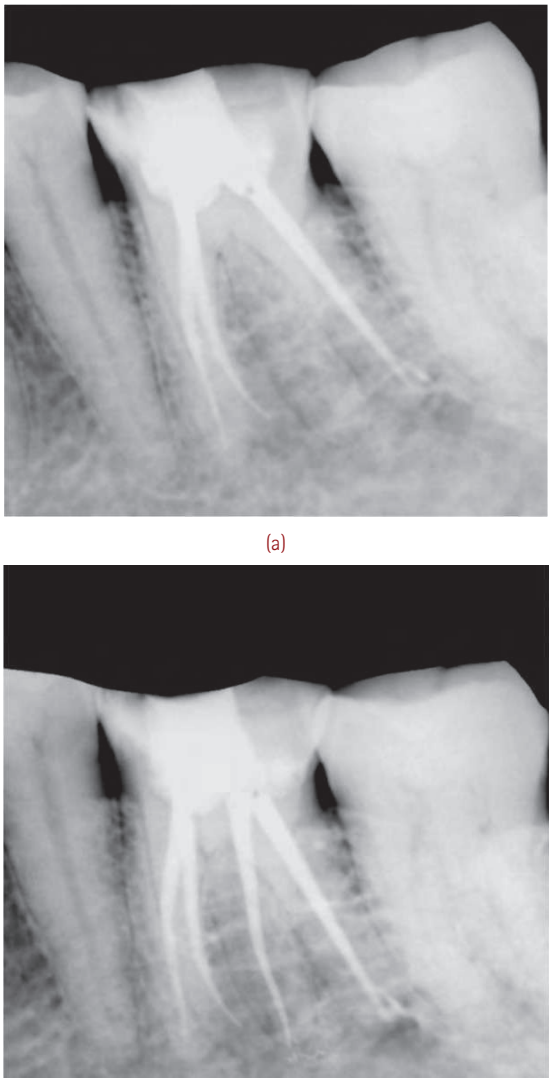
Anomalies: The mandibular second molar may have a third root, or it may have one conical root with one conical canal.

MANDIBULAR THIRD MOLAR

Average Tooth Length: The average length of this tooth is 18 mm.

Pulp Chamber: The pulp chamber of the mandibular third molar anatomically resembles the pulp chamber of the mandibular first and second molars. It is large and possesses many anomalous configurations such as C-shaped root canal orifices.

Roots and Root Canals: The mandibular third molar usually has two roots and two canals, but occasionally one root and one canal or three roots and three canals may be present. The root canals are generally large and short.



(a)

(b)

Figure 13.54 Radix entomolaris: (a) Endodontically treated mandibular first molar with a missed radix entomolaris root canal. (b) Mandibular molar with three distinct roots and four canals.

Clinical Significance: The alveolar socket of the mandibular third molar may project on to the lingual plate of the mandible. The apex of the root may be in close proximity to the mandibular canal.

Access Opening: The access opening for the mandibular third molar is created as for the mandibular first and second molars, with the variations that anatomic structure dictates.

Anomalies: The mandibular third molar frequently has a complex anatomic structure.

ANOMALIES OF PULP CAVITIES

Certain developmental anomalies of the pulp cavities may render the execution of endodontic procedures difficult or impossible.

- In *dentinogenesis imperfecta*, the pulp cavities may be small or even obliterated.
- *Hyperparathyroidism* may cause pulp calcification and loss of lamina dura.
- *Hypofunction of the pituitary gland* may lead to retarded eruption of teeth and to open root apices.
- *Dentinal dysplasia* is a hereditary condition characterized by obliteration of the pulp chamber and defective root formation. In some cases of dentinal dysplasia, the root development is disturbed, with obliteration of the root canals.
- *Taurodontism* is characterized by a short tooth and a much-larger-than-normal pulp chamber (**Fig. 13.59**). It may be a throwback to ancient humans because a large pulp chamber is characteristic of Neanderthals. Taurodontism is probably due to a lack of invagination of the epithelial root sheath during development. It may be considered an ethnic or familial trait because it occurs in family groups, such as in Eskimos.

Figure 13.60 presents the common errors in access cavity preparation of mandibular molars.

DENS IN DENTE

A *dens in dente* is an invagination within the crown or root of the lingual surface of the tooth. This invagination creates a space within the tooth that is lined with enamel and communicates with the oral cavity. This malformation or anomaly may occur in any anterior tooth, but *it is most often observed in maxillary lateral incisors*. At times, more than one tooth is affected. Invagination of the lingual enamel of maxillary incisor teeth often causes widening of the pulp chamber (**Fig. 13.61**).

Such teeth are predisposed to decay because of the anatomic malformation, and pulp disease may result before the root apex is fully developed. Intentional filling of the defect may prevent pulp involvement in such cases.

DENS EVAGINATUS

Dens evaginatus is a developmental anomaly that produces an extra cusp-like structure, usually in the area of the transverse ridge of premolars. It is formed during early tooth development by the proliferation and evagination of the enamel epithelium into the stellate reticulum, with resulting protuberance of enamel and dentin with a pulp horn. The cusp-like structure is subject to wear or fracture that exposes the pulp, with the sequelae of pulp and periapical disorders. Although this anomaly is predominantly found in persons of Mongolian ancestry, it has also been reported in Caucasians. The majority of cases reported have been in premolars, but incisors (**Fig. 13.62**), cuspids, and molars have also been involved. Dens evaginatus can occur unilaterally or bilaterally.

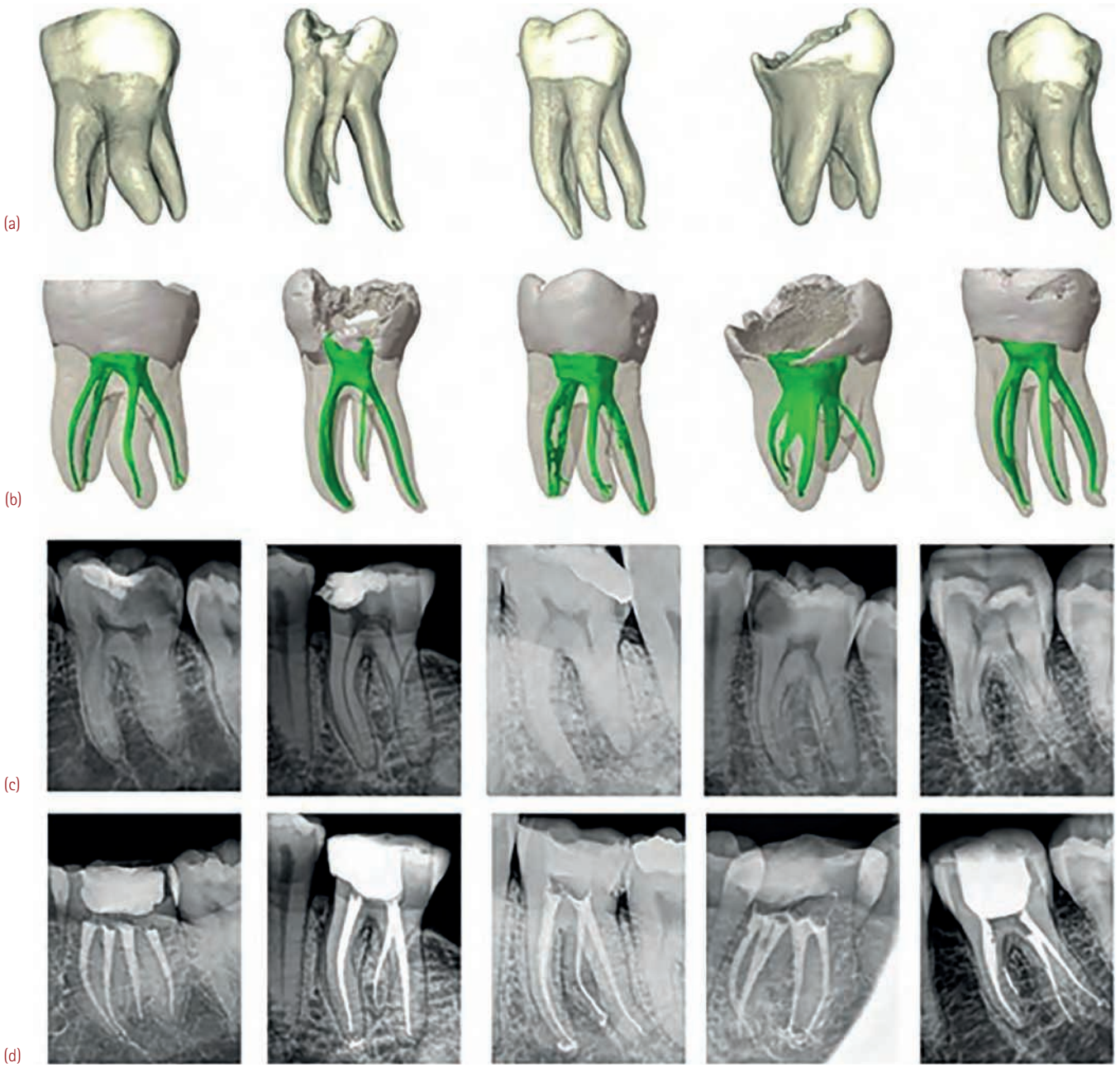


Figure 13.55 (a) Micro-CT scans and 3D reconstructions of the external and internal anatomy of five three-rooted mandibular molars with a supernumerary third root or radix. (b) 3D models showing the internal anatomy of the specimens. (c) Preoperative digital radiographs of similar cases treated as shown in above reconstructions. (d) Postoperative digital radiographs of similar cases treated as shown in above reconstructions (*Case Courtesy:* Roheet Khatavkar, India).

Table 13.13 Root Canals and Apical Foramina in Mandibular Second Molars

Investigators	Roots	One Canal and One Foramen (%)	One Canal and Two Foramina (%)	Two Canals and One Foramen (%)	Two Canals and Two Foramina (%)
Pineda and Kuttler	Mesial	58.0	–	20.6	21.4
	Distal	73.0	–	12.7	14.3
Vertucci	Mesial	27.0	9.0	38.0	26.0
	Distal	92.0	1.0	3.0	4.0

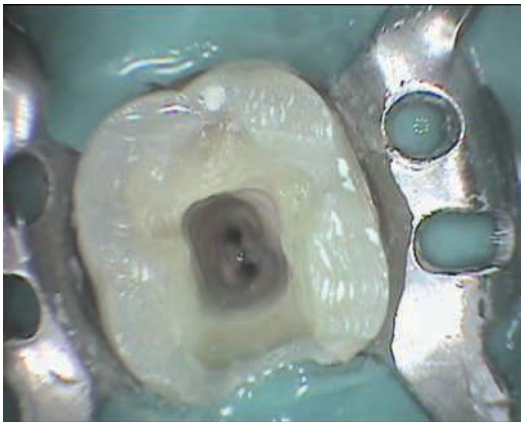


Figure 13.56 Mandibular second molar with two canals.

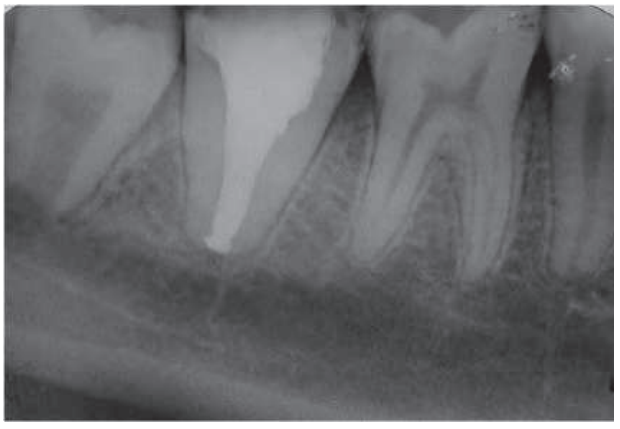


Figure 13.57 Mandibular second molar with a C-shaped canal and a single conical root.

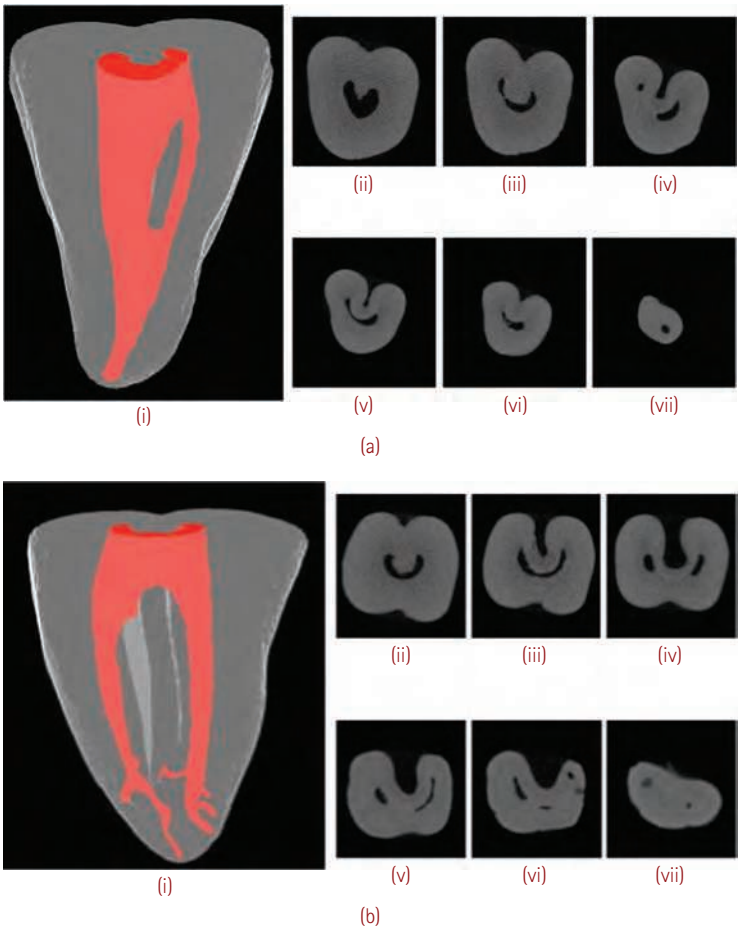


Figure 13.58 (a) Type I C-shaped canal system (merging type): (i) 3D reconstructed root canal image; (ii) cross-section 1 mm from the apex; (iii) cross-section 4 mm from the apex; (iv) cross-section 6 mm from the apex; (v) cross-section 8 mm from the apex; (vi) cross-section 11 mm from the apex; (vii) cross-section 12 mm from the apex (orifice). (b) Type II C-shaped canal system (symmetrical type): (i) 3D reconstructed root canal image; (ii) cross-section 1 mm from the apex; (iii) cross-section 3 mm from the apex; (iv) cross-section 4 mm from the apex; (v) cross-section 8 mm from the apex; (vi) cross-section 11 mm from the apex; (vii) cross-section 12 mm from the apex (orifice). *(continued)*

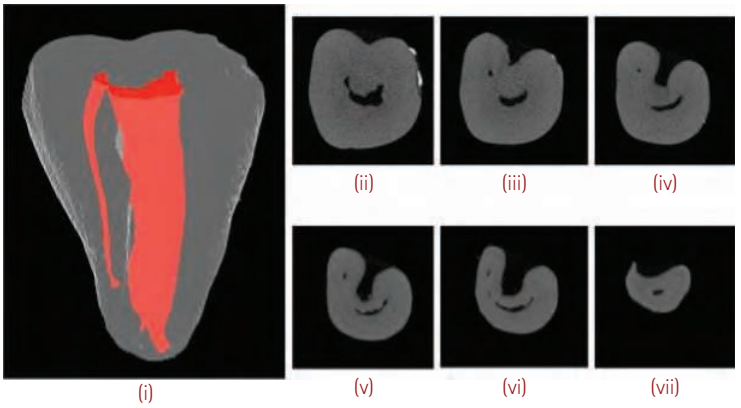


Figure 13.58 *(continued)* (c) Type III C-shaped canal system (asymmetrical type): (i) 3D reconstructed root canal image; (ii) cross-section 1 mm from the apex; (iii) cross-section 3 mm from the apex; (iv) cross-section 5 mm from the apex; (v) cross-section 7 mm from the apex; (vi) cross-section 9 mm from the apex; (vii) cross-section 10 mm from the apex (orifice). (*Courtesy: Bing Fan, Wuhan University, China.*)

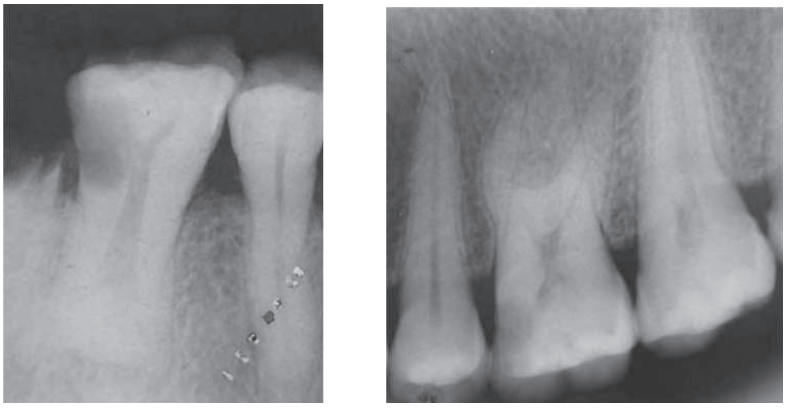


Figure 13.59 Taurodontism, characterized by short roots and a large pulp chamber.

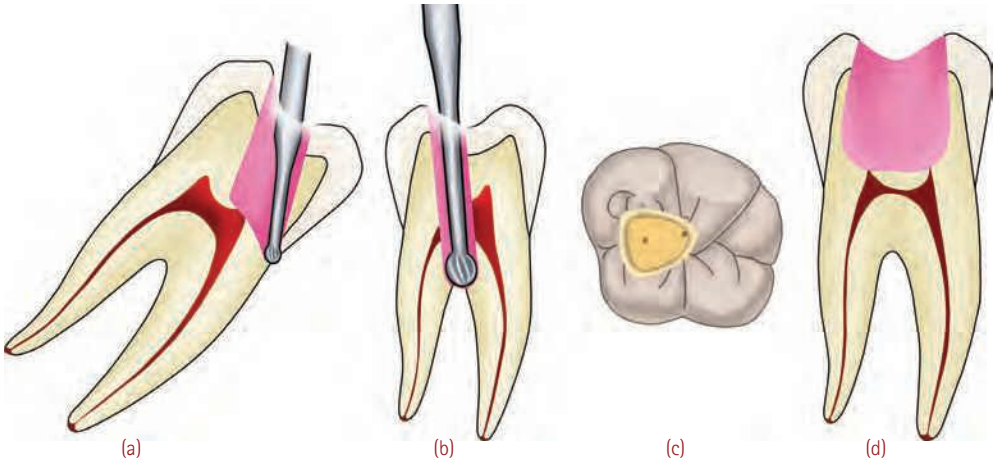
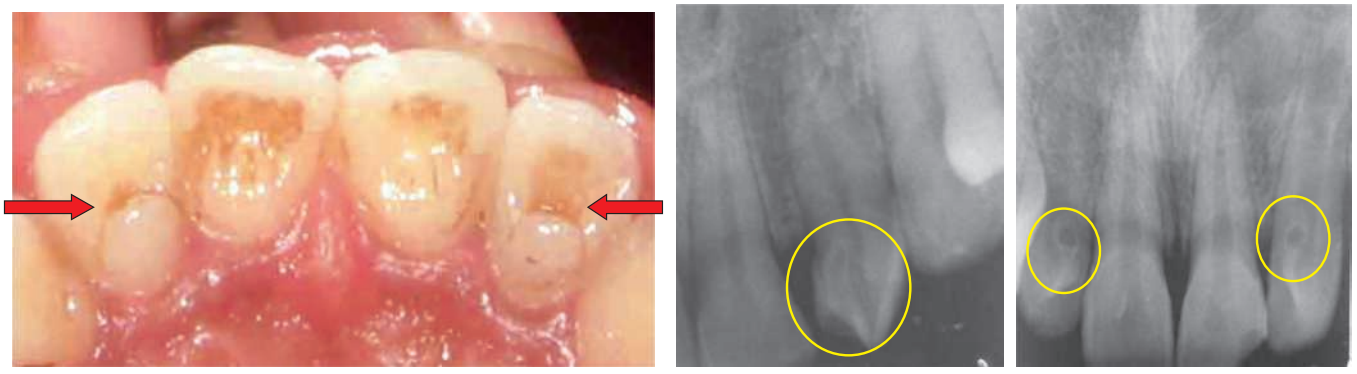


Figure 13.60 Common errors in access openings of mandibular molars: (a) Perforation of crown: caused by failure to direct the bur parallel to the long axis of the tooth. (b) Perforation in furcation: caused by using a long-shank bur at high speed and not realizing the depth of the pulp chamber. The depth of most pulp chambers is approximately 6 mm. (c) Faulty cavity preparation: caused by not following the proper anatomy of the occlusal table. The mesiobuccal orifice is present beneath the mesiobuccal cusp. The fourth canal is usually located buccally to the distal canal and under the distobuccal cusp tip. (d) Gouging and leaving roof of the pulp chamber: caused by not directing the bur at right angles to the occlusal table and not penetrating completely. If the opening appears shallow with openings to the canal separated by light-colored dentin, one should suspect that the opening is incomplete. The floor of the pulp chamber in a multirooted tooth is somewhat darker and may have grooves connecting the canal orifices.



(a) (b) (c)

Figure 13.61 Clinical and radiographic features of dens in dente.



Figure 13.62 Clinical appearance of dens evaginatus in a maxillary incisor.



Figure 13.63 Palatal developmental groove in relation to the maxillary lateral incisor.

PALATOGINGIVAL DEVELOPMENTAL GROOVE

A palatogingival developmental groove may be present in maxillary central and lateral incisors (**Fig. 13.63**). This groove, which appears as an invagination of the enamel, originates in the cingulum of the incisors and ends apically at various levels of the root. It is believed that it is an attempt by the tooth bud to form a second root. Once the integrity of the periodontal attachment is broken in the area of the anomaly, a probable linear periodontal defect will develop to the level of the groove apically. The result is a self-perpetuating periodontal defect. Radiographically, the lesion created by the anomaly produces a radiolucency along the length of the groove. This radiolucency can be differentiated from a vertical root fracture by the clinical presence of the developmental groove.

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14 Shaping and Cleaning of the Radicular Space: Instruments and Techniques

What we remove from the pulp space, is far more important than what we replace it with ....

Endodontic treatment can be divided into three main phases:
1. Proper access preparation into the pulp space
2. Shaping and cleaning of the root canal
3. Obturation

The initial step for shaping and cleaning the root canal is proper access to the chamber that leads to straight-line penetration of the root canal orifices. The concepts of achieving proper access into the pulp space are elaborated in Chapter 13. The next step is exploration of the root canal, extirpation of the remaining pulp tissue or gross debridement of the necrotic tissue, and verification of the working length. This step is followed by proper instrumentation, irrigation, debridement, and disinfection of the root canal. Obturation completes the procedure.

Definitions

- *Shaping and cleaning* of the root canal consists of removing the pulp tissue and debris from the canal and shaping the canal to receive an obturating material.
- *Pulpectomy*, or pulp extirpation, is the complete removal of a normal or diseased pulp from the pulp cavity of the tooth. The operation is sometimes inappropriately referred to as *devitalization*.
- *Debridement*: When food or other debris have accumulated in the pulp cavity, in addition to the residual necrotic pulpal debris, the removal of this material from the pulp cavity is referred to as *debridement*.

Using sequentially larger sizes of files and irrigating and disinfecting the canal to clear it of debris, one shapes the canal to receive a well-compacted filling that seals the root canal apically and laterally to prevent any leakage.

The importance of adequate canal shaping and cleaning, rather than reliance on antiseptics, cannot be overemphasized. Histologic examination of pulpless teeth in which root canal therapy has failed often shows that the canals were not completely cleaned. Obturation of an improperly cleaned canal would still lead to an endodontic failure irrespective of the quality of obturation (**Figs 14.1** and **14.2**).



Figure 14.1 Endodontic failure in a well-obturated lower molar.

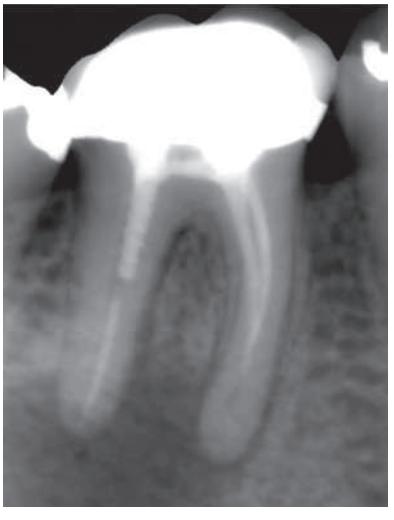


Figure 14.2 Endodontic failure in a poorly obturated lower molar.

SHAPING AND CLEANING OF RADICULAR SPACE

Shaping and cleaning of the root canal comprises the most important phase of endodontic treatment. Other aspects of treatment cannot be neglected, however, because they are all interrelated and contribute to the success of endodontic therapy.

The objectives of shaping and cleaning are as follows:
- To debride and remove the infected tissues out of the root canal system without compromising the structural integrity of the root

Table 14.1 Schilder's Objectives of Shaping and Cleaning of the Root Canal System

Mechanical Objectives	Biological Objectives
• Should have a continuous, tapering, conical shape, with the narrowest cross-sectional diameter apically and the widest diameter coronally • The walls should taper evenly toward the apex and should be confluent with the access cavity • To give the prepared root canal the "quality of flow," i.e., a shape that permits plasticized gutta-percha to flow against the walls without impedance • Should keep the apical foramen as small as practical • Should shape and clean the canal without transporting the apical foramen	• Confinement of instrumentation to the roots themselves • Ensuring that the necrotic debris are not forced beyond the foramen • Removal of all tissues from the root canal space • Creation of sufficient space for optimal obturation of the radicular space

- To shape/contour the root canal walls for the purpose of:
  - Providing access and facilitating the movement of irrigants to the apical third of the root canal system
  - Providing space to seal the root canal completely with a well-compacted, inert filling material

To help achieve these objectives, each individual root canal should be examined radiographically and explored with endodontic instruments. The examination should include an assessment of the canal length, shape, size, curvature, entrance orifice, location of foramina, canal ramifications, and presence of calcifications or obstructions. The objectives of shaping and cleaning of the root canal system proposed by Schilder are given in **Table 14.1**.

GOALS OF SHAPING OF THE RADICULAR SPACE

Root canals should be widened for four reasons:

1. To eliminate microorganisms on the canal surface mechanically
2. To completely remove pulp tissue, because even when a vital pulp is extirpated, tags of pulp tissue and odontoblasts cling to the canal wall and are not removed with the body of the pulp; they later undergo necrosis and provide an environment for bacterial growth
3. To increase the capacity of the root canal to permit irrigating solutions to reach the apical third for effective disinfection
4. To shape the root canal to receive gutta-percha, because the wider the canal, the easier it is to fill it

ENDODONTIC INSTRUMENTS FOR SHAPING AND CLEANING

STANDARDIZATION OF ENDODONTIC STAINLESS STEEL INSTRUMENTS

At one time, root canal instruments were made according to the whim of manufacturers, with no definite specifications regarding diameter, taper, or length of the cutting blades. *Ingle and LeVine* suggested a definite increment in diameter as the size progressed while maintaining a constant taper of all blades regardless of size. Their recommendations are given in **Box 14.1** (see also **Fig. 14.3**).

COMPONENTS OF AN ENDODONTIC FILE

- ***Taper:*** Taper denotes the per millimeter increase in file diameter from the tip toward the file handle. It is denoted either in numericals or in percentile. The traditional ISO instruments were standardized to have #.02 taper or 2% taper. In other words, a size #20 ISO file will have *a tip diameter of 0.20 mm* and would have a 0.22 mm diameter 1 mm from the tip and 0.24 mm diameter 2 mm from the tip and 0.26 mm diameter 3 mm from the tip.

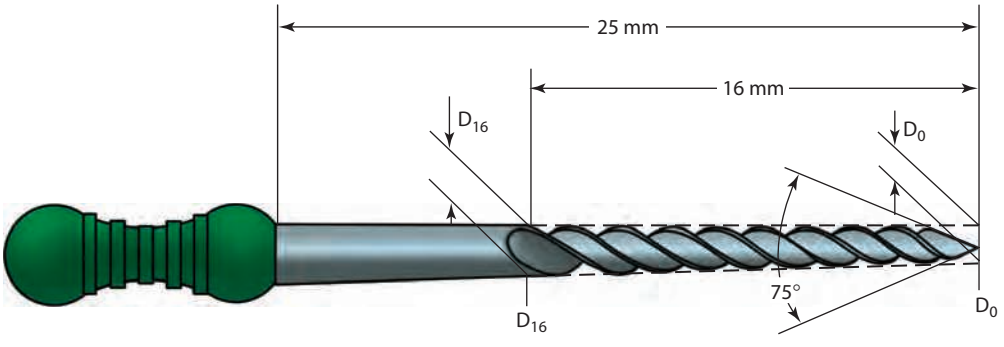


Figure 14.3 Specifications for an endodontic instrument. D_0, diameter at the tip, in hundredths of millimeters; D_{16}, diameter in hundredths of millimeters at the end of the cutting blade, i.e., 16 mm from D_0. The taper of the instrument from D_0 to D_{16} is in increments of 0.02 mm in width per millimeter of length. The tip angle of the instrument should be 75 ± 15°.

Box 14.1

Ingle and LeVine's Standardization of Endodontic Hand Instruments

- Instruments shall be numbered from 10 to 100, the numbers to advance by 5 units to size 60 and then by 10 units to size 100. This has been revised to include numbers from 6 to 140.
- Each number shall be representative of the diameter of the instrument in hundredths of a millimeter at the tip; e.g., No. 10 is 10/100 or 0.1 mm at the tip, No. 25 is 25/100 or 0.25 mm at the tip, and No. 90 is 90/100 or 0.9 mm at the tip.
- The working blade (flutes) shall begin at the tip, designated site D_0, and shall extend exactly 16 mm up the shaft, terminating at designated site D_{16}.
- The diameter of D_{16} shall be 32/100 or 0.32 mm greater than that of D_0; e.g., a No. 20 reamer shall have a diameter of 0.20 mm at D_0 and a diameter of 0.20 plus 0.32 or 0.52 mm at D_{16}. This sizing ensures a constant increase in taper of 0.02 mm/mm for every instrument regardless of size.

Following specifications were added later:

- The tip angle of an instrument should be 75 ± 15°.
- Instrument sizes should increase by 0.05 mm at D_0, between Nos. 10 and 60, e.g., Nos. 10, 15, and 20, and they should increase by 0.1 mm from Nos. 60 to 150, e.g., Nos. 60, 70, and 80.
- Nos. 6 and 8 have been added for increased instrument selection.
- In addition, instrument handles have been color coded for easier recognition (**Table 14.2**).

Table 14.2 Specifications of Files and Reamers

Color Code	New Number	Diameter*	
		D_0 (mm)	D_{16} (mm)
Pink	6	0.06	0.38
Gray	8	0.08	0.40
Purple	10	0.10	0.42
White	15	0.15	0.47
Yellow	20	0.20	0.52
Red	25	0.25	0.57
Blue	30	0.30	0.62
Green	35	0.35	0.67
Black	40	0.40	0.72
White	45	0.45	0.77
Yellow	50	0.50	0.82
Red	55	0.55	0.87
Blue	60	0.60	0.92
Green	70	0.70	1.02
Black	80	0.80	1.12
White	90	0.90	1.22
Yellow	100	1.00	1.32
Red	110	1.10	1.42
Blue	120	1.20	1.52
Green	130	1.30	1.62
Black	140	1.40	1.72
White	150	1.50	1.82

*Distance on the shaft between D_0 and D_{16} is 16 mm.

Greater tapered instruments have been developed with 4, 6, 8, and even 10% taper. Tapered instruments help in preparing canals of wider diameter without *overenlarging* the canal at working length. Thus, a 30-size file with 2% taper, 30-size file with 4% taper, and 30-size file with 6% taper all would have the same tip diameter of 0.30 mm. The diameter along the file would be drastically enlarged with an increase in the taper (**Table 14.3**; **Fig. 14.4**).

- *Tip design*: Original stainless steel root canal instruments usually possess a sharp, cutting tip. However, rotary instruments currently are manufactured with ***modified noncutting tips*** as these noncutting tips cause less canal transportation and remove debris better than traditional instruments having conventional cutting tips.
- *Flute*: It is the groove or relief on the working surface of the file which collects the debris as the file cuts through the substrate.
- *Chip space*: The chip space denotes the cleaning effectiveness of an instrument as an increase in chip space denotes improved ability to remove debris out of the root canal.
- *Blade (cutting edge)*: It is the working area of the file and is the surface with the greatest diameter that follows the flute as it rotates.
- *Land*: In certain file designs, a surface projects axially from the central core to the cutting edge between the flutes. This feature is incorporated to reduce canal transportation and supports the cutting edge.

Table 14.3 Influence of Taper on the Diameter of Endodontic Instruments

Size of Instrument	Taper of Instrument (%)	Tip Diameter (mm)	1 mm Above Tip (mm)	2 mm Above Tip (mm)	3 mm Above Tip (mm)
No. 30	2	0.30	0.32	0.34	0.36
No. 30	4	0.30	0.34	0.38	0.42
No. 30	6	0.30	0.36	0.42	0.48

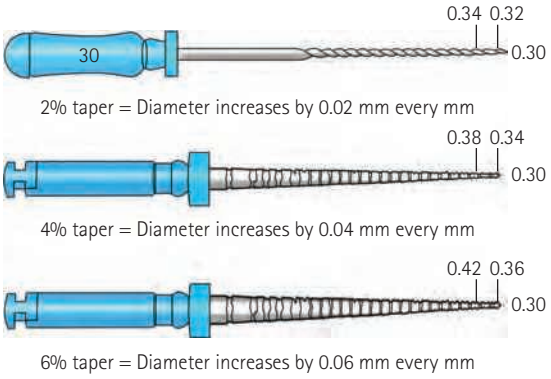


Figure 14.4 Comparison of 2, 4, and 6% tapered instruments



Figure 14.5 Barbed broach used for extirpation of the pulp and gross debridement of the root canal.

- *Pitch*: It is the distance from one cutting edge to the next. A file with a short pitch will have more spirals than a file with a longer pitch.
- *Rake angle*: On perpendicular sectioning of a file, the angle which the leading edge forms with the radius of the file is known as the rake angle. If it forms an obtuse angle, then the rake angle is considered to be positive. An acute angle is termed negative rake angle.
- *Helix angle*: It is the angle the cutting edge forms with the long axis of the file.

CLASSIFICATION OF ENDODONTIC SHAPING INSTRUMENTS BASED ON METHOD OF USE (BOX 14.2)

GROUP I: HAND-OPERATED ENDODONTIC INSTRUMENTS

1. Barbed Broaches

Barbed broaches were the earliest endodontic instruments used to extirpate the pulp and enlarge the canal. A barbed broach is a short-handled endodontic instrument often used for the extirpation of the entire pulp and for the removal of necrotic debris, absorbent points, cotton pledgets, and other foreign materials from the root canal (**Fig. 14.5**).

It is manufactured from a tapered, round, soft iron wire in which angled cuts are made into the surface to produce barbs. Barbed broaches are available in a variety of sizes, from triple extrafine (XXXF) to extracoarse (XC).

The selection of a suitably sized broach for the removal of the pulp and gross debridement is important. A barbed broach that is too wide does not permit removal of all the pulp tissue, or it may force the pulp apically as it is inserted in the canal. It may also bind in the canal as it is rotated and may thereby break, or the barbs may become embedded in the dentin as the broach is withdrawn. On the other hand, if the broach is too narrow, it will not engage the pulp tissue sufficiently to allow its removal.

By comparing the size of the broach with the size of the last instrument used in the root canal or an estimated size of the image in a radiograph, one should select a barbed broach that fits loosely into the apical third of the root canal. The root canal is irrigated with a 5.2% solution of sodium hypochlorite, and the barbed broach is introduced until one notes unforced contact with root canal walls. The broach is withdrawn about 1 mm and is rotated 360° to engage the pulp tissue; it is withdrawn again to remove the pulp tissue.

Box 14.2

Classification of Endodontic Shaping Instruments

- *Group I:* Hand-operated endodontic instruments
  1. Barbed broaches and rasps
  2. K-type reamers and files
  3. Hedstroem files
- *Group II:* Low-speed stainless steel endodontic instruments with latch-type attachments
  1. Gates-Glidden drills
  2. Peeso reamers
- *Group III:* Ultrasonic and sonic instruments
- *Group IV:* Engine-driven nickel–titanium endodontic instruments (most commonly used)
  1. Rotary instrumentation
  2. Reciprocating instrumentation
  3. Canal adaptive instrumentation
     (a) Self-adjusting file (SAF)
     (b) XP-Endo Shaper and Finisher

Clinical Note

- Barbed broaches were originally recommended to be used in the straight part of the root canals and are not inserted into the root canal until the canal has been enlarged throughout up to a size No. 20 or 25 reamer or file. This precaution prevents accidental breakage of broaches inside the canal.
- Barbed broaches break easily, especially if they bind in the root canal. *To avoid binding and breakage, many clinicians* ***avoid the use of broaches*** *and initiate root canal exploration and instrumentation with #10, 8, or 6 sized K files.*

2. K-Type Reamers and Files

In the early 1900s, Kerr Manufacturing Company designed and manufactured new K-type endodontic instruments to improve the efficiency of root canal preparation.

- Originally manufactured from round, tapered piano wire (carbon steel), most instruments are now manufactured from a variety of stainless steel blanks. The stainless steel wire is ground along its long axis into a four-sided (square cross-section) or three-sided (triangular cross-section) tapered shaft that is twisted into flutes extending 16 mm from the top to the tip of the cutting blade. The introduction of nickel–titanium (NiTi) alloy for manufacturing endodontic instruments has improved canal shaping due to its improved flexibility as compared to stainless steel.
- The traditional reamer, manufactured from a triangular blank, and file, manufactured from a square blank, are still made by a few companies; however, most manufacturers make reamers and files from similar blanks, and such ***reamers and files differ only in the number of flutes along their blade*** (**Fig. 14.6a** and **14.6b**).

Clinical Note

- Clinically, files and reamers are recommended to be used in a penetration, rotation, and retraction motion.
- Files can also be employed in a filing or a rasping motion once canal patency is achieved.
- Heuer reported that files are manufactured from blanks twisted to produce *tighter flutes*, and reamers are manufactured with *looser flutes*.
- As the use of *square blanks* results in instruments that *resist fracture more effectively* than those made from triangular blanks, square blanks are generally used for smaller, fragile instruments.
- When instrument fracture is no longer a critical factor, such as in larger instruments, triangular blanks are used because the triangular-blanked instruments cut approximately 2.5 times more efficiently.

The number of flutes twisted into each blade of a similar-sized instrument determines whether that instrument is a reamer (less flutes) or a file (more flutes). For example, a No. 30 reamer may have 15 flutes per 16-mm blade, and a No. 30 file may have 22 flutes per 16-mm blade (**Fig. 14.7a** and **14.7b**).

Reamers and K-type files do not break unless they have an undetected defect in the steel shaft or until the instrument is strained or deformed, i.e., rotated on its axis when bound in a root canal for several 360° twists. The more flexible the instrument, the more full turns a blade can withstand before breaking. If an instrument is used with a maximum turn of 90°, and if it is withdrawn periodically for inspection, the chance of instrument fracture is obviously reduced. Once an instrument is deformed, however, it does not continue to cut under pressure: instead, it continues to deform until it fractures. Once deformed, the instrument must be discarded.

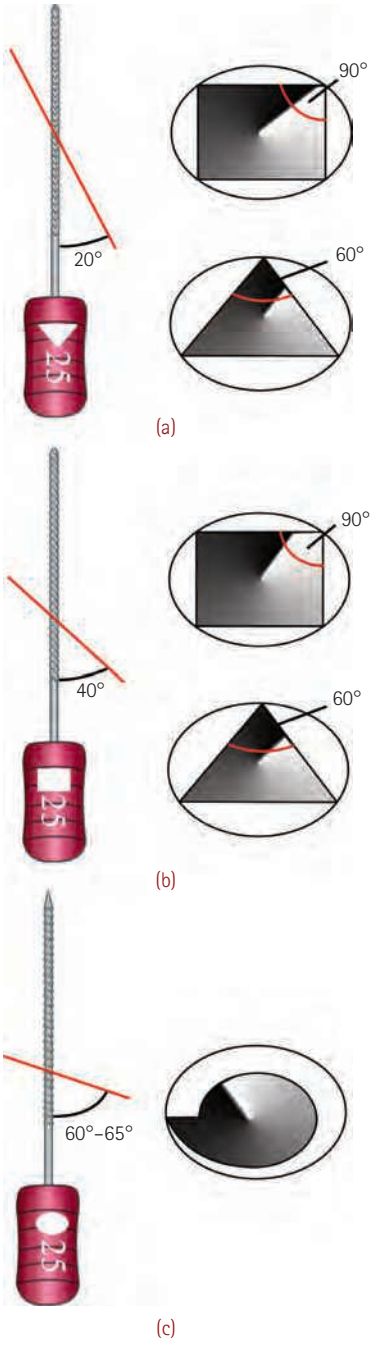


Figure 14.6 Endodontic instruments used for cleaning and shaping the root canal: (a) K-file, traditionally made from a square blank. (b) K-reamer, traditionally made from a triangular blank. (c) Hedstroem file, machined from a round blank to produce spiral flutes.

Modifications

- *K-flex file:* Rhomboidal or diamond-shaped blanks have been twisted to produce a file called K-flex (SybronEndo/Kerr, USA). The manufacturer claims that this design increases the flexibility and cutting efficiency of the instrument. The rhomboidal blank produces alternating high



(a) (b) (c)

Figure 14.7 (a) K-files. (b) K-reamers. (c) Hedstroem files.

and low flutes that are supposed to make the instrument more efficient in removal of debris.

- *Flex-R file:* The stainless steel file's metallic memory to return to its original position increases the tendency to transport or ledge the canal. A reduction in the cutting tip angle makes the file stay more centered within the canal and enables a more circumferential cutting action. This modified-tip file has been marketed as the Flex-R file (Moyco/Union Broach, USA).

3. Hedstroem Files

Hedstroem files, also known as H-files, are manufactured from a round stainless steel wire machined to produce spiral flutes resembling cones or a screw. This instrument has a higher cutting efficiency than K-instruments, but it is fragile and fractures easily (**Figs 14.6c** and **14.7c**). The better cutting efficiency is attributed to its more positive rake angle and to its blade which has a cutting rather than a scraping angle. The clinician should always employ the Hedstroem file in only one direction, *retraction*, and never in a torquing action.

Modifications

- *Safety Hedstroem:* It is a Hedstroem file with a noncutting side in order to prevent ledging in curved canals.
- *HyFlex file:* It has a cross-section which presents an "S" shape instead of the traditional single-helix teardrop cross-section of the Hedstroem file.
- *Unifiles:* They are machined from round stainless steel wire by cutting two superficial grooves to produce flutes in a double-helix design. They resemble the Hedstroem file in appearance and are less subject to fracture, but are less efficient. They are no longer marketed.
- *S-file:* It has a double-helix cross-section and is a variation of the Unifile.



Clinical Note

- Stainless steel and nickel–titanium root canal instruments have replaced *carbon steel instruments* because they are more flexible and are therefore less likely to fracture when strained (deformed), and they are less susceptible to corrosion, usually caused by contact with sodium hypochlorite solution.
- Instruments are available in three lengths:
  - *Short:* 21 mm
  - *Standard:* 25 mm
  - *Long:* 31 mm

Ordinarily, 21- and 25-mm-long instruments are used, but 21-mm instruments are needed for molars, especially when the patient cannot open the mouth wide, and 31-mm instruments are necessary for cuspids and other teeth in which a 25-mm instrument cannot reach the apical foramen.

GROUP II: LOW-SPEED STAINLESS STEEL INSTRUMENTS WITH LATCH-TYPE ATTACHMENT

The most commonly used low-speed rotary stainless steel instruments in endodontics are as follows:

1. Gates-Glidden drills
2. Peeso reamers

1. Gates-Glidden Drills

The Gates-Glidden drill has a long, thin shaft ending in a flame-shaped head, with a safe tip to guard against perforations (**Fig. 14.8a**). The flame head cuts laterally and is used with gentle, apically directed pressure. The long shaft is designed to break at the neck, the narrowest diameter that lies adjacent to the handpiece. If the drill binds during use, it will fracture at the neck of the shaft and will extrude from the tooth. The fractured segment is easily removed by grasping the broken shaft with pliers and pulling it out of the tooth.



(a)



(b)

Figure 14.8 (a) Gates-Glidden drill. Note the flame-shaped head with a safe tip. (b) Peeso reamer. Note the long, sharp flutes and the safe tip.

Clinical Note

- ***Drux burs*** are designed similarly to the Gates-Glidden (GG) drill, but have a flexible shaft.
- The GG drill is used to:
  - Remove the lingual shoulder during access preparation of the anterior teeth
  - Enlarge root canal orifices

2. PEESO REAMERS

The Peeso reamer has long, sharp flutes connected to a thick shaft (**Fig. 14.8b**). It cuts laterally and is primarily used for the preparation of post space when gutta-percha has to be removed from the obturated root canal.

Both Gates-Glidden drills and Peeso reamers are made of stainless steel and are used with an electric slow-speed handpiece in a rotational speed range of 800–1200 rpm. These aggressive cutting instruments are inflexible and should be used at slow speed in a contra-angled engine-driven handpiece and with extreme caution to prevent overinstrumentation and perforations. The diameters of Gates-Glidden drills and Peeso reamers are given in **Table 14.4**.

Table 14.4 Diameter of Slow-Speed Rotary Stainless Steel Instruments

Size	Diameter	
	Gates-Glidden Drills (mm)	Peeso Reamers (mm)
No. 1	0.5	0.7
No. 2	0.7	0.9
No. 3	0.9	1.1
No. 4	1.1	1.3
No. 5	1.3	1.5
No. 6	1.5	1.7

GROUP III: ULTRASONIC AND SONIC INSTRUMENTS

Ultrasonic and sonic instruments have been developed mainly for cleaning the root canals and have a limited role in shaping of the root canals. The *ultrasonic* instrument consists of a piezoelectric or a magnetostrictive unit that generates ultrasonic waves. The piezoelectric units are better in that they are more powerful and generate lesser heat than the magnetostrictive systems. The handpiece holds a K-file or a specially designed diamond file that, when activated, produces movements of the shaft of the file between 0.001 and 0.004 inch at a frequency of **25–30 kHz**.

This oscillating movement produces the cutting action of the file and creates an ultrasonic wave of irrigant solution, which is delivered along the side of the file into the root canal. The ultrasonic vibration produces heat that increases the chemical effectiveness of the irrigating solution. It also produces two significant physical processes:

1. *Cavitation:* This is the growth and collapse of bubbles, with a resulting increase in the mechanical cleansing activity of the solution. Because of this increase in thermal and mechanical activity of the irrigating solution delivered into the root canal, removal of debris and tissue from the isthmus and removal of the smear layer are more efficient. The bactericidal action of the irrigating solution also increases. However, the root canal diameter does not permit cavitation significantly.
2. *Acoustic streaming:* This is the formation of small but intense eddy currents or fluid movements around the oscillating instrument. This improves the cleaning ability of the irrigant through hydrodynamic stresses.

Before ultrasonic instrumentation, the apical third of the root canal should be instrumented to at least the size of a No. 30 to No. 40 file. This is because both acoustic streaming and cavitation are totally dependent on the free oscillation of the instrument. Hence, *ultrasonic devices have very limited application in the shaping of the root canal.* They do improve the cleaning ability of the irrigant and help in debriding regions that are difficult to access, such as the isthmus of a canal.



Figure 14.9 Sonic handpiece. (*Courtesy: Micro Mega.*)

Sonic handpieces operate at **2–3 kHz** when used inside root canals (**Fig. 14.9**). They are similar in shape and weight to dental handpieces and are attached to existing air and water lines. These instruments are used in a manner similar to the ultrasonic system in instrumentation of the root canals. The only difference is that the sonic system uses water as an irrigant and requires special instruments known as follows:

- Rispi Sonic
- Shaper sonic
- Trio sonic (or Helio sonic)

Clinical Note

Both the sonic and ultrasonic instruments have been reported to cause transportation of the root canal if used carelessly. Currently both ***sonic and ultrasonic devices are not indicated for shaping of the canal*** and are more indicated for cleaning applications inside the root canal.

GROUP IV: ENGINE-DRIVEN NICKEL–TITANIUM INSTRUMENTS (MOST COMMONLY USED)

1. Rotary Endodontic Instrumentation

The advent of NiTi has led to the development of numerous types of endodontic instruments which can be employed in a truly rotary or 360° revolution within a curved root canal.

Nickel–Titanium

One of the most significant changes in the practice of endodontics occurred with the evolution of ***Nitinol*** by Walia and colleagues, an alloy composed of **ni**ckel and **ti**tanium that was developed by the **N**aval **O**rdinance **L**aboratory, hence the name Nitinol.

- This alloy consists of 55% nickel and 45% titanium by weight.
- This superelastic alloy does not exhibit proportional strain under stress until a specific level is attained that ultimately causes fracture.
- This unique property is due to the *austenitic* crystalline structure of the alloy which gets transformed into a *martensitic* crystalline structure under stress. Thus, Nitinol exhibits *shape memory*, i.e., the ability to return to its original shape once the stress is removed.

Table 14.5 gives an overview and salient features of the most widely used rotary NiTi systems in endodontics (also refer to **Fig. 14.10**).

Clinical Note

Recent Advances in Nickel–Titanium Metallurgy

- *R phase:* The R phase is an intermediate phase with a rhomboidal structure that can form during forward transformation from martensite to austenite on heating and reverse transformation from austenite to martensite on cooling.
- *M-wire technology:* This system is composed of three crystalline phases—deformed and microtwinned martensite, premartensitic R phase, and austenitic phase. Some of the rotary systems based on this technology are ProTaper Next and Twisted Files.
- *Controlled memory wires:* This system consists of subjecting the files to a specialized heat treatment with an austenitic finish temperature of approximately 55°C, e.g., HyFlex rotary instruments.

2. Reciprocating Endodontic Instrumentation

- The reciprocating instruments function at unequal bidirectional angles. The counterclockwise engaging angle is five times the clockwise disengaging angle and is designed to be less than the elastic limit of the file. Thus, a 150° clockwise motion would be followed by a 30° counter clockwise motion (**Fig. 14.11**).
- Strategically, after three counterclockwise and clockwise cutting cycles, the file will have rotated 360°, or one complete circle.
- This novel reciprocating movement allows a file to progress more readily, cut efficiently, and effectively auger debris out of the canal, e.g., WaveOne Gold system (**Fig. 14.12a**) and Reciproc Blue (**Fig. 14.12b**).

Clinical Note

The advent of reciprocating instruments has brought in single-file shaping systems that aim to simplify the shaping procedure and reduce the operative time of the procedure. However, if improperly used, these files can caused inadvertent extrusion of periapical debris causing increased postoperative pain.

3. Canal Adaptive Endodontic Instrumentation

Traditional rotary and reciprocating instruments shape the canal according to the instrument design (based on instrument taper, tip diameter, and cross-sectional design). However, the root canal anatomy is highly diverse and eccentric in cross-section. Hence, another concept of shaping is in the development of file designs that adapt themselves to the canal anatomy. This concept aims to conserve radicular dentin by emphasizing more on cleaning that canal rather than just enlarging the canal.



Figure 14.10 Different commonly available rotary nickel–titanium endodontic file systems: (a) Profile. (*Courtesy: Dentsply Maillefer.*) (b) LightSpeed. (*Courtesy: Lightspeed Inc.*) (c) ProTaper. (*Courtesy: Dentsply Maillefer.*) (d) Hero. (*Courtesy: MicroMega.*) (e) K3. (*Courtesy: SybronEndo.*) (f) FlexMaster. (*Courtesy: VDW.*) (g) M2. (*Courtesy: VDW.*) (h) ProTaper Next. (*Courtesy: Dentsply Sirona.*) (i) Twisted files. (*Courtesy: SybronEndo.*) (j) TruNatomy files. (*Courtesy: Dentsply Sirona.*)

(a) Self-Adjusting File (SAF)

This was the first system developed based on this concept and comprised a single instrument, namely, the SAF, introduced by Zvi Metzger.

Concept

The file three dimensionally adapts both longitudinally and along the cross-section of the root canal system and this is its most characteristic feature. This results in a uniform cutting

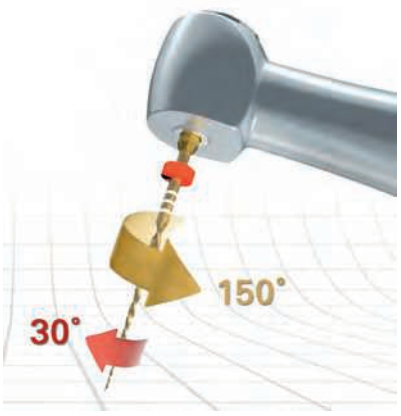
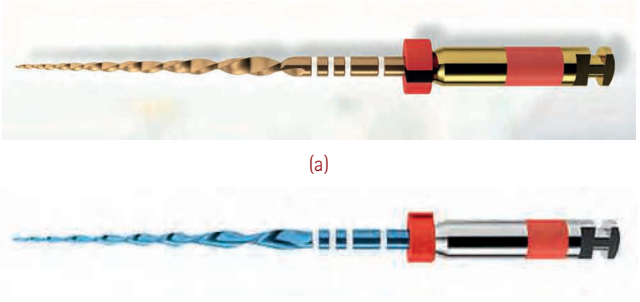


Figure 14.11 Reciprocating endodontic instrumentation.



(a)

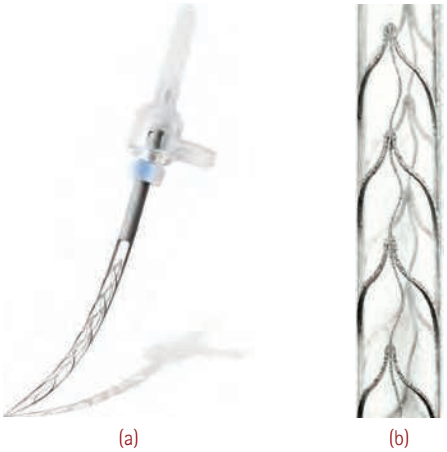
(b)

Figure 14.12 (a) WaveOne Gold system. (*Courtesy: Dentsply Sirona.*) (b) Reciproc Blue. (*Courtesy: VDW.*)

action of the dentin from the canal walls (60–75 µm thick) and preserves the basic shape of the root canal.

Design (Fig. 14.13)

Designed to be used as single-use files, the SAF system consisted of a hollow compressible NiTi lattice with a thin-walled pointed cylinder 1.5 or 2.0 mm in diameter. It operated with a modified vibrating handpiece generating 3,000–5,000 vibrations/min at an amplitude of 0.4 mm. Another advantage of the system was the feature of continuous irrigation by a silicon tube to the irrigation hub on the file.



(a) (b)

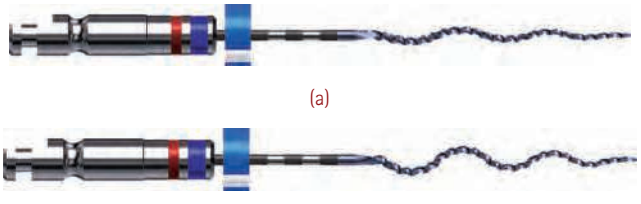
Figure 14.13 (a) The SAF instrument. (b) NiTi lattice. (*Courtesy: Zvi Metzger, Israel.*)

Clinical Note

The SAF system is no longer commercially available.

(b) XP-Endo Shaper and Finisher

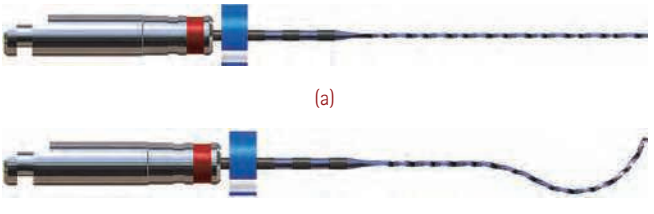
- XP-Endo Shaper instrument is a rotary snake-shaped instrument made of a proprietary alloy (MaxWire, Martensite-Austenite Electropolish Flex, FKG Dentaire). Due to this alloy, *the file has an ability to change its shape according to the temperature.* When cooled, in its martensitic phase, the file stands straight with a size #30 and an initial taper of 0.01. However, when introduced to body temperature, it changes to its austenitic phase assuming a snake shape that can achieve a final minimum canal preparation of 30/0.04 when using this instrument alone (**Fig. 14.14**).
- XP-Endo Finisher is an anatomical finishing file that consists of a small-core-size (tip size 25 and nontapered) rotary NiTi instrument made of a proprietary alloy (MaxWire, Martensite-Austenite Electropolish Flex, FKG Dentaire). When submitted to body temperatures, it changes to its austenitic phase (A-phase) assuming a spoon shape of 1.5 mm depth in the final 10 mm of its length. According to the manufacturer, when the instrument is placed inside the canal in the rotation mode, the A-phase shape allows the files to access and clean areas that other instruments might not have reached, without damaging dentin or altering the original canal shape (**Fig. 14.15**).



(a)

(b)

Figure 14.14 (a) XP Endo Shaper when cooled is in its Martensitic phase. (b) XP Endo Shaper at body temperature changes into Austenitic phase assuming a snake-like shape (*Courtesy: FKG Dentaire.*)

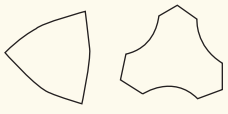


(a)

(b)

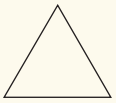
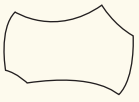
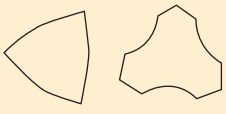
Figure 14.15 (a) XP Endo Finisher when cooled is in its Martensitic phase. (b) XP Endo Finisher at body temperature changes into Austenitic phase assuming a spoon-like shape (*Courtesy: FKG Dentaire.*)

Table 14.5 Classification of Current Nickel–Titanium File Systems

Instrument System	Cross-Sectional Design	Tip Design	Taper	Other Features
First generation			**Constant taper**	• **Radial lands** • **Neutral or negative rake angle**
ProFile (Dentsply Maillefer)	 Triple-U shape with radial lands. Neutral rake angle planes dentin walls	Noncutting	Fixed taper. 2, 4, and 6%	20° helix angle and constant pitch
GT Files (Dentsply Maillefer)	 Triple-U shape with radial lands	Noncutting	Fixed taper. 4, 6, 8, 10, and 12%	Files have a short cutting portion. Variable pitch
Light Speed Instruments (Lightspeed, San Antonio, TX)	 Triple-U shape with radial lands	Noncutting	Specific instrument sequence produces a tapered shape	Thin, flexible noncutting shaft and short cutting head
Second generation				**Active cutting blades without radial land**
ProTaper (Dentsply Maillefer)	 Convex triangular shape, sharp cutting edges, no radial lands. F3, F4, F5 files have U-flutes for increased flexibility	Shaping files—partially active tips Finishing files—noncutting	Variable taper along the length of each instrument	Pitch and helix angle balanced to prevent instruments screwing into the canal
K3 (SybronEndo)	 Positive rake angle for cutting efficiency, three radial lands, and peripheral blade relief for reduced friction	Noncutting	Fixed taper. 2, 4, and 6%	Variable pitch and variable core diameter
FlexMaster (VDW, Germany)	 Convex triangular shape with sharp cutting edges and no radial lands	Noncutting	Fixed taper. 2, 4, and 6%. Intro file has 11% taper	Individual helical angles for each instrument size to reduce screw-in effect

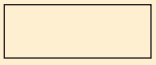
(*continued*)

Table 14.5 Classification of Current Nickel–Titanium File Systems (*continued*)

Instrument System	Cross-Sectional Design	Tip Design	Taper	Other Features
RaCe (FKG, Switzerland) EndoWave (J. Morita)	 Triangular shape (except RaCe 15/0.02 and 20/0.02 which have a square shape), two alternating cutting edges, no radial lands	Noncutting	Fixed taper. 2, 4, 6, 8, and 10%	Alternating cutting edges along the file length due to alternating twisted and untwisted segments (RaCe), or a continuous wave design (EndoWave). Intended to reduce screw-in effect
Quantec SC, LX (SybronEndo)	 S-shape design with double-helical flute, positive rake angle, and two wide radial lands	Cutting (SC). Noncutting (LX)	Fixed taper. 2, 3, 4, 5, 6, 8, 10, and 12%	Flute space becomes progressively larger distal to the cutting blade
Mtwo (VDW, Germany)	 S-shaped design with two cutting edges, no radial lands. Minimum core width to improve flexibility	Noncutting	Fixed taper. 4, 5, 6, and 7%	Variable pitch. Steep helical angle designed to reduce screw-in effect
Third generation				**Files that employ thermally pretreated alloys such as M-wire and R-phase alloys**
ProTaper Gold (Dentsply Sirona)	 Convex triangular shape, sharp cutting edges, no radial lands. F3, F4, F5 files have U-flutes for increased flexibility	Shaping files—partially active tips Finishing files—noncutting	Variable taper along the length of each instrument	Heat-treated Ni–Ti alloy
Twisted File (SybronEndo)	 Triangular shape, no radial lands	Noncutting	Fixed taper. 4, 6, 8, 10, and 12%	Variable pitch. Made by twisting a ground blank in combination with heat treatment; aims to increase superelasticity and cyclic fatigue resistance
HyFlex CM (Coltene)	Triangular cross-sectional design	Noncutting	4, 6, 8% taper	They are made from heat-treated controlled memory (CM) Ni–Ti alloy
Fourth generation				**Ni–Ti instruments used in reciprocal motion**
Wave One (Dentsply Sirona)	Modified convex triangle	Noncutting	Variable taper	M-wire alloy
Reciproc (VDW)	S-shaped cross-section	Noncutting	Variable taper	M-wire alloy

(*continued*)

Table 14.5 Classification of Current Nickel–Titanium File Systems (*continued*)

Instrument System	Cross-Sectional Design	Tip Design	Taper	Other Features
Fifth generation				**Rotary instruments with asymmetric cross-section**
ProTaper Next (Dentsply Sirona)	 Off-centered rectangular cross-section, no radial land, sharp cutting edges	Noncutting	4, 6, 7, 8, 9%	M-wire technology Asymmetric rotary motion
One Shape (Coltene—MicroMega)	Variable cross-section, three cutting edges transition to two cutting edges coronally	Noncutting	6%	Electropolished to enhance cutting efficiency
TruNatomy (Dentsply Sirona)	Off-centered cross-section	Noncutting	Regressive taper	0.8 mm maximum flute diameter makes this one of the thinnest rotary files available

ENDODONTIC MOTORS FOR SHAPING

Traditional micromotors cannot be used with rotary NiTi endodontic shaping instruments, as these instruments need to be used with the following:

- *Ultralow speeds*
  - The manufacturer-recommended speeds for the currently available NiTi rotary instruments are in the range of **150–600 RPM** with the exception of the LightSpeed instruments which work at an optimal RPM of 1500.
  - This range of RPM can be achieved with the help of torque-limited handpieces (e.g., 1:64 or 1:128) attached to either an electric motor or an air-powered motor (**Fig. 14.16a**).
  - The other alternative is to use an electric/battery-powered slow-speed motor with a handpiece (**Fig. 14.16b–14.16d**) wherein not only the speed of the instrument rotation but also the torque can be controlled.
- *Specific torque setting*
  - NiTi is not a strong alloy and achieves shaping of the root canal due to the cross-sectional design of the file (with limited cutting edges) that is rotated with a specific speed and an optimal torque setting.
  - Torque-controlled handpieces would prevent inadvertent fracture of the instrument due to torsional fatigue by stopping the rotation of the instrument when the instrument experiences excessive loads above the preset torque setting.
  - The torque settings for each rotary instrument may vary and should be set according to the manufacturer's instructions.
  - Most rotary NiTi instruments are recommended to be used between **1.5 and 4.0 N cm** torque levels.

CLASSIFICATION OF ENDODONTIC MOTORS

I. *Torque-controlled handpieces*
   1. These handpieces have to be either connected to an electric motor or an air-powered motor.
   2. They possess an integrated torque control setting that can be adjusted by a swivel-type ring adjustment around the handle of the handpiece.
   3. The torque settings are preset by the manufacturer and cannot be altered.
   4. The operator has to select one of the preset torque settings while using the rotary endodontic files.

II. *Electric torque-controlled motors*
   1. They have the handpiece and motor integrated into one single device.
   2. Several popular torque and speed settings are preset in the library memory of these motors that get displayed on the LCD panel while using these motors. Alternately, the operator can also program his/her preferred torque and speed settings while using this device.
   3. They have an auto stop function that enables a motor to automatically stop rotating once the preset torque level is reached. This in-built safety function reduces the incidence of fractured rotary instruments while shaping the root canal.
   4. They also have an optional auto reverse function which enables the instrument to reverse itself once the instrument auto stops on reaching the set torque level.
   5. There are two types of these motors:
      (a) Corded electric controlled motors
      (b) Cordless electric controlled motors

III. *Combined rotary and reciprocal motors*
   1. The newer-generation motors give the clinician an option of using either the rotary or the reciprocal motion while using NiTi files.



(a) (b) (c)

(d)

Figure 14.16 (a) Gear reduction handpiece (1:64 or 1:128). (*Courtesy: Anthogyr, SA.*) (b) Electric/battery-powered slow-speed endodontic motors with torque control. X-SMART. (*Courtesy: Dentsply Maillefer.*) (c) Electric/battery-powered slow-speed endodontic motors with torque control. TCM Endo III. (*Courtesy: SybronEndo.*) (d) X-SMART IQ cordless endodontic motor. (*Courtesy: Dentsply Sirona.*)

2. The clinician needs to buy this kind of motor for using reciprocating files in clinical practice.
3. *Adaptive motors:* These are the newer generation of combined rotary and reciprocal motors wherein the rotary files are used in rotary mode but would change to reciprocal mode once the file exceeds a certain stress inside the canal. The instrument once again goes back to rotary motion once the intracanal stress is reduced.

Clinical Note

Electric torque-controlled motors are popular and offer several advantages over the torque-controlled handpieces such as the following:

- Preset rotations per minute
- Preset maximum torque for different instruments and systems in order to prevent instrument fracture
- Autoreverse function when the maximum torque level is reached
- Ergonomic friendly

GUIDELINES FOR SHAPING OF A ROOT CANAL

The tooth to undergo root canal therapy is identified by penetrating the enamel at the site of the access cavity. The rubber dam is applied and the field of operation is disinfected; i.e., the tooth, clamp, and rubber dam are scrubbed with a sterile cotton-tip applicator saturated with a 5.2% solution of sodium hypochlorite. The access preparation is completed as described in Chapter 13.

In posterior teeth, after complete removal of the roof of the pulp chamber, the coronal pulp is removed with sharp endodontic spoon excavators. The chamber is irrigated with a 5.2% solution of sodium hypochlorite and is dried with suction. Next, the canal orifices are located by probing with endodontic explorers along the anatomical grooves located in the chamber floor and leading to the root canals or at the point angle formed by the walls and floor of the pulp chamber. These anatomical grooves, sometimes called the *dentinal map*, unite the canal orifices that are present at the end of the grooves. The grooves are darker than the floor of the pulp chamber (**Fig. 14.17**).

The operator must be familiar with the anatomical variation encountered in different teeth and must search for them in every tooth using radiographs and visual and tactile exploration. A dental operating microscope (DOM) or a dental magnification loupe is a valuable tool in ensuring the tracing and negotiation of complex root canal anatomy.

The shaping process of a root canal can be broadly classified into the following five phases:

1. *Phase I:* Glide path determination (canal patency)
2. *Phase II:* Coronal pre-enlargement (orifice enlargement)
3. *Phase III:* Working length measurement
4. *Phase IV:* Root canal shaping techniques
5. *Phase V:* Root canal working width



Figure 14.17 Anatomical groove on the pulpal floor of a mandibular first molar uniting the root canal orifices.

PHASE I: GLIDE PATH DETERMINATION (CANAL PATENCY)

The concept of creating a patent path up to the working length without altering or blocking the original root canal anatomy is known as ***glide path determination or canal patency****.*

Endodontic instruments to establish glide path can be classified into the following:

I. *Hand glide path instruments*
   1. The glide path is established by using a precurved ISO size 10 or ISO size 8 (rarely ISO size 6) stainless steel K-file in a reaming motion. These files hence at times are referred to as *patency files*.
   2. This helps in maintaining a continuous and clear path from the canal orifice to the apical foramen by removing debris, especially when combined with irrigation. The technique of patency filing is illustrated in **Figures 14.18** and **14.19**.
   3. A clinician might require multiple files to establish the glide path in a single canal with extreme curvature or in a calcifying canal.
   4. In canals that are calcified or with obstructions, stiffer files such as **C+ file** (**Fig. 14.20**) or **C-Pilot file** are recommended.

II. *Rotary glide path instruments:* Certain specially designed NiTi rotary instruments aid in establishing the glide path and are used in conjunction with stainless size 10 or smaller K-files, for example, ProGlider (Dentsply Sirona) and Scout Race (FKG).

In some instances, reactions of the pulp to inflammatory changes have caused calcification and blockage of an orifice or of most of the root canal. Radiographs taken at different angulations provide useful information on the extent of the calcification and the feasibility of opening the root canal.

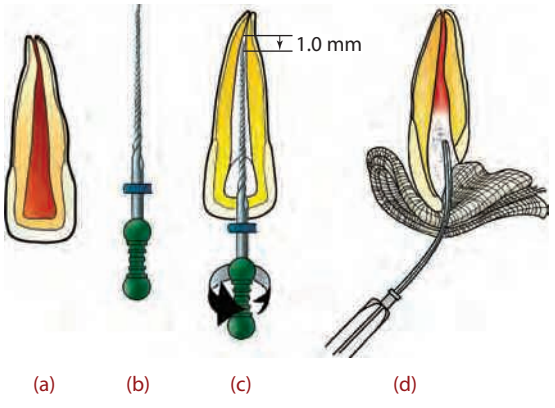
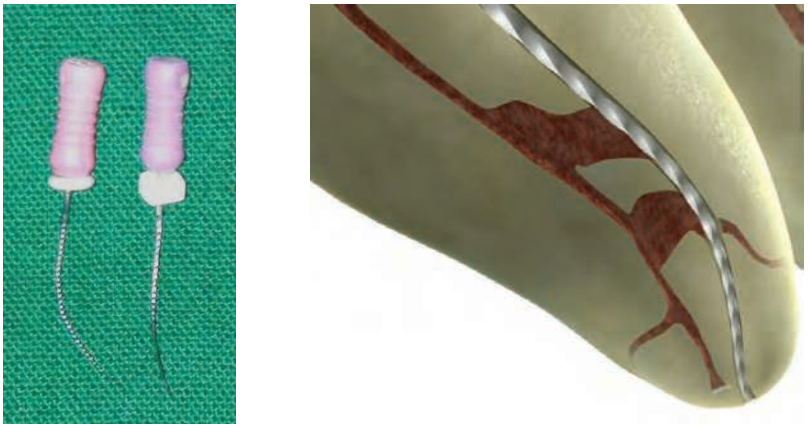


Figure 14.18 Patency filing: (a) Radiograph (schematic view) is studied for anatomical variations and size of the image of the root canal. (b and c) A size 10 K-file is precurved and introduced into the canal passively just through the apical foramen. (d) The root canal is copiously irrigated with a 5% solution of sodium hypochlorite to remove loose debris and blood.



(a) (b)

Figure 14.19 (a) Precurved files of varying angulations. (b) Patency filing: a precurved size 10 K-file being negotiated up to the estimated working length.



Figure 14.20 C+ file. (*Courtesy: Dentsply Sirona.*)

A blocked orifice can be opened by picking out the calcified tissue with a sharp endodontic explorer or by removing the blockage using slow-speed, small, round burs. If the foregoing procedures are not successful, a chelating agent, *ethylenediaminetetraacetic acid (EDTA) gel*, is used. Root canals that are partially calcified can be opened by cautious penetration of the calcified canal with ultrasonic access refining tips. The penetration is monitored by successive radiographs in order to avoid root perforation, until the canal is patent.

PHASE II: CORONAL PRE-ENLARGEMENT (ORIFICE ENLARGEMENT)

It is a concept of enlarging the coronal third of the root canal prior to the estimation of the working length.

The working length of the tooth should be determined only after coronal pre-enlargement of the canal is completed. This concept of coronal pre-enlargement is recommended for the following reasons:

- Root canals have multiplanar curvatures that increase the torsional stresses on shaping instruments as they proceed apically. Enlarging the orifice and 2–3 mm of the coronal third reduces the stresses on subsequent shaping instruments.
- The coronal third of the root canal contains the maximum pulp tissue and enlarging this space reduces the amount of periapical debris extrusion during subsequent shaping procedures as well as during estimation of the working length.

Coronal pre-enlargement is achieved with the help of ***orifice enlargers*** (in NiTi systems, **Fig. 14.21**) or with Gates-Glidden drills (currently not recommended).

Potential Advantages

- It prevents premature binding of the shaping instrument to the canal walls.
- It removes the coronal third debris before the shaping instruments negotiate the apical third. This reduces the potential for extrusion of debris beyond the working length.
- Coronal pre-enlargement allows the operator to gauge the apical third of the canal more accurately.

Clinical Note

Orifice enlargers are instruments that are meant for enlarging the canal only at the level of the orifice and hence the instrument and enlargement should be *restricted to a depth of 2–3 mm into the canal orifice.*

PHASE III: WORKING LENGTH MEASUREMENT

Definition: *Working length is defined as the distance from a coronal reference point to the point at which canal preparation and obturation should terminate.*

This is usually the apical terminus of the root canal, also termed the minor constriction or the minor diameter of the apical foramen (**Box 14.3**).



Figure 14.21 ProTaper SX orifice enlarger. (*Courtesy: Dentsply Sirona.*)

Anatomical Considerations (Figs 14.22 and 14.23)

Theoretically, the canal preparation should extend apically to the cementodentinal junction. This junction is located at or near the greatest constriction (minor diameter) of the apical foramen. The cementodentinal junction does not always coincide with apical constriction and is located 0.5–0.75 mm short of the anatomical apex. Thus, it is *clinically recommended to terminate instrumentation and obturation within 0.5–1.0 mm short of the radiographic apex.*

Clinical Note

Kuttler's Study

- The apical foramen does not normally exit at the anatomical apex. It deviates by 0.5–3 mm. This variation is more marked due to continuous deposition of cementum in older patients.
- The distance of the minor diameter of the foramen from the cemental surface is at an average of 0.5 mm in young teeth and 0.75 mm in mature teeth.

Box 14.3

Terminologies

- *Anatomical apex:* It is defined as the tip or the end of the root determined morphologically.
- *Radiographic apex:* It is defined as the tip or the end of the root determined radiographically.
- *Apical foramen (major diameter):* It is the main apical opening of the root canal. It is frequently eccentrically located away from the anatomical or radiographic apex.
- *Apical constriction (minor diameter):* It is the apical portion of the root canal having the narrowest diameter.
- *Cementodentinal junction:* It is the region where the dentin and cementum are united. It is a histologic landmark.

RADIOGRAPHS

Radiograph plays an important role in cleaning and shaping because it permits the operator to form a visual conception of the internal tooth structure and periradicular tissue. It is an exact road map of the anticipated journey between the access opening into the pulp chamber and the apical root foramen. The clinician must learn to interpret or rather read a radiograph to assist in instrument selection for exploration of the complicated root canal system. **Box 14.4** gives an overview of the various techniques clinically available to measure the working length of a root canal.

Clinical Note

- The clinician should "read" the preoperative radiograph carefully for the extent of decay and presence of atypical anatomy, pulp stones, root and canal curvatures, presence of furcal or periradicular radiolucencies, and obstructions such as root canal fillings, posts, or broken instruments (**Fig. 14.24**).
- On an undistorted periapical radiograph, one can measure the distance between the roof and the floor of the pulp chamber and the occlusal surface to determine the depth of the access cavity and thus to avoid inadvertent perforations (**Fig. 14.25**).

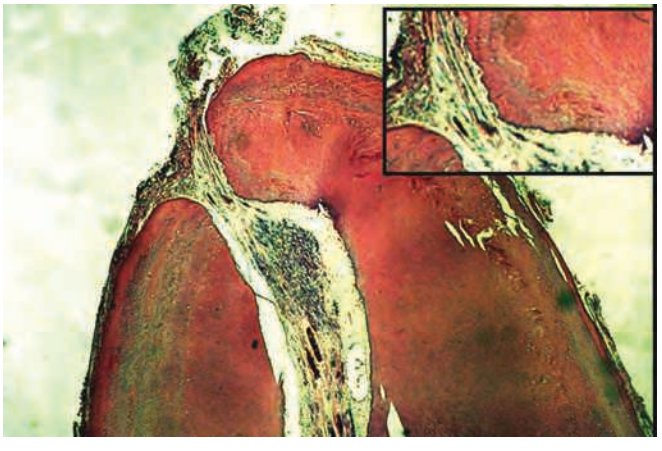


Figure 14.22 Histologic section demonstrating the anatomy of the root apex.

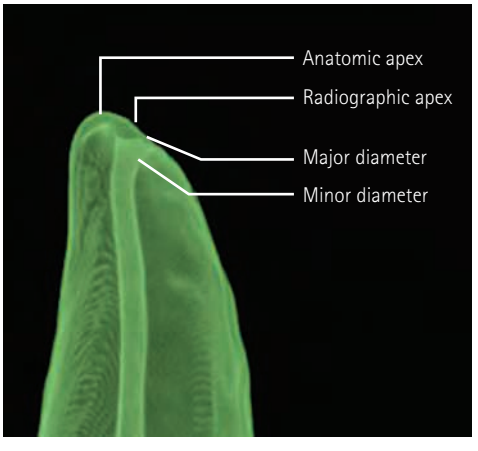


Figure 14.23 Micro-CT image of a maxillary central incisor demonstrating the apical canal anatomy.

Box 14.4

Methods of Determining Working Length

I. Electronic apex locators *(recommended)*
II. Radiographic methods
  1. Ingle's technique
  2. Others
    a. Best's method
    b. Bregman's method
    c. Bramante's technique
    d. Grossman's method
    e. Weine's method
  3. Kuttler's method
  4. X-ray grid method
  5. Xeroradiography
  6. Direct digital radiography
III. Nonradiographic methods *(not recommended)*
  1. Tactile sense
  2. Apical periodontal sensitivity
  3. Paper point method



Figure 14.24 Preoperative "reading" of a radiograph is invaluable in revealing complex root canal anatomy.

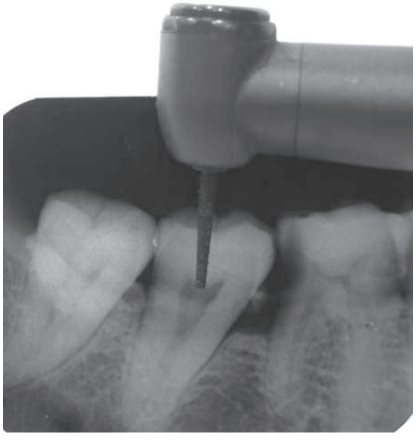


Figure 14.25 Preoperative assessment of the distance between the occlusal surface and the roof of the pulp chamber.

Clinical Note

The most appropriate technique for the assessment of working length is by using a combination of electronic apex locator along with Ingle's radiographic technique.

I. ELECTRONIC METHOD OF DETERMINING WORKING LENGTH (ELECTRONIC APEX LOCATORS)

In recent years, electronic devices have been developed for determining the working length of a root canal without resorting to radiography. Currently, an electronic apex locator (EAL) is the ***most optimal and accurate method to establish the root canal working length***.

Development

- *Cluster (1918):* Proposed the concept of measuring the canal length electronically
- *Suzuki (1942):* Principle and design of an EAL
- *Sunada (1962):* Introduction of the first commercial EAL

Concept

The working length is determined by comparing the electrical impedance of the periodontal membrane with that of the oral mucosa both of which should be similar at 6.5 kΩ. This is done with the help of an EAL cord that has two ends. One end is termed a "lip hook" that is kept in contact with the oral mucosa of the patient while the other end is termed "file holder" that is a probe which is attached to an endodontic instrument (K-file or rotary file). The attached file is slowly inserted into the root canal up to the estimated working length. When the endodontic file touches the soft tissues of the periodontal membrane, the electrical-resistance gauges for both oral mucosa and periodontal ligament would have similar readings. By measuring the depth of insertion of the endodontic file, one may determine the exact working length of the root canal (**Fig. 14.26**).

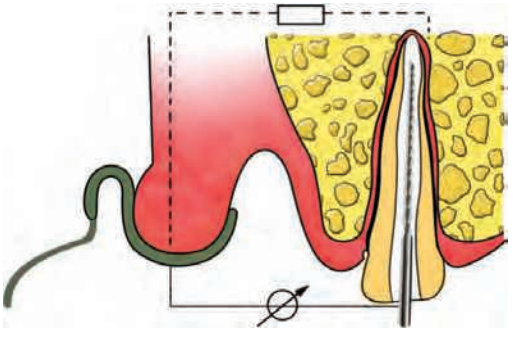


Figure 14.26 Principle of electronic apex locator. Readers are recommended to view the clinical demonstration video of use of electronic apex locator in the digital resources given along with this textbook.



(a) (b)

Figure 14.27 (a) Root ZX/Dentaport ZX apex locator. (*Courtesy: J. Morita Inc.*) (b) Propex IQ apex locator. (*Courtesy: Dentsply Sirona.*)

Classification of Electronic Apex Locators

- **First generation—*resistance-based electronic apex locator:*** These are the first generation of apex locators which were developed based on the *resistance principle*. They worked best in dry canals. However, the presence of pus, pulpal tissue, blood, and irrigants leads to inaccurate readings. The first apex locator based on this principle was the *root canal meter*. The other models based on the same principle include *Endodontic Meter* and *Endodontic Meter S II*.
- **Second generation—*impedance-based apex locator:*** In order to overcome the problems associated with the resistance-based apex locators, Inoue introduced the concept of impedance-based apex locators, the Sono Explorer apex locator. This device would indicate the apex when two impedance values approach each other. This apex locator had to be calibrated with the periodontal sulcus prior to each use. This procedure was technique sensitive and error prone.
- **Third generation—*multiple-frequency apex locator:*** These apex locators determine the canal terminus as the difference between two impedance values at two different frequencies of 1 and 5 kHz. This was introduced as the Endex apex locator.
- **Fourth generation—*multiple-frequency ratio-based apex locator:*** A newer apex locator was introduced (Root ZX by J. Morita, Japan) that uses two wavelengths whose impedance could be compared as a ratio (**Fig. 14.27a**). These are superior to other apex locators in the presence of fluids and electrolytes. The other apex locators which follow the similar principle include Propex IQ (Dentsply Sirona; **Fig. 14.27b**) and Elements Diagnostic EAL (SybronEndo).

A newer advance is the integration of the apex locator with the battery-powered endodontic slow-speed handpiece. The advantage is that these handpieces (Tri Auto ZX II by J. Morita) (**Fig. 14.28**) have the following automatic functions:

- The file starts to automatically rotate the moment the instrument is introduced into the canal.
- If the preset torque level for the instrument is exceeded, then the handpiece automatically stops and reverses rotation.



Figure 14.28 Tri Auto ZX II. (*Courtesy: J. Morita Inc.*)

- The integrated apex locator stops the file rotation and reverses the moment the file tip extends beyond the working length.

Limitations of EAL

The accuracy of EAL may be altered in teeth with the following:

- Immature apices (open apex)
- Calcified or blocked canals
- Excessive hemorrhage/excessive inflammatory exudate in the canal
- Measurements get altered when the file contacts any metallic restoration or when measurement is taken through a tooth having a metallic crown prosthesis

Clinical Note

The clinician should note that electronic apex locators are now considered the most ideal method to measure the working length of a root canal. They can be used alone without the need of taking any radiographs. However, ***this textbook recommends the combined use of an apex locator along with the radiographic technique*** for accurate clinical measurement of the root canal working length.

II. INGLE'S RADIOGRAPHIC TECHNIQUE FOR MEASURING WORKING LENGTH

Clinical Prerequisites

- *Knowledge of average length of teeth:* The setting of an instrument stop to a length short of the anticipated working length for each canal is valuable in confining instruments to a root canal to prevent trauma or forcing of debris and bacteria into the periradicular tissue.
- *Instrument precurving:* The desired instrument curvature is attained by grasping the blade with a gauze sponge and bending the instrument in a gentle slope (**Fig. 14.29**). An instrument that aids in bending the file appropriately has been introduced and is known as Endobender (SybronEndo, USA; **Fig. 14.30**).
- *Stable occlusal reference point*
  - Anterior teeth → Incisal edges
  - Posterior teeth → Cusp tips (**Fig. 14.31**)
- The reference point must be a definite and reliable point or surface to ensure exactness in all subsequent measurements. Incisal edges or cusps that are undermined or fractured should be ground until a sound surface is attained.
- Silicone stopper on the file is set to these reference points and the extent of the file from the bottom of the stopper to the tip of the instrument is used to determine the estimated working length.
- These stoppers also have an added advantage because they do not have to be removed from the instrument during sterilization. In addition to designating the working length, the teardrop tip can be positioned to indicate instrument curvature, a prepared gentle curvature made on the instrument blade that facilitates insertion of the instrument into a canal orifice and penetration to the root apex in fine, tortuous canals.

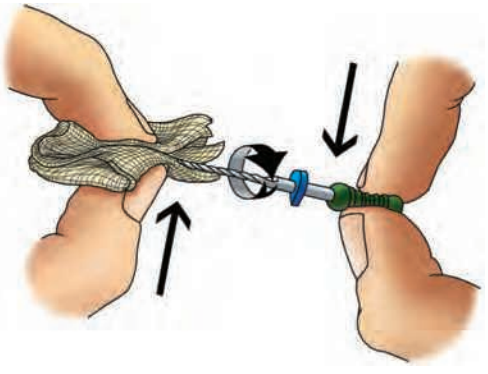


Figure 14.29 Files are curved by grasping the blade with a gauze sponge and bending the blade until the desired angulation is attained.



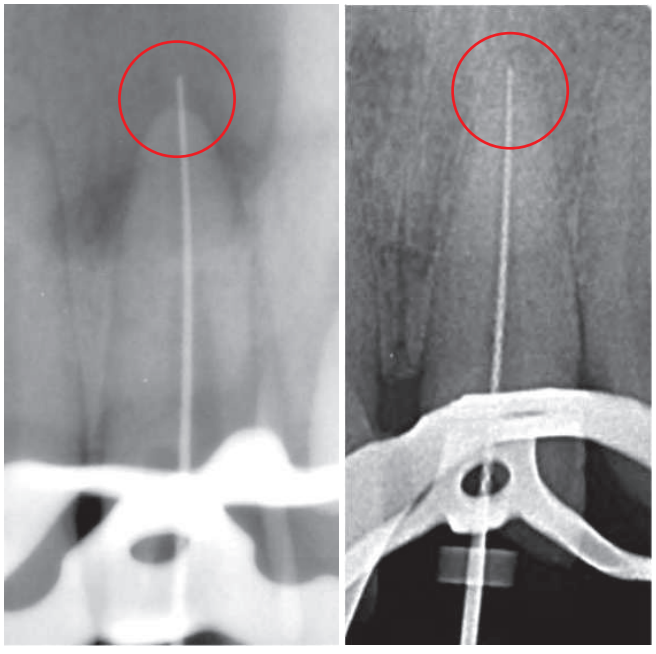
Figure 14.30 Endobender. (*Courtesy: SybronEndo.*)



Figure 14.31 Silicone rubber stop on a size 10 K-file adjusted to the appropriate reference point.

Clinical Technique

- Diagnostic or exploratory instruments are usually Nos. 6, 8, or 10 K-files. These instruments are flexible enough to follow root canal curvatures and to fit into fine tortuous canals and are stiff enough to be inserted through debris and tissue until they reach the root apex. Initially, the K-file is inserted into the root canal through the access cavity with a slight *reaming motion* to bypass any obstruction or debris and is gently teased along the entire canal length until it has been inserted to the estimated working length of the canal. When an instrument is removed from the canal, the operator should examine it for curvatures that were not apparent by tactile sensation or radiographic examination; examples are a buccal curvature in the palatal canal of a maxillary first molar or a palatal curvature in a maxillary lateral incisor. One should record any observed anatomical variations and use this information during shaping, cleaning, and obturation of the root canal.
- The original diagnostic radiograph can now be referred and measured to *estimate the working length* of the tooth from the occlusal surface to the root apex. *The estimated working length is kept as 1 mm short of the length of the tooth measured on the radiograph.* This is done to compensate for the radiographic image distortion and for the fact that the minor diameter is always present short of the anatomical apex.
- The precoronal enlargement of the canal is completed with the help of either orifice enlargers or Gates-Glidden drills. This step is recommended before taking the working length X-ray.



(a) (b)

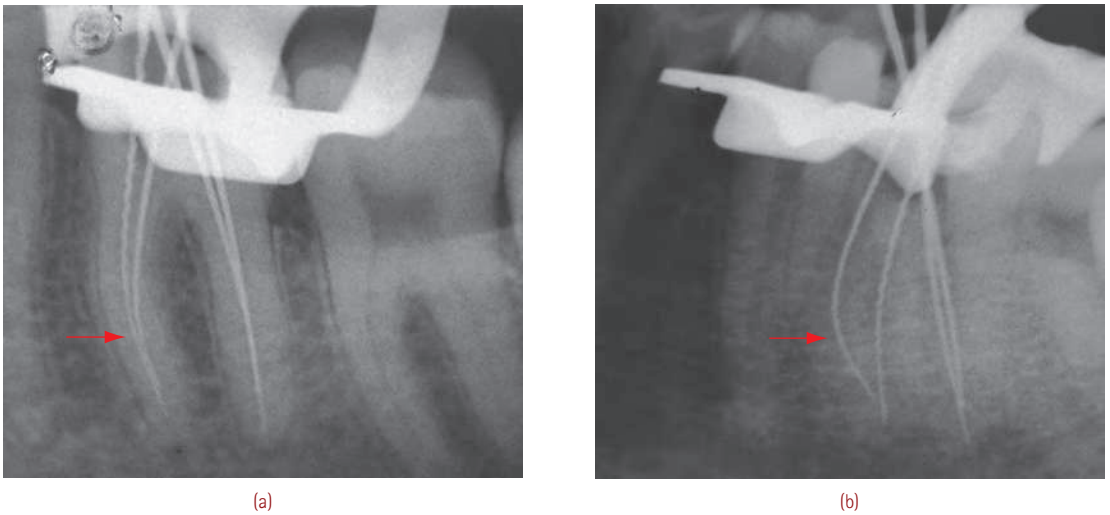
Figure 14.32 (a) Working length beyond the radiographic apex of a maxillary incisor. (b) Working length 0.5 mm short of the radiographic apex of a maxillary incisor.

- A working length instrumentation radiograph is taken to compare the exact position of the instrument in the root canal with the measured depth of insertion (**Fig. 14.32**).
- The exact working length for each canal is determined by adjusting the length of insertion, so the *tip of the instrument ends 0.5–1.0 mm from the radiographic root apex.*
- If a change of tactile sensation during exploration of the root canal suggests that the instrument is at the apical constriction, even though it seems short of the estimated working length, one should take a radiograph to verify the location of the instrument tip. Once the exact length between the reference point on the tooth surface and the apical constriction (or 0.5–1.0 mm short of the radiographic root apex) is known, the instrument stops. It should be adjusted accordingly so that the subsequent sequential instrumentation ends within the root canal at the established terminus.
- The working length should be arbitrarily established *0.5–1.0 mm shorter than the radiographic canal length* because the actual length of the tooth is less than the radiographic image and the apical foramen is approximately 0.3 mm short of the actual root tip. Certain anatomical studies have reported the cementodentinal junction (CDJ) to be situated about 0.4–0.7 mm away from the root apex.
- Two *length-determination radiographs* may be necessary at times, one at the normal angulation and the other at a *20° mesial or distal horizontal angulation*. The tridimensionality gained from these two views allows better visualization of the configuration of the root canal and its terminus. When two root canals are present in a single root, e.g., the mesial root of a mandibular molar or two roots aligned in the same plane, such as in the maxillary first premolar, two radiographs from different angulations will separate the images of the root canals (**Fig. 14.33**).

Clinical Note

Weine's Modification

- If *periapical bone resorption* is evident in a radiograph, the working length should be reduced to *1.5 mm short of the radiographic apex* as the apical constriction would have been destroyed by the resorption.
- If *apical root resorption* is seen, the working length is reduced to *2 mm short of the radiographic apex*. In such an event, an apical stop is created short of the radiographic apex to prevent overinstrumentation and subsequent overfilling of the root canal.



(a) (b)

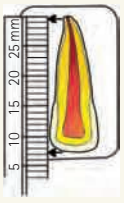
Figure 14.33 Different horizontal angulations in the radiograph enable to distinguish the two canals present in the same root.

This procedure completes the tactile exploration of the root canal and establishes the exact working length to be used during sequential instrumentation of the root canal. The summary of the technique is given in **Box 14.5**.

Box 14.5

Ingle's Radiographic Method of Working Length Determination

Diagnostic radiograph used to *estimate* the working length of the tooth by measuring the tooth from a stable occlusal reference point till the radiographic apex

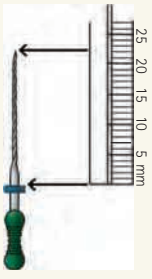


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Subtract atleast 1 mm from this length as

- Minor constriction is always present short of the anatomic apex
- Compensation for radiographic image distortion

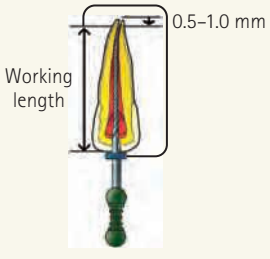
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This measurement is transferred to a diagnostic instrument with a silicon stop, which is placed in the root canal and working length radiograph taken

↓



On the radiograph, measure the difference between the end of the instrument and the radiographic apex of the root

↓

Tip of the instrument ends 0.5 mm–1.0 mm from the radiographic root apex **(Working length established)**

Short of the radiographic apex by more than 1.0 mm

Add this value to the earlier estimated length and adjust stopper on the diagnostic instrument accordingly
Retake the working length radiograph

Beyond the radiographic apex

Reduce this value from the earlier estimated length and adjust stopper on the diagnostic instrument accordingly
Retake the working length radiograph

INSTRUMENTATION GUIDELINES

In cleaning and shaping a root canal, the following guidelines should be observed.

INSTRUMENT GUIDELINES

- Instruments should be fitted with instrument stops.
- Instruments should be used in a sequence of sizes starting from smaller sized instruments to larger sizes.
- All instrumentation should be done using sterile instruments in a wet canal.
- Instruments should be checked for deformation and discarded if strain is present.

SHAPING AND CLEANING GUIDELINES

A. Anatomical Considerations

The most critical area for canal disinfection is the apical 3–4 mm, which should be enlarged to facilitate the flow of irrigants to the biologically crucial apical third.

B. Precurving

- In shaping a root canal, one should always precurve the stainless steel file blade before instrumentation. This procedure facilitates the insertion of the instrument to its working length and prevents ledging of the canal walls. The curvature of the blade can be estimated by reviewing the diagnostic radiograph and observing the anatomical features of the root canal.
- The curve is prepared by grasping the blade with a gauze sponge and carefully bending the blade until the desired curvature is attained (**Fig. 14.34**). The directional silicone stop should be set to indicate the direction in which the file has been curved.

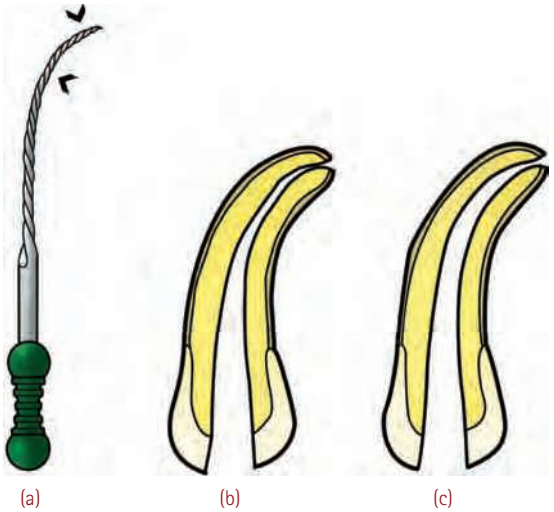


Figure 14.34 Modification of an instrument to shape a root canal: (a) Precurved file. (b and c) Root canal before and after shaping and cleaning.

Clinical Note

Precurving of files is *restricted to stainless steel instruments*.

C. Irrigation

Irrespective of the instrumentation motion, frequent irrigation of the root canal facilitates instrumentation, debrides the canal, and helps to disinfect the canal. Ideally, 2 mL of the irrigant per canal per instrument change is clinically recommended. (Refer Chapter 15 for more details on irrigants and irrigation protocols.)

D. Restricting Instruments and Irrigants within the Root Canal Space

Instruments and irrigants should be confined to the root canal to prevent trauma to periradicular tissues, and debris should not be forced through the apical foramen. One must not force an instrument if it binds.

E. Recapitulation

Returning to a smaller instrument from time to time before advancing to a larger size helps to prevent the packing of dentin filings and ensures patency of the root canal through the apical foramen.

F. Removal of Dentinal Debris from Used Instruments

The dentinal debris created during the shaping procedure partially clogs the flutes of the instrument. This debris should be removed by squeezing the blade between layers of wet gauze and turning the instrument counterclockwise (**Fig. 14.35**). Before reinserting, the instrument should be inspected for deformation. No instrument should be reinserted into the same canal/other canal without performing this step.

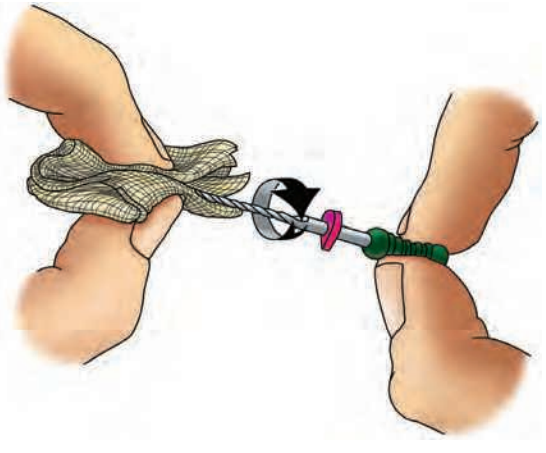


Figure 14.35 Instrument is cleaned of debris by holding the blade between layers of wet gauze under digital pressure and turning it counterclockwise.

PHASE IV: ROOT CANAL SHAPING TECHNIQUES (Box 14.6; Table 14.6)

The endodontic hand instruments can be employed in any one of the functional motions described in **Box 14.7**.

Table 14.7 presents the summary of principle techniques of root canal instrumentation.

I. STEP-BACK TECHNIQUE

1. Conventional Step-Back (Telescopic) Technique

In the step-back preparation of the root canal, the canal is enlarged first in the apical third to at least a No. 25 or 30 instrument and then each consecutively larger root canal instrument is used for shaping the middle third and coronal part of the root canal (**Fig. 14.37**).

- Shaping and cleaning of the root canal begins on completion of gross debridement and determination of the exact working length.
- The size 10 file followed by a size 15 file is inserted directly through the canal orifice to the desired length. K-files are used in a reaming motion against the walls of the root canal (**Fig. 14.37c**). Care should be taken not to use filing motion as this would cause inadvertent ledging of the canal. The entire canal is then irrigated and all the solution and debris are aspirated out of the canal. The file is inspected for deformation, debrided after cleaning its flutes by squeezing a cotton sponge around the blade while

Box 14.6

Techniques of Shaping and Cleaning

I. Step-back technique
   1. Conventional step-back
   2. Passive step-back
II. Crown-down (step-down) technique and its modifications
   1. Crown-down pressureless
   2. Double flare
   3. Balanced force
III. Hybrid technique

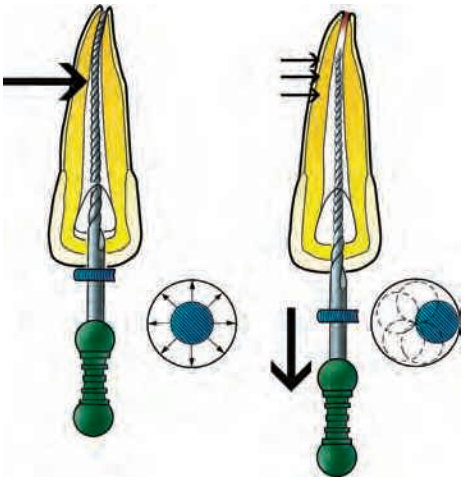
Table 14.6 Summary of Techniques for Shaping and Cleaning the Root Canal System

Authors	Year	Name of Technique
Ingle	1961	Standardized technique
Clem, Weine, Schilder	1969–74	Step-back, serial preparation
Abou Rass	1980	Anticurvature filing
Marshall, Pappin	1980	Crown-down pressureless
Goerig	1982	Step-down
Fava	1983	Double flare
Roane	1985	Balanced force
Lim and Stock	1987	Circumferential filing
Torabinejad	1994	Passive step-back
Yared	2008	Reciprocation technique

Box 14.7

Functional Motions of Manual Instrumentation

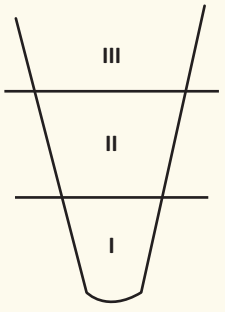
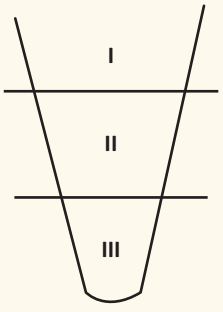
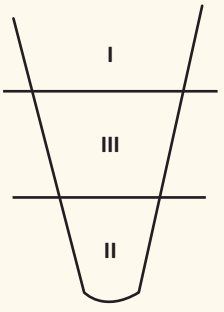
- *Reaming:* The instrument is used with a clockwise rotating–pushing motion, limited to a quarter to a half turn, and disengaged with a mild pulling motion when bound (**Fig. 14.36**).
- *Filing:* Filing indicates a push–pull motion with the instrument. The instrument is placed into the canal at the desired length, pressure is exerted against the canal wall, and the rake of the flutes rasps the wall as the instrument is withdrawn without turning and the pressure is maintained throughout the procedure.
- *Watch winding:* The instrument is reciprocated back and forth in a clockwise–counterclockwise motion and then retracted to remove the debris.
- *Circumferential filing:* Following the cleaning and shaping of the root canal with a small reamer and reaming to the root apex (working length), the same-size file is inserted into the root canal to the apex, laterally pressed against one side of the canal wall and withdrawn with a pulling motion, to file the dentinal wall. The file is reinserted and the procedure is repeated circumferentially around the walls of the canal until the next-size reamer could be used. In narrow root canals, reamers are used alternately with files in sequence of sizes to produce a uniformly instrumented and enlarged canal.
- *Anticurvature filing:* This motion was described by *Abou Rass and Jastrab*. The furcal wall of the canals in the mesial roots of molars is prone to perforation during coronal enlargement of the canals. In order to prevent this error, anticurvature filing is advocated wherein the top of the handle of the instrument is *pulled into* the curvature while the shank end of the handle is *pushed away* from the inside of the curve (anticurvature). This motion balances the cutting flutes against the safer part of the root canal.



(a) (b)

Figure 14.36 Reaming motion is the technique of inserting a file into a canal and employing continuous quarter to half turn clockwise rotation and disengagement with a mild pulling motion. This procedure is performed around all the walls of the root canal.

Table 14.7 Summary of Principal Techniques of Root Canal Instrumentation

Features	Step-Back	Step-Down	Hybrid
Author	Clem, Weine	Goerig	Recommended by this textbook for use with stainless steel instruments
Concept	Involves preparation of the apical third initially followed by middle and coronal third of the canal using larger instrument sizes	Involves preparation of the coronal two-thirds of the canal first followed by middle and apical third of the canal	Involves a combination of crown-down and step-back techniques
Sequence of instrumentation	 • Phase I: Apical-third instrumentation • Phase II: Middle third • Phase III: Coronal third	 • Phase I: Coronal-third instrumentation • Phase II: Middle third • Phase III: Apical third	 • Phase I: Coronal-third instrumentation • Phase II: Apical third • Phase III: Middle third
Recommended instruments	Hand instruments	Hand and rotary instruments	Hand and rotary instruments
Principle motion of instrumentation	Coronal instrumentation with reaming motion and apical instrumentation with circumferential filing	Reaming motion	Coronal instrumentation with reaming motion and apical instrumentation with circumferential filing
Advantages	• Popular technique employed with 2% standardized SS files • Ability to prepare a proper apical stop prior to preparation of the middle third and coronal third of the root canal	• Shaping is easier • Elimination of the bulk of the tissue, debris, and microorganisms from coronal and middle third before apical shaping • Minimizes debris extrusion • Better access and control over apical enlarging instruments • Better penetration of irrigants	• Ability to shape the canal predictably with hand instrumentation using stainless steel instruments • Optimizes the advantages of crown-down and step-back techniques
Limitations	• Extrusion of debris into the periapex • Tendency to straighten in the canal • Loss of working length	• Gauging of the apical third is done as the last phase of the procedure	• Middle third preparation has to be done carefully in order to prepare a continuous tapered canal preparation

rotating the file counterclockwise, and the filing procedure is repeated. Once the area of the apical foramen is clean, the apical third of the preparation is started.

- The apical third is serially enlarged to develop an apical stop of at least size 25 file.
- The next stage is the step-back preparation, which is achieved by increasing the size of the files and decreasing the length, i.e., by using sizes 30, 35, 40, and 45 files at 1, 2, 3, and 4 mm short of working length, respectively, to produce a coronal taper.
- To prepare the body of the canal, each sequentially larger file is inserted until it makes unforced contact with the walls of the canal, and the walls are reamed once at this new length (**Fig. 14.37d**).
- The patency of the apical canal segment, which has been enlarged to size 25, must be ensured by continued use of this file after each step back (recapitulation).
- Once the body of the canal preparation is complete, Nos. 2 and 3 Gates-Glidden drills are used to further funnel the preparation coronally.
- Circumferential filing using the master apical file (MAF) can be used to smooth out and further refine the steps created by the step back. This preparation allows an adequate amount of coronal space in the root canal for lateral compaction.

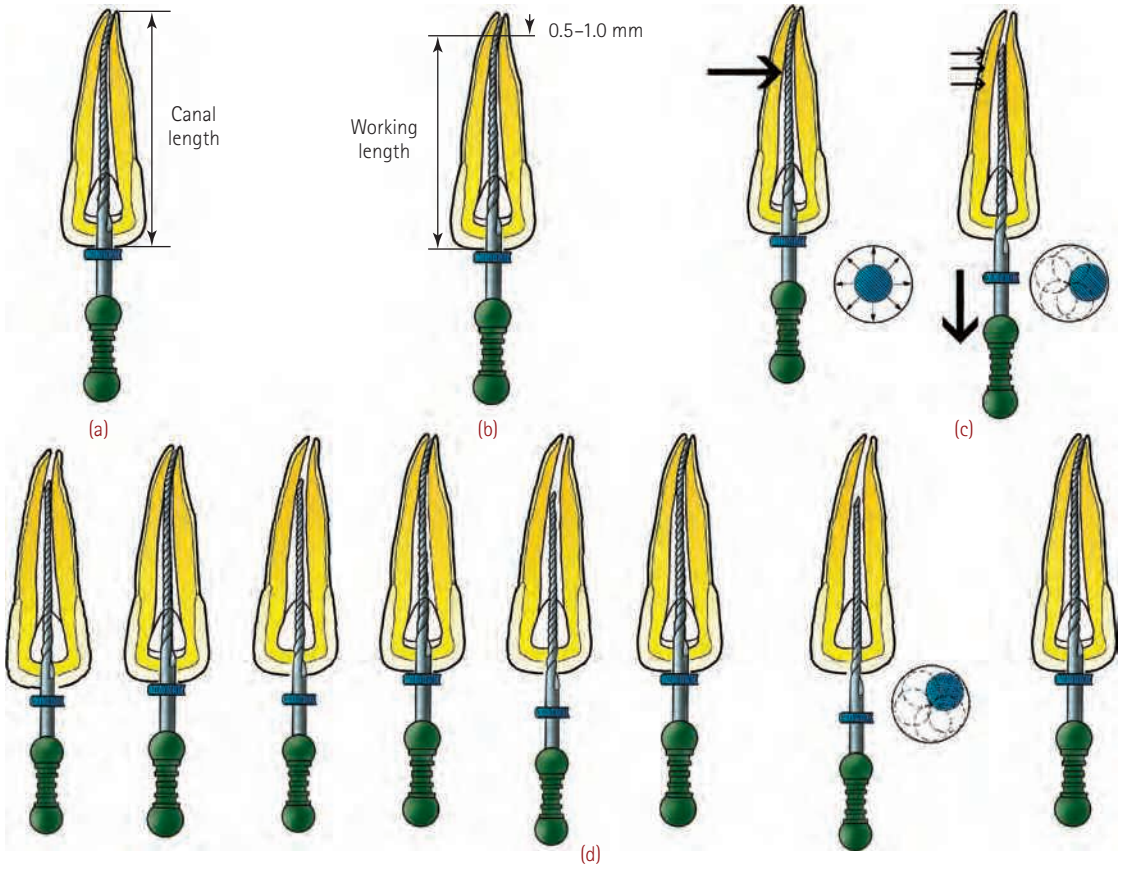


Figure 14.37 (a and b) Estimating the working length radiographically. (c) The size 10 K-file followed by the size 15 K-file is used in a reaming motion against the walls of the root canal. (d) Care should be taken to irrigate and recapitulate the canal between each instrument change as we sequentially enlarge the canal at working length to at least size 25. Once apical enlargement is completed, "step back" is started with sequentially larger files completing the middle third and coronal third canal preparation with each file working 1 mm short of the previous small-sized instrument.

- All instrumentation is performed in combination with copious irrigation to prevent blockage of the canal with dentinal or pulp debris, but cautiously to prevent forcing of irrigating solution beyond the apical foramen. The body of the canal is instrumented with at least three to four larger files, with recapitulation between each size.
- Instrumentation is finished when the walls are smooth and clean and when the preparation shows continuous taper in an apical direction.

2. Passive Step-Back Technique

This technique was introduced by Torabinejad. It involves the insertion of progressively larger hand instruments as deep as they can be passively placed. Subsequently, Gates-Glidden drills are used for additional coronal enlargement followed by apical instrumentation using the step-back technique.

II. CROWN-DOWN TECHNIQUE

Concept

The concept of first instrumenting the coronal third of the root canal before apical shaping was first advocated by Goerig et al. The original crown-down technique is known as step-down technique.

Clinical Note

Most *rotary nickel–titanium systems* employ crown-down instrumentation technique.

Crown-Down (Step-Down) Technique

- Patency of the canal is first established with a size 8 or 10 K-file.
- This procedure involves the preparation of the coronal two-thirds of the canal using Hedstroem files of size #15, #20, and #25 to a working length depth of 16–18 mm or to the point where the file starts binding.
- This is followed by flaring the coronal segment of the canal with the help of Gates-Glidden drill Nos. 2 and 3 and sometimes No. 4 with each drill being used sequentially shorter. Care should be taken in directing the Gates drills away from the furcation to avoid strip perforation.
- The next phase involves apical instrumentation with a small size 10 or 15 K-file followed by working length determination.

- A large file (ISO K-file size 60) is then placed in the canal to the level of binding and the canal is instrumented using a watch winding motion until resistance is encountered.
- The process is repeated with sequentially smaller files until the working length is reached.
  - Recapitulation with a size 10 or 15 file in between each change of instrument is necessary to ensure that the canal does not get clogged by the dentin debris being created.
  - Canals should be irrigated with appropriate irrigants (Chapter 15) in between each change of the instrument to facilitate debridement and cleaning of the canal.
- The apical portion of the canal is now enlarged to the appropriate MAF size which would vary from canal to canal and from tooth to tooth.
- The final canal taper is accomplished by the MAF used in a circumferential filing motion.

Modifications

The three modifications of this technique are as follows:

1. Crown-down pressureless technique
2. Double-flare technique
3. Balanced force technique

Table 14.8 presents the sequence of instrumentation for the various types of crown-down instrumentation techniques.

1. Crown-Down Pressureless Technique

This technique was suggested by Marshall and Pappin. Early coronal flaring with Gates-Glidden drills is followed by an incremental removal of dentin from coronal to apical direction, and hence called "crown-down" technique. Straight K-files are then used in a large to small sequence with a reaming motion and no apical pressure—hence called "pressureless" technique (**Table 14.8**).

2. Double-Flare Technique

This technique was proposed by Fava (**Table 14.8**).

3. Balanced Force Technique

Roane and Sabala are credited with developing the balanced force technique which employs a new K-type file design known as Flex-R file (Moyco Union broach) or FlexoFile (Dentsply Maillefer) or any flexible triangular file with a modified noncutting tip.

Technique

- This technique can be described as positioning and preloading an instrument through clockwise rotation and then shaping the canal with counterclockwise rotation.
- The coronal third of the canal is prepared using the crown-down technique.
- After pressureless insertion of a Flex-R or a FlexoFile, the instrument is rotated clockwise, 90°, using only light apical pressure.
- The instrument is then rotated counterclockwise, 180–270°, and sufficient apical pressure is used to keep the file at the same insertion depth during this step. In this step, dentinal shavings are removed with a characteristic clicking sound.
- After two or three cycles, the file loaded with dentinal shavings is removed from the canal with a prolonged clockwise rotation. This action loads the debris into the flutes.
- Sequential files are used in a crown-down fashion before preparing the apical third to the appropriate MAF size.
- Roane firmly believed in enlarging the apical area to sizes larger than generally practiced. A minimum enlargement of size 45, 1.5 mm short of the apical foramen in curved canals, is recommended and size 80 in single-rooted teeth,

Table 14.8 Sequence of Instrumentation of Various Crown-Down Techniques

Crown-Down (Step-Down) Technique	Crown-Down Pressureless Technique	Balanced Force Technique	Double-Flare Technique
#15–25 H-files to the point of canal binding	#35 K-file to the point of canal binding	Coronal enlargement with GG drills Nos. 2 and 3	Coronal to apical shaping with K files up to the working length
↓	↓	↓	↓
GG drills Nos. 2 and 3	GG drills Nos. 2 and 3	Middle to apical shaping with Flex R files up to the working length using balanced force technique	Step back with K-files of ascending sizes
↓	↓		
Coronal to apical shaping with K files up to the working length	Coronal to apical shaping with K files up to the working length		

GG, Gates-Glidden.

carrying the preparation through to "full length" of the radiographic apex of the root.
- The balanced force technique has shown to reduce canal transportation and ledging.

Advantages of Crown-Down Techniques

- Shaping of the canal is subjectively easier than the step-back technique.
- The removal of coronal obstructions allows removal of the bulk of tissue, debris, and microorganisms before apical shaping.
- This technique minimizes the extrusion of debris through the apical foramen, thereby preventing postoperative discomfort.
- It allows better access and control over the apical enlarging instrument, thus decreasing the incidence of zipping.
- It allows better penetration of the irrigants.
- Working length is less likely to change while employing this technique.

III. HYBRID TECHNIQUE

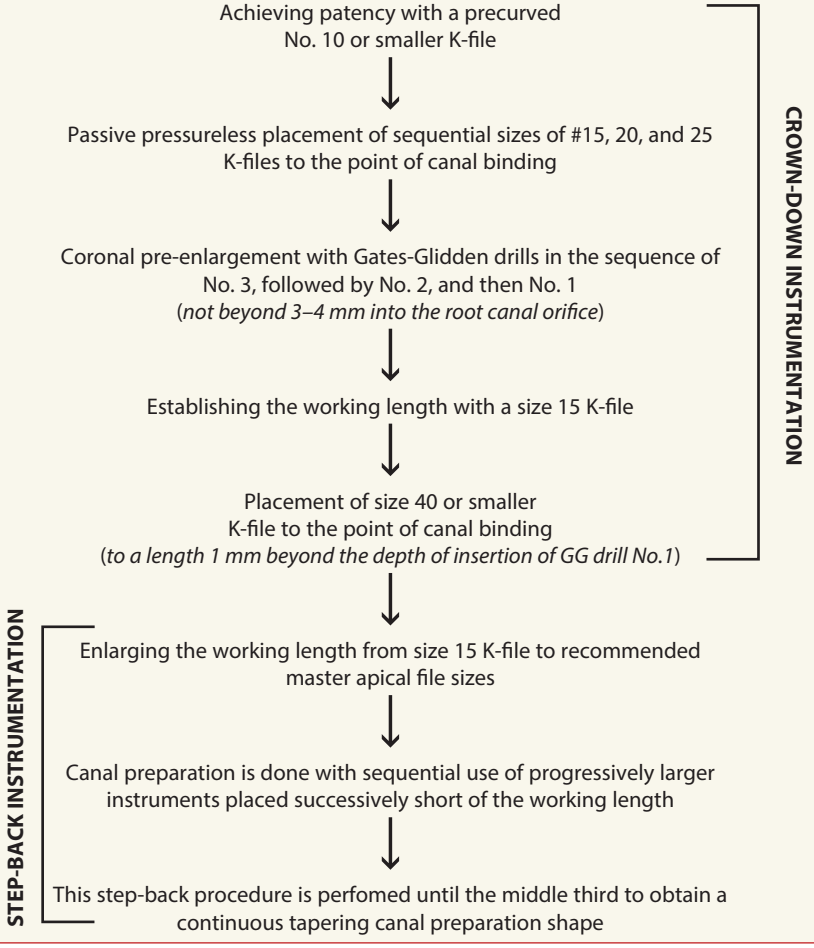
This technique refers to a combination of step-down instrumentation followed by a step-back technique. The procedure of the hybrid technique is given in **Box 14.8**.

Advantages of Hybrid Technique

- Ability to shape the canal predictably with a combination of hand and rotary stainless steel instruments
- Optimizes the advantages of crown-down and step-back techniques

Box 14.8

Hybrid Technique



PHASE V: ROOT CANAL WORKING WIDTH

The surface of a root canal is irregular and is interspersed with recesses, crevices, and fissures, the result of deposition of secondary and reparative dentin.

What constitutes complete and adequate root canal preparation: *how large, how wide*? The answer is often dictated by the anatomical structure and accessibility of the canal, as well as by the skill of the operator. Inadequate preparation limits the ability of the operator to clean, debride, disinfect, and fill the canal. Overzealous preparation leads to iatrogenic problems, unnecessary weakening of the tooth, and susceptibility to fracture, perforations, spatial movement of the apical foramen, and even root-tip fracture.

Traditional Concept

Root canals are often inadequately enlarged. In the past, two guidelines were considered sufficient for instrumentation:

1. *Enlarge a root canal at least three sizes beyond the size of the first instrument that binds.*
2. *Enlarge the canal until clean, white dentinal shavings appear in the flutes of the instrument blade.*

Both these guidelines *cannot be clinically recommended anymore*. The color of dentinal shavings is no indication of the presence of infected dentin or organic debris. Root canals should be enlarged, regardless of initial width, to remove irregularities of dentin and to make the walls of the canal smooth and tapered. The prepared root canal should be smooth and large enough to allow adequate debridement and obturation.

Current Concept

Ideally, the minimum size to which a root canal should be enlarged *cannot be standardized and varies from case to case*. The factors that should be taken into consideration before deciding the optimum size of enlargement at working length are as follows:

- Initial canal width which has to be assessed both clinically and radiographically. The canal of a narrow tooth, such as a mandibular incisor, cannot be enlarged as much as the canal of a mandibular canine. Various researchers have attempted to find the width of the apical constriction for different root canals.
- Whether the root canal is vital, calcified, or infected.
- Presence or absence of periradicular pathology/resorption.
- Radius of canal curvature which could make the shaping procedure more difficult.
- Canal configuration, with more attention to be given to complex anatomies such as a C-shaped canal and the isthmus region. An overview of the apical constriction diameters of maxillary and mandibular teeth is provided in **Tables 14.9** and **14.10**, respectively. The recommended MAF sizes are given in **Table 14.11** and clinical advantages and disadvantages between choosing larger versus smaller MAF sizes are given in **Box 14.9**.

Box 14.9

Clinical Advantages and Disadvantages of Master Apical File (MAF) Size: Small Versus Large

Root Canal Preparation MAF Size	Advantages	Disadvantages
Small master apical file size	• Conservative removal of radicular dentin • Maintains original root canal anatomy • Reduces chances of canal transportation • Reduces risk of irrigant extrusion	• Increased chances of leaving behind infected tissues • Reduced penetration and effectiveness of root canal irrigation in the critical apical third • Not ideal for lateral compaction obturation technique
Larger master apical file size	• Increased probability of physical disruption of bacterial biofilms due to mechanical removal of radicular dentin • Improved dynamics for irrigant penetration into the apical third of root canal	• Increased risk of operator errors such as canal transportation, ledge formation, and extrusion of irrigants and obturation material • Not ideal for thermoplastic obturation technique

Table 14.9 Maxillary Apical Constriction Diameters

	Investigators											
	Kuttler (1955)	**M (1956)**	**Tronstad (1977)**	**Kasahara (1990)**	**Stein (1990)**	**Sabala Review (1991)**	**Tronstad Suggested (1991)**	**Mizutani (1992)**	**Gutmann Suggested (1997)**	**Ghanai (1999)**	**Wu (2000)**	**Ponce (2003)**
No. of teeth examined	268	110	220	510	111			90		40	180	18
Centrals	25–35		45	60	19	80	70–90	42	35–60		35	30
Laterals	25–35		60		19	80	60–80	37	25–40		45	30
Cuspids	25–35		45		19	80	50–70	38	30–50		35	35
First premolar	25–35	20	50		19	60	35–90		25–40		40	
One canal			70			60					30	
Two canals			20									
Three canals												
Second premolar	25–35			19			35–90		25–40			
One canal			70			80					40	
Two canals			35			45–60					30	
Molars	25–35				19							
MB root		25				45	35–60		25–40		45	
One canal			60							30–40	20	
Two canals			40							25–35	20	
DB root		25	40			45	35–60		25–40	20–50	25	
Palatal root		35	40			60	80–100		25–40	40–55	35	

Data are presented as ISO file size. (Adapted with permission from Baugh, D., and Wallace, J.: The role of apical instrumentation in root canal treatment: a review of the literature. *J. Endod.*, **31**:333–40, 2005.)

Table 14.10 Mandibular Apical Constriction Diameters

	Kuttler	Green	Tronstad	Stein	Sabala	Tronstad	Miyashita	Gutmann	Mauger	Wu
Centrals	25–35		70	19	60	35–70	40	25–40	50	40
Laterals	25–35		70	19	60	35–70	40	25–40	50	40
Cuspids	25–35		70	19	80	50–70		30–50	50	
First premolar	25–35		35			35–70		30–50		
One canal				19	80					35
Two canals					45–60					25
Second premolar	25–35		40			35–70		30–50		
One canal				19	80					35
Two canals					45–60					25
Molars	25–35									
M root		25	60	19	45	35–45		25–40		40
D root		30	60		60	40–80		25–40		50

Data are presented as ISO file size. (Adapted with permission from Baugh, D., and Wallace, J.: The role of apical instrumentation in root canal treatment: a review of the literature. *J. Endod.*, **31**:333–40, 2005.)

Table 14.11 Recommended Master Apical File Sizes for Maxillary and Mandibular Teeth

	Recommended Master Apical File Size	
Tooth Type	**Maxillary**	**Mandibular**
Central incisors	50–70	25–40
Lateral incisors	45–60	25–40
Canines	45–60	30–50
Premolars	25–40	30–50
Molars		
• Mesiobuccal	25–40	25–40
• Distobuccal/mesiolingual	25–40	25–40
• Palatal/distal	30–50	25–40

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15 Irrigants and Intracanal Medicaments

Medicine heals doubts as well as diseases.
—Karl Marx

The shaping and cleaning of the root canal constitutes one of the most important phases of endodontic therapy. Instrumentation of the canal reduces the microbial content of the root canal to a great extent. However, the root canal anatomy provides areas in which bacteria can persist and thrive (**Figs 15.1** and **15.2**).

Individual microorganisms proliferate to form populations which occur as *microcolonies*. The root canal system with necrotic pulp provides space for microbial colonization and affords the microorganism a moist, warm, nutritious, and anaerobic environment, protected from host defenses due to lack of microcirculation in the necrotic pulp tissue.

Clinical Note

A wide variety of microorganisms have been identified to invade depths up to 2,000 µm into the dentinal tubules (**Table 15.1**).

It has become increasingly clear that the largest proportion of endodontic diseases of both pulp and periradicular tissues is due to the presence of microorganisms, although mechanical and manual challenges of root canal debridement remain. Therefore, the success of treatment depends on the ability to remove these microorganisms and prevent reinfection.

One of the neglected phases of endodontic treatment is the eradication of microorganisms and the complete removal of minute fragments of organic debris, necrotic tissue, pulp remnants, and dentinal shavings from the root canal.

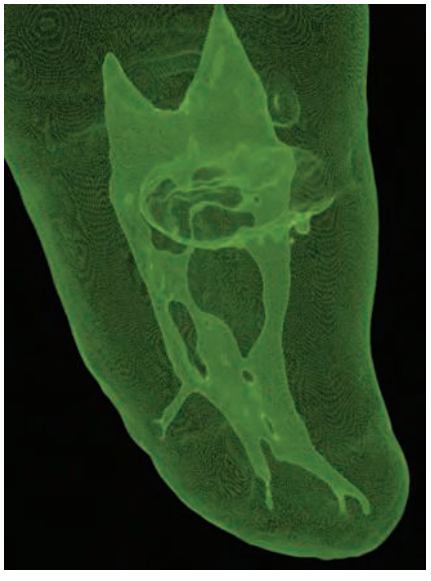


Figure 15.1 Three-dimensional micro-CT view of a mandibular first premolar demonstrating the complexity of the root canal system and a challenge to shaping and cleaning techniques.

Clinical Note

- It is important to appreciate that while hand and rotary instrumentation produce *shape*, it is the irrigants that *clean and disinfect* the root canal system.
- Irrigants not only are important for the removal of debris and dentinal chips produced during shaping and cleaning but also are of critical importance in eradicating the intraradicular microbial infection.

IRRIGANTS

OBJECTIVES OF IRRIGATION

- Remove the debris created during shaping of the root canal.
- Lubricate the root canal.
- Dissolve organic and inorganic tissues.
- Remove and prevent the formation of smear layer.

Through the years, different irrigating solutions have been recommended. A stream of hot water discharged from an insulated syringe, physiologic saline solution, a 30% solution of urea, urea peroxide solution in glycerine, a solution of chloramine, sodium hypochlorite, and sodium hypochlorite in conjunction with ethylenediaminetetraacetic acid (EDTA) are just a few.

An ideal irrigant should have most of the ideal requirements listed in **Box 15.1**. However, none of the currently available irrigating solutions has all the properties needed. A combined use of separate irrigants is the clinical protocol recommended to ensure successful outcome of endodontic treatment.

IRRIGATING SOLUTIONS

Some of the commonly employed irrigants during endodontic procedures are given in **Box 15.2**.

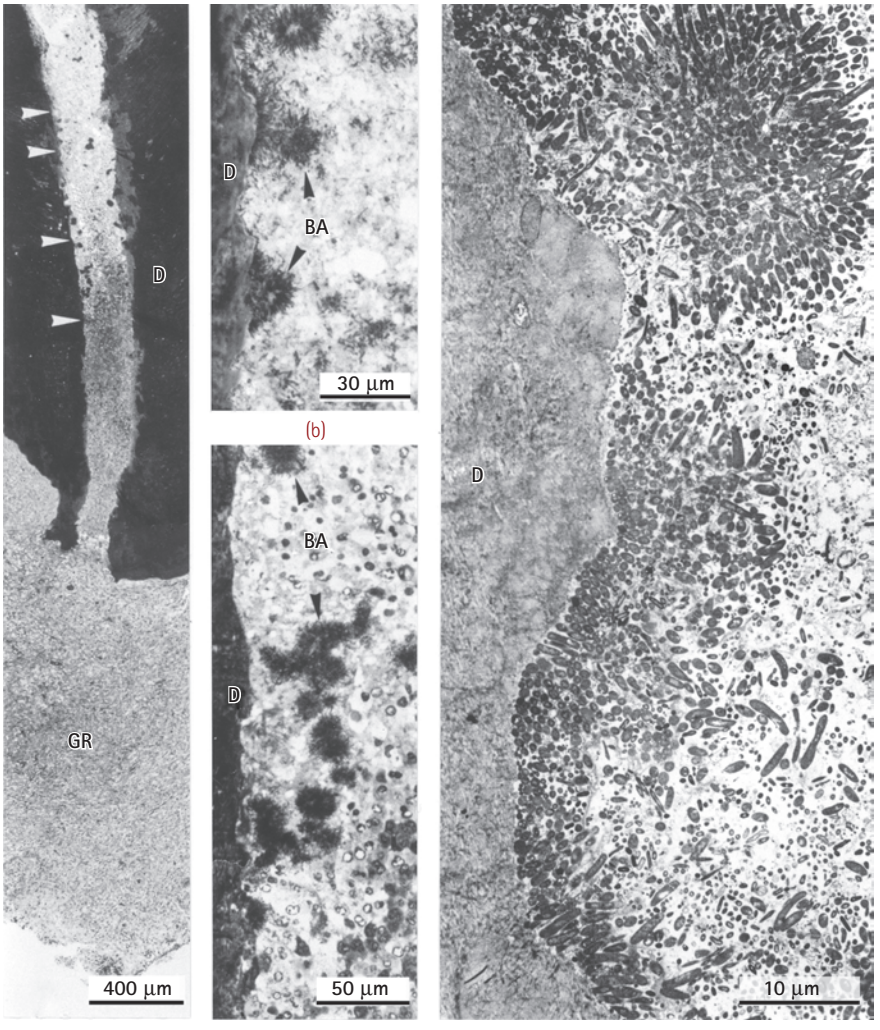


Figure 15.2 Axial views of an endodontic microbial biofilm of a human tooth with apical periodontitis (GR) and previously untreated root canal. The areas within the axial section of the tooth (a) in between the upper two and the lower two arrowheads are magnified in (b) and (c), respectively. Note the biofilm as dense bacterial aggregates (BA) sticking (b) to the dentinal (D) wall and also remaining suspended among neutrophilic granulocytes in the fluid phase of the root canal (c). A transmission electron microscopic view (d) of the pulpodentinal interface shows bacterial condensation on the surface of the dentinal wall forming a sessile biofilm. Magnifications: (a) ×46, (b) ×600, and (c and d) ×2350. (Adapted from Nair, P.N.R.: Apical periodontitis: A dynamic encounter between root canal infection and host response. *Periodontology*, **13**:121–48, 2000, 1997.)

Box 15.1

Ideal Requirements of an Endodontic Irrigant

- Antimicrobial activity
- Mechanically flushes out the debris from the root canal
- Nontoxic and nonirritating to the periapical tissues
- Dissolves necrotic and vital pulp tissues
- Serves as a lubricant
- Removes the smear layer
- Low surface tension
- Has no adverse effect on the physical properties of dentin
- Does not interact with the sealing ability of either the root canal sealer or the obturating material
- Is easy to use and economical

MOST COMMONLY USED IRRIGANTS

Sodium Hypochlorite

Sodium hypochlorite (NaOCl), a reducing agent, is a clear, straw-colored solution containing about 5% of available chlorine. It is the most widely used irrigating solution.

History

- *Dakin (1915)*: Recommended 0.5% NaOCl for treating wounds during World War I
- *Coolidge (1919)*: Introduced NaOCl in endodontics

Table 15.1 Dentinal Tubule Infection: Microorganisms Identified Along with Depth of Penetration

Author	Year	In Vivo/ In Vitro	Method of Determination	No. of Teeth	Depth of Penetration
Matsuo	2003	In vivo	Immunohistochemistry	40	70% had bacteria in tubules up to cementum *Fusobacterium, Eubacterium alactolyticum, E. nodatum, Lactobacillus casei, Peptostreptococcus micros*
Weiger	2002	In vitro	Fluorescent photomicroscope	24	*Streptococcus sanguis, Enterococcus faecalis* up to 150 µm
Siqueira	2002	In vivo	SE	15	300 µm Cocci and rods
Peters and Wesselink	2001	In vivo	Light	25	375 µm *Fusobacterium, Prevotella intermedia, Porphyromonas gingivalis, Actinomyces israelii*
Peters and Wesselink	2000	In vitro	Light	Bovine	Up to 2000 µm *Ent. faecalis, A. israelii*
Berkiten	2000	In vitro	SE	28	*P. intermedia* 26 µm, *S. sanguis* 383 µm
Waltimo	2000	In vitro	Light	Human	Yeasts 60 µm
Siqueira	1996	In vitro	SE	Bovine	Heavy penetration *Por. endodontalis, F. nucleatum, A. israelii, Por. gingivalis, Propionibacterium acnes, Ent. faecalis*
Love	1996	In vivo	Light	Human	200 µm in cervical and midroot 60 µm in apical *S. gordonii*
Perez	1996	In vitro	SE	Bovine	1300 µm *S. sanguis*
Sen	1995	In vivo	SE	Human	10–150 µm Cocci, rods
Nagoka	1995	In vivo	SE	Human	2100 µm
Perez	1993	In vitro	Light microscopy and SE	Bovine	*S. sanguis, P. intermedia, A. naeslundii*
Perez	1993	In vitro	Light microscopy and SE	Bovine	792 µm *S. sanguis*
Orstavik	1990	In vitro	SE	Bovine	600–1350 µm *S. sanguis, Ent. faecalis, Escherichia coli, Pseudomonas aeruginosa*
Ando and Hoshino	1990	In vivo	Light microscopy	Human	500–2000 µm *Lactobacillus, Streptococcus, Propionibacterium, Peptococcus*
Haapasalo and Orstavik	1987	In vitro	SE	Bovine	300–400 µm *Ent. faecalis*
Armitage	1983	In vivo	Light microscopy	Human	Half way up to dentinocemental junction
Akpata	1982	In vitro	Light microscopy	Human	Half way through tubules *S. sanguis, Ent. faecalis*

(Adapted with permission from Baugh, D., and Wallace, J.: The role of apical instrumentation in root canal treatment: A review of the literature. *J. Endod.*, **31**:333–40, 2005.)

Box 15.2

Classification of Root Canal Irrigants

- **Most commonly used irrigants**
  - Sodium hypochlorite **(NaOCl)**
  - Ethylenediaminetetraacetic acid **(EDTA)**
  - Chlorhexidine digluconate **(CHX)**
- **Other recently introduced irrigants**
  - 1-Hydroxyethylidene-1,1-bisphosphonate (HEBP), also called etidronic acid
  - Iodine potassium iodide (IKI)
  - Antibiotic-containing irrigants
    - MTAD
    - Tetraclean
  - QMix

Mechanism of Action

NaOCl on ionization produces hypochlorous acid and hypochlorite ion. These are responsible for the antimicrobial ability of NaOCl. Destruction of bacteria takes place in two phases:

1. Penetration into the bacterial cell wall
2. Chemical combination with the protoplasm of the bacterial cell and disruption of DNA synthesis

According to Estrela et al., the mechanism of action of sodium hypochlorite occurs due to the following properties and interactions:

- Saponification reaction
- Amino acid neutralization
- Hypochlorous acid formation
- Chloramination reaction
- High alkaline pH >11

Properties

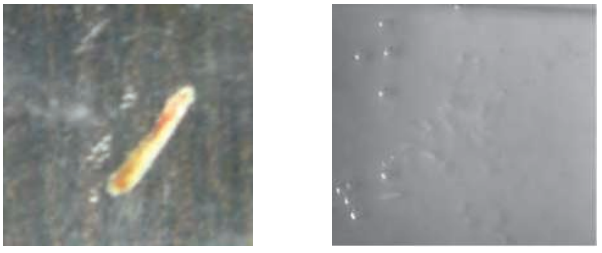
a. Concentration

No unanimity of opinion exists as to which concentration of sodium hypochlorite should be used in root canal therapy. If the canal is filled with the solution during the entire cleaning and shaping procedure, the irrigant will act as a lubricant, a solvent of pulp tissue, and a potent antimicrobial.

- On the basis of published data, a *0.5–5.2% sodium hypochlorite solution* (NaOCl) can be used as an irrigant in the root canal. The most effective concentration recommended is 5.2% sodium hypochlorite (NaOCl) (**Fig. 15.3**).
- However, *2.5% NaOCl* is a commonly employed concentration as it decreases the potential for toxicity while maintaining some tissue-dissolving and antimicrobial activity. When using lower-concentration NaOCl solutions, it is recommended to increase both volume and exposure time.

b. Tissue Dissolution Ability

The NaOCl completely dissolves an entire pulp in 20 minutes to 2 hours, whereas the next most effective solution requires at least 24 hours to accomplish the same result (**Fig. 15.3a** and **15.3b**). Although this solvent action of sodium hypochlorite on tissue has been confirmed, other investigators have found sodium hypochlorite less effective in narrow root canals compared to in wide ones.



(a) (b)

Figure 15.3 (a) Extirpated pulp placed into NaOCl solution. (b) Pulp completely dissolved by NaOCl solution.

The pulp-dissolving ability of this irrigant is useful during the cleaning and shaping of inaccessible areas such as the isthmus region and C-shaped canal systems (**Figs 15.4–15.6**). **Box 15.3** presents factors required to increase the efficacy of sodium hypochlorite.

Drawbacks of NaOCl

- Cytotoxicity and caustic effects on healthy periradicular tissues on inadvertent extrusion during the irrigating procedure. Such *sodium hypochlorite accidents* are the reason for lower concentration, 0.5–1 or 2.5%, of NaOCl being more commonly preferred by clinicians. It does not remove the inorganic component of the endodontic smear layer.
- It has an unpleasant taste.
- The solution should be kept in a cool place, away from sunlight.

Clinical Note

- 5.25% sodium hypochlorite is the *most commonly used* endodontic irrigant.
- According to Torabinejad et al., during instrumentation, a 1.3% solution of sodium hypochlorite is beneficial as a *working solution*.
- The chlorine ion, which is responsible for tissue dissolution and antibacterial ability of NaOCl, is unstable and gets consumed rapidly, probably within 2 minutes. Hence, *continuous replenishment* of NaOCl during irrigation is key to enhance its effectiveness.
- NaOCl accidents can be avoided by ensuring that the irrigating needle is *passively placed* in the apical third of the canal without allowing the needle to bind tightly to the root canal.

Ethylenediaminetetraacetic Acid (EDTA)

History

The chelating agent ethylenediaminetetraacetic acid, commonly called EDTA, was introduced into endodontic practice by *Nygaard-Østby*.

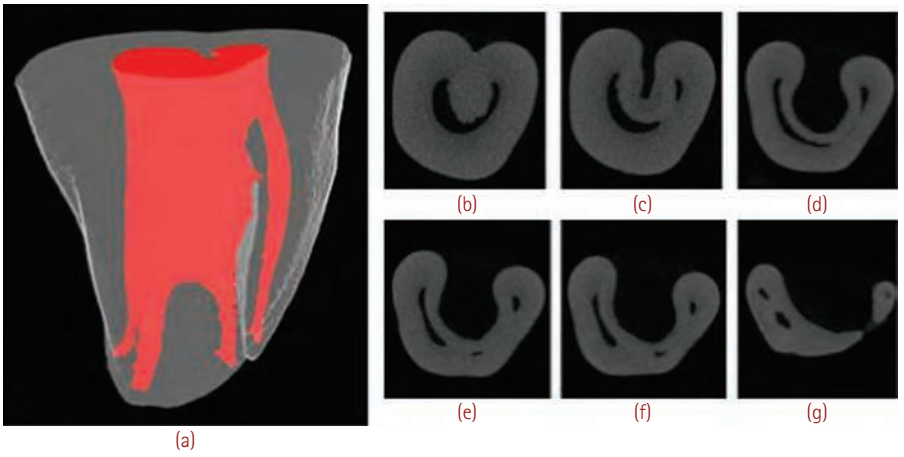


Figure 15.4 Trifurcation of the distal canal in a C-shaped canal system: (a) Three-dimensional reconstructed root canal image. (b) Cross-section at 10 mm from apex (orifice). (c) Cross-section at 9 mm from apex. (d) Cross-section at 6 mm from apex. (e) Cross-section at 5 mm from apex. (f) Cross-section at 4 mm from apex. (g) Cross-section at 2 mm from apex. (*Courtesy: Prof. Bing Fan, Wuhan University, China.*)

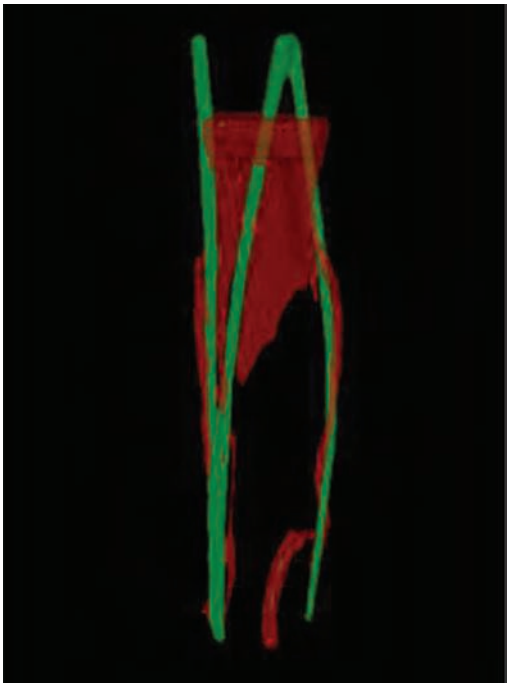


Figure 15.5 The bifurcation of the main canal in the middle or apical third is the main reason for missing a canal in C-shaped canal treatment. The figure shows a bifurcation of the canal in the apical part; the initial file could negotiate only one canal. Extravagant use of small files and 5.25% NaOCl is key to thorough debridement of narrow canal isthmuses. (*Courtesy: Prof. Bing Fan, Wuhan University, China.*)

Box 15.3

Modes of Increasing the Efficacy of Sodium Hypochlorite

The decrease in concentration is safer but reduces the effectiveness of NaOCl. This can be compensated by the following:

- *Refreshment*: The volume of the irrigant employed is increased.
- The *exposure time* of dentin to NaOCl is increased.
- *Ultrasonic activation* of the irrigant has been advocated to improve the effectiveness of NaOCl as well as to enable the irrigant to reach into the complex isthmuses of the root canal.
- Warming the irrigant increases the effectiveness of NaOCl.

Mechanism of Action

Seventeen percent EDTA is relatively nontoxic and only slightly irritating in weak solutions. It forms highly stable, soluble, metal chelates in combination with heavy metals or alkaline earth ions.

EDTA functions by forming a calcium–chelate solution with the calcium ion of dentin; the dentin thereby becomes more friable and easier to instrument. Many clinicians use some form of EDTA routinely during shaping and cleaning of the root canal and find it effective for achieving canal patency, enlargement, and smear layer removal.

EDTA, a chelating agent, has been used as an irrigating solution. This solution removes the inorganic component of the endodontic smear layer. The smear layer is a combination of dentin, pulpal, and bacterial debris (**Fig. 15.7**). Some clinicians advocate the removal of the smear layer by irrigating the canal with sodium hypochlorite followed by EDTA (**Fig. 15.8**).

The effects of EDTA have been studied both in vitro and in vivo, and the following conclusions have been reported:

- EDTA is effective in softening dentin.
- Irrigation with EDTA removes the inorganic part of the smear layer.
- The extent of demineralization by EDTA is proportional to the exposure time.
- EDTA has no deleterious effect when used clinically as an irrigating solution.

EDTA as an irrigant is employed by depositing a few drops into the pulp chamber with a syringe and then carefully pumping the solution into the root canal with a fine root canal instrument.

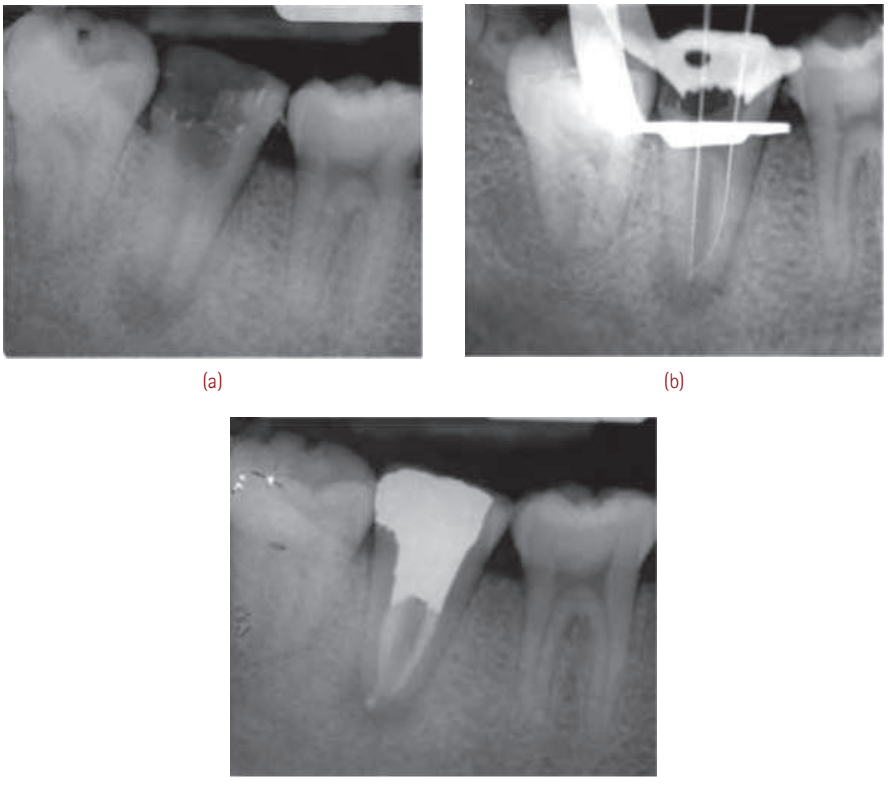


Figure 15.6 Use of NaOCl in the management of C-shaped canals: (a) Radiograph shows a mandibular molar with C-shaped root canal anatomy. (b) Working length radiograph. (c) Root canal obturated with warm vertical condensation technique. (*Courtesy: Prof. Bing Fan, Wuhan University, China.*)

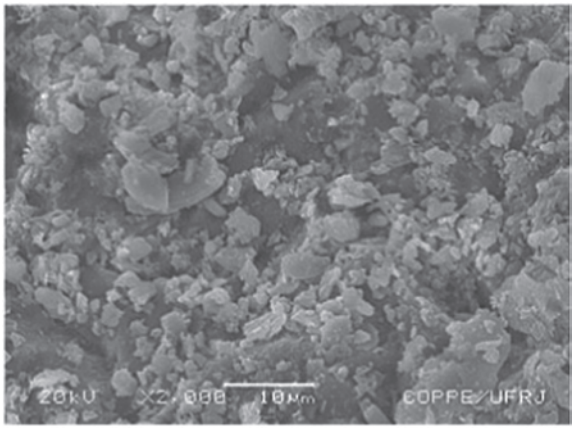


Figure 15.7 SEM image of an endodontic smear layer. (*Courtesy: Alessandra Sverberi Carvalho, Brazil.*)

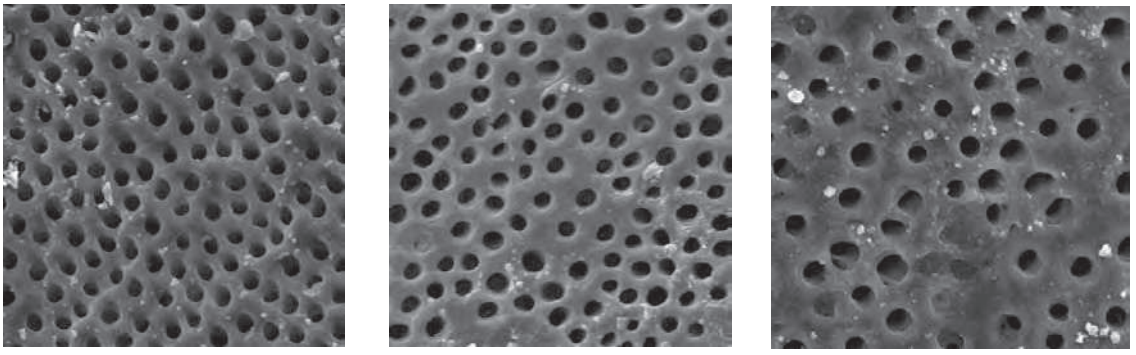
When it is difficult to introduce a file into the canal due to intracanal calcifications or iatrogenic blockade, ***EDTA gel*** can be used and one should try to negotiate such canals with an instrument coated with EDTA gel. If the root canal of a posterior tooth is narrow and if one risks breaking a fine instrument, it is better to pump EDTA into the canal and wait for 1 minute before attempting instrumentation. Once the apical foramen has been reached and the canal has been enlarged, the canal should be irrigated in the usual manner.

Clinical Note

- EDTA as an irrigant employed alone is ineffective and hence is recommend to be used as the *final irrigant* (for removal of the inorganic part of the smear layer) after using NaOCl (for removal of the organic part of the smear layer).
- Care should be taken to ensure that NaOCl and EDTA are not mixed as their *interaction makes NaOCl to lose its tissue-dissolving capacity*, with virtually no free chlorine detected in the combinations
- The recommended regimen for irrigation is to employ 5.25% NaOCl for irrigation during the shaping of the root canal followed by 17% EDTA for 1 minute as a final rinse before obturating the canal.

Chlorhexidine Digluconate (2%)

Chlorhexidine digluconate (CHX) is a cationic bisbiguanide which is utilized as an irrigating solution as well as an intracanal medicament. The structure consists of two symmetric four-chlorophenyl rings and two bisguanide



(a) (b) (c)

Figure 15.8 (a) SEM of canal walls instrumented with NaOCl 2.5% + EDTA 17%. Cervical third (original magnification, ×2000). (b) SEM of canal walls instrumented with NaOCl 2.5% + EDTA 17%. Middle third (original magnification, ×2000). Absence of smear layer and open tubules. (c) SEM of canal walls instrumented with NaOCl 2.5% + EDTA 17%. Apical third (original magnification, ×2000). (*Courtesy: Alessandra Sverberi Carvalho, Brazil.*)

groups held together by a central hexamethylene chain. It is less toxic compared to other commonly employed irrigants.

Mechanism of Action

CHX possesses a broad-spectrum antimicrobial activity against most common endodontic pathogens. It also possesses bacteriostatic and bactericidal activity. Two percent CHX is capable of electrostatically binding to negatively charged bacterial surfaces. The antimicrobial activity of CHX against gram-positive bacteria and yeasts is attributed to its ability to permeate the microbial cell wall and cause coagulation of the cytoplasmic components.

Moreover, CHX is very effective against *E. faecalis*, which is one of the most common pathogens identified in root canal–filled teeth exhibiting clinical failure. The most important clinical characteristic of chlorhexidine is its *substantivity*, which refers to its sustained action within the root canal. This property imparts to its potential of preventing bacterial colonization of root canal walls for prolonged periods of time.

Limitations

- CHX lacks tissue-dissolving ability.
- It does not remove the smear layer and hence has to be employed in conjunction with other irrigants.

Clinical Note

- The use of chlorhexidine digluconate irrigant is *not recommended* in regenerative endodontic procedures.
- CHX should not be allowed to interact with NaOCl as their interaction produces an *orange-colored precipitate*. Care must be taken to ensure that these two irrigants are not used clinically during the same appointment or if used in the same appointment, then after using NaOCl the canals should be first flushed with normal saline before introducing the CHX irrigant.
- The antimicrobial ability of CHX is dependent on its concentration. Hence, *CHX 2% concentration is recommended* as an endododontic irrigant while most periodontal mouthrinses employ CHX in 0.12% concentration.

OTHER RECENTLY INTRODUCED IRRIGANTS

1-Hydroxyethylidene-1,1-Bisphosphonate (HEBP, also Called Etidronic Acid)

- HEBP is a weak chelator and a potential alternative to EDTA.
- HEBP does not interact with NaOCl and thus can be used in conjunction with NaOCl. This combination could potentially remove the endodontic smear layer as it is being created during root canal shaping procedures.

Iodine Potassium Iodide (IKI)

- IKI is a broad-spectrum antimicrobial irrigant used in a concentration of 2–5% in endodontics.
- A potential disadvantage of iodine-containing irrigants is a possible allergic reaction in some patients.

Antibiotic-Containing Irrigants

MTAD

One of the recently introduced irrigants is MTAD (**Fig. 15.9**) which contains the following:



Figure 15.9 MTAD irrigant (BioPure MTAD). (*Courtesy: Dentsply Tulsa.*)

- Aqueous solution of 3% doxycycline, a broad-spectrum antibiotic
- 4.25% citric acid, a demineralizing agent
- 0.5% polysorbate 80 detergent (Tween 80)

It is commonly employed after initial irrigation with 1.3% NaOCl. Further research is needed to validate its clinical effectiveness.

Tetraclean

- It is similar in composition to MTAD with a lower concentration of doxycycline.

QMiX

- Composition: QMix contains a CHX-analog, triclosan, and EDTA as a decalcifying agent.
- It is recommended to be used as a final rinse after NaOCl as an irrigant for its antimicrobial and smear layer removal properties.

Clinical Note

- None of the recently introduced irrigants mentioned above have been able to show clinical results superior to the traditionally used irrigants.
- Currently, NaOCl remains as the *primary irrigant of choice*.
- EDTA (for smear layer removal ability) and CHX (for its antimicrobial substantivity) are useful *adjunct irrigants* to be used along with NaOCl in contemporary endodontics.

IRRIGATION GUIDELINES

The technique of irrigation is simple. The only instruments required are the following:

i. ***Disposable Luer lock syringes***: Color coded for different irrigants (**Fig. 15.10**)
ii. ***Closed-ended 30-gauge side-vented needles*** for apical third irrigation (**Fig. 15.11a** and **15.11b**).



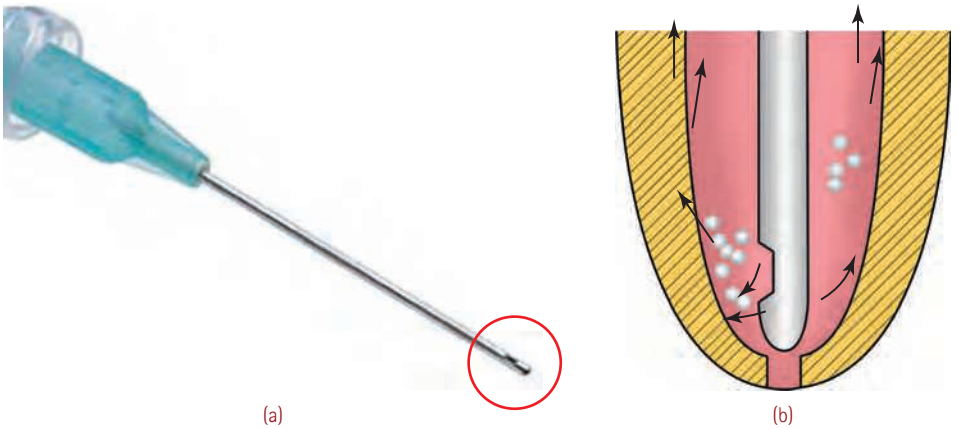
(a) (b)

Figure 15.10 Disposable Luer lock syringes of various volumes.

iii. ***Open-ended 25- to 27-gauge needles*** for coronal and middle third root canal irrigation

The technique of irrigation is as follows:

- The use of a ***rubber dam is mandatory*** to ensure adequate isolation of the pulp space as well as to prevent the irrigants from coming in contact with the oral soft tissues.
- Keep *separate color-coded syringes* for different irrigants to avoid procedural errors and inadvertent irrigant interactions.
- The tip of the needle is placed near the root canal orifice and the NaOCl irrigant is discharged until it fills the pulp chamber. This *working solution* keeps the pulp space lubricated and ensures more exposure time of NaOCl with radicular dentin. Root canal shaping both with hand and with rotary instrumentation is always performed keeping the canal lubricated with the irrigant.
- The open-ended 25- to 27-gauge needle ejects the irrigant a greater rate of flow and directs the irrigant flow apically. It is effective but has the drawback of causing inadvertent extrusion of the irrigant periapically if used in the apical third region. Hence, open-ended needles are *indicated for irrigating the coronal and middle third* of a root canal only



(a) (b)

Figure 15.11 (a) Closed-ended and 30-gauge side-vented endodontic irrigation needle. (b) Side-vented endodontic irrigation needle prevents the apical extrusion of the irrigant.

(maximum depth of insertion is 3 mm short of working length). They are not indicated to be used in the apical third of a root canal.

- All needles irrespective of gauge and design should be inserted passively without binding into the root canal. Sufficient room between the needle and the canal wall allows for the return flow of the solution and avoids forcing of solution into the periradicular tissues (**Fig. 15.11b**).
- The 30-gauge needle should be inserted at a distance of ***1–3 mm short of the working length*** without binding. When one is certain that the needle does not bind, the solution should be ejected from the syringe with little or no pressure on the plunger.
- The objective is to irrigate the canal and not to force the solution under pressure into the periradicular tissues. During the shaping and cleaning of the root canal, care should be taken that the canals are always full of fresh solution.
- Irrigation should be followed by thorough drying of the root canals after the completion of shaping and cleaning. Final drying should be effected with absorbent points.
- Care should be taken to avoid extrusion of the irrigant due to its toxicity. Possible extrusion and *"sodium hypochlorite accident"* can be avoided by employing a needle with side vents (**Fig. 15.11b**), as they minimize the apical irrigating pressure. The reader is referred to Chapter 7 for details regarding the management of sodium hypochlorite accident.

Apart from the chemical nature of the irrigants, the factors that determine the efficacy of irrigants are listed in **Box 15.4**.



Clinical Note

- Adequate irrigation is an important aspect of the cleaning process. The type, concentration, and volume of irrigant are important variables in ensuring adequate cleaning of the root canal space.
- Studies have shown that frequent irrigation of the canal is mandatory, and irrigation is more complete in properly enlarged canals.
- Penetration of the irrigant is more effective in canals with larger diameters than in canals with smaller diameters.
- The irrigating solution should be constantly exchanged to maintain its efficiency.
- Increasing the temperature of NaOCl has also been demonstrated to improve its efficacy; however, temperature might not play a role for other irrigants.

IRRIGANT ACTIVATION/AGITATION

Irrigant activation/agitation is the process of activating an irrigant through the introduction of an instrument into the canal and moving it within the canal with a reciprocating, oscillating, or rotating action. The various techniques of irrigant agitation are given in **Box 15.5**.

Box 15.4

Factors Affecting the Efficacy of an Irrigant

- Volume of the irrigant used
- Concentration of the irrigant
- Frequency of irrigation
- Temperature of the irrigant
- Length and time of intracanal contact
- Gauge of the irrigating needle
- Depth of penetration
- Diameter of the prepared canals
- Age of the irrigating solution

I. MANUAL

a. Syringe irrigation with needles
b. Brushes
c. Manual dynamic agitation

a. Syringe Irrigation with Needles

This technique involves dispensing of an irrigant into the root canal using irrigation needles/cannulae of varying gauges. The advantage of this technique is length control; however, it results in a weak mechanical flushing action. The recommendations for syringe irrigation are as follows:

- *Gauge*: Sizes 27 and 30 most commonly recommended
- *Depth of insertion*: 1–3 mm from the working length
- *Design*: Blunt-ended side-vented needle for apical third and open-ended needles for coronal and middle third of a root canal

b. Brushes

These are adjunctive aids in canal debridement or agitation of irrigants. The bristles help in cleaning the uninstrumented recesses of the radicular pulp space. Examples include the Endobrush (C&S Micro-Instruments Ltd., Ontario, Canada) and NaviTip FX (Ultradent Products Inc., South Jordan, UT).

c. Manual Dynamic Agitation

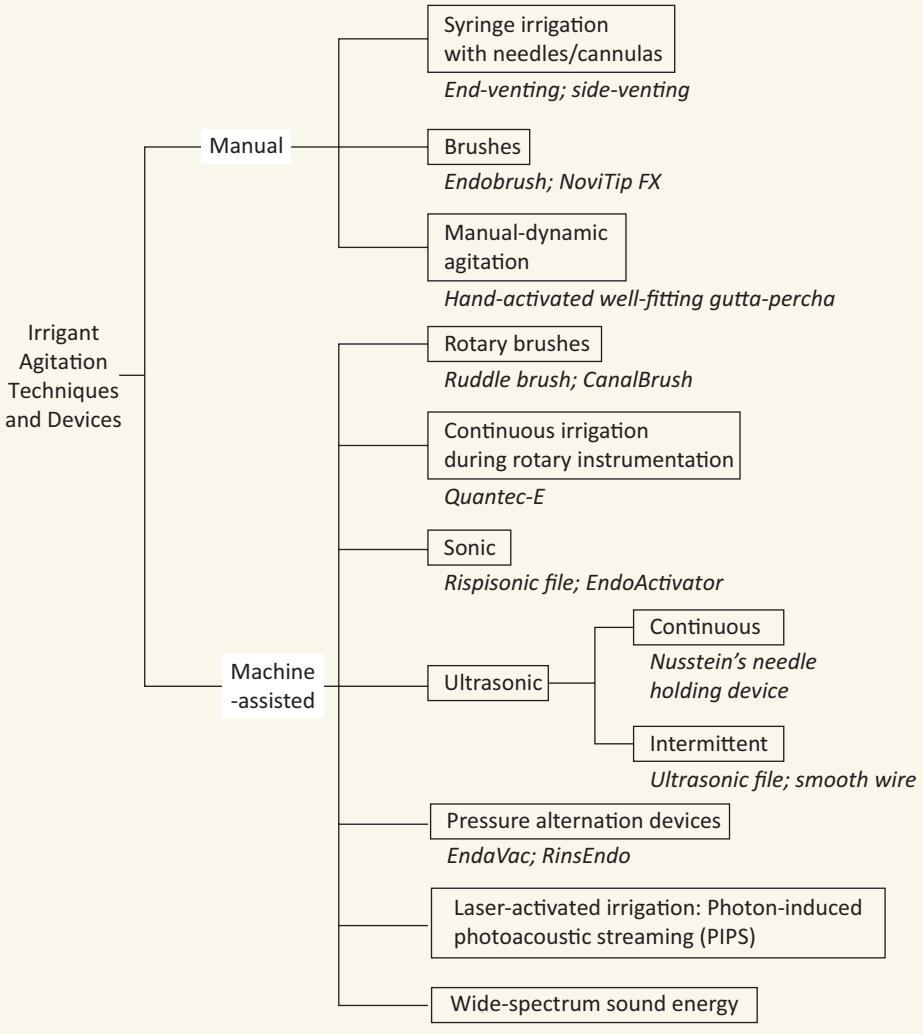
In this technique, a well-fitted greater taper gutta-percha master cone is moved up and down the instrumented canal containing the irrigant in short 2- to 3-mm strokes. The frequency of the push–pull motion is 100 strokes per 30 seconds. This results in a hydrodynamic effect improving irrigant exchange and replacement.

II. MACHINE ASSISTED

a. Rotary brushes
b. Continuous irrigation during instrumentation
c. Sonic irrigation
d. Ultrasonic irrigation
   i. Continuous ultrasonic irrigation (CUI)
   ii. Passive ultrasonic irrigation (PUI)
e. Pressure alternation devices
   i. Endovac
   ii. Rinsendo

Box 15.5

Irrigant Agitation Techniques (Adapted from Gu, S., et al.: Review of contemporary irrigant agitation techniques and devices. *J. Endod.*, 35:791–804, 2009.)



f. Laser-activated irrigation: Photon-induced photoacoustic streaming (PIPS)
g. Wide-spectrum sound energy

a. Rotary Brushes

They consist of microbrushes attached to rotary handpieces, e.g., CanalBrush (Coltene).

b. Continuous Irrigation During Instrumentation

The device contains an irrigant delivery unit attached to the Quantec-E irrigation system (SybronEndo, Orange, CA), which provides increased irrigation depth and duration.

c. Sonic Irrigation

This technique involves sonic waves operating at a frequency of 1–6 kHz which help in irrigant activation, e.g., EndoActivator® System (Dentsply Sirona). It consists of a portable handpiece with three different sizes of polymer tips operating at 10,000 cycles/minute (**Fig. 15.12**).



Figure 15.12 EndoActivator, a sonic irrigant activation system. (*Courtesy: Dentsply Sirona.*)

d. Ultrasonic Irrigation

Richman (1967) introduced ultrasonics in endodontics. Ultrasonic irrigation modality operates at frequencies of 25–30 kHz setting up transverse vibrations with a characteristic pattern of nodes and antinodes.

Types

1. *Ultrasonic Instrumentation (UI):* In UI, irrigation is combined with simultaneous ultrasonic instrumentation.
2. *PUI:* This technique was developed by Weller et al. in 1980. It relies on the transmission of acoustic energy from an oscillating file or a smooth wire to an irrigant in the root canal. The energy is transmitted by means of ultrasonic waves and can induce acoustic streaming and cavitation of the irrigant (**Fig. 15.13**).

Technique

After the root canal has been shaped to the master apical file (irrespective of the preparation technique used), a small file or smooth wire (e.g., size 15) is introduced in the center of the root canal, as far as the apical region. The root canal is then filled with an irrigant solution and the ultrasonically oscillating file activates the irrigant.

Clinical Note

The application of sonic and ultrasonic activation devices is best performed following canal shaping. As the root canal has already been shaped, the file or wire can move freely and the irrigant can penetrate more easily into the apical part of the root canal system.

e. Pressure Alternation Devices

i. EndoVac (Fig. 15.14)

The device consists of a macrocannula and a microcannula connected via a tubing to an irrigating syringe and the high-speed suction of a dental unit.

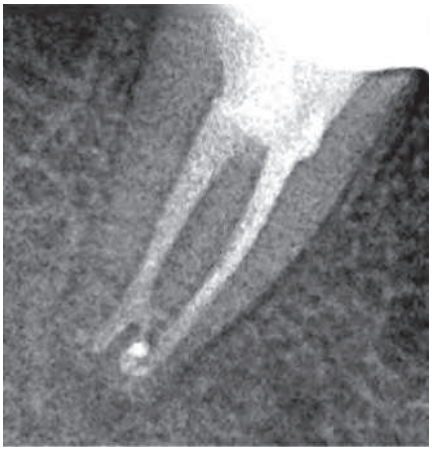


Figure 15.13 Apical canal ramifications can be effectively cleaned with the help of NaOCl with passive ultrasonic activation.



Figure 15.14 EndoVac irrigation system. (*Courtesy: SybronEndo, USA.*)

The macrocannula aids in the gross, initial flushing of the coronal part of the root canal while the microcannula can be positioned at the working length to facilitate irrigation.

Mechanism of Action: The EndoVac functions on negative-pressure irrigation technology with the following advantages:

- Irrigation at the working length with minimal irrigant extrusion
- More debris removal at 1 mm from the working length
- Avoids air entrapment

ii. RinsEndo

It is based on pressure-suction technology that aspirates the delivered irrigating solution into an irrigation needle that is placed close to working length and at the same time activates the needle with oscillations of 1.6 Hz amplitude.

f. Laser-Activated Irrigation: Photon-Induced Photoacoustic Streaming

PIPS employs a 2940-nm erbium laser to pulse extremely low energy levels of laser light to create photoacoustic shockwaves throughout the entire root canal system without enlarging the root canals. The PIPS tip is placed in the pulp chamber only and not in the canals. The PIPS tapered tip creates a pressure wave that streams irrigants throughout the root canal system.

g. Wide-Spectrum Sound Energy

GentleWave (Sonendo, USA) consists of a central unit from which high-pressure pumps send high-speed degassed irrigants to a special handpiece with the tip of the handpiece placed into the pulp chamber of the tooth (**Fig. 15.15**). The irrigant is sucked back through several small holes in the handpiece covering the access cavity.

Clinical Note

- Ultrasonic and sonic activation of irrigants are the most popular irrigant activation techniques currently employed by clinicians
- Manual dynamic activation is a simple technique for the activation of irrigants if the operator is not having access to other activation methods.



Figure 15.15 Mechanism of action of GentleWave. (*Courtesy: Sonendo, USA.*)

INTRACANAL MEDICAMENTS

Disinfection of the pulp space is an important step during and after cleaning and shaping. It primarily involves cleaning and shaping the root canal space with endodontic instruments along with irrigants. However, in certain clinical conditions, the polymicrobial nature of the endodontic infection demands the use of an intracanal medicament in addition to the irrigants.

Intracanal medicaments are used for root canal disinfection as part of controlled asepsis in an infected root canal and their role is secondary to shaping and cleaning of the root canal. The ideal requirements of a root canal medicament are given in **Box 15.6**, while **Box 15.7** presents the indications for intracanal medicaments.

HISTORICAL PERSPECTIVE

- Grossman mentioned about the utilization of *polyantibiotic paste* as an intracanal medicament in weeping canals or where there was a continuous seepage from the pulp space. He had mentioned about PBSC containing *penicillin, bacitracin*, and *streptomycin* with *cryolite* as a vehicle. PBSCN combination was also advocated with N standing for neomycin as an antifungal agent.
- The original classification of intracanal medicaments is redundant today as majority of these preparations are *not used* in contemporary endodontics due to their reported toxicities.

Box 15.6

Grossman's Requirements of an Ideal Root Canal Medicament

- It should be an effective antimicrobial agent.
- It should be nonirritating to the periradicular tissues.
- It should remain stable in solution.
- It should have a prolonged antimicrobial effect.
- It should be active in the presence of blood, serum, and protein derivatives of tissue.
- It should have low surface tension.
- It should not interfere with the repair of periradicular tissues.
- It should not stain the tooth structure.
- It should not induce a cell-mediated immune response.

Box 15.7

Chong and Pittford's Indications of Intracanal Medicaments

- To dry persistently wet or the so-called *weeping canals*
- To eliminate any remaining microbes in the pulp space
- To render root canal contents inert
- To neutralize tissue debris
- To act as a barrier against leakage from an interappointment dressing in symptomatic cases

Clinical Note

Intracanal antibiotics are no longer recommended as many of the antibiotics tested are bacteriostatic in nature and thereby prevent the growth of microorganisms without killing them.

- *Phenol* and related volatile compounds were used for many years by endodontists and general practitioners for disinfection and caustic action. *Camphorated monochlorophenol (CMCP)* was one of the most commonly used medicaments for many years, but not anymore.
- *Formocresol*, is no longer recommended to be used as an intracanal medicament.
- *Eugenol* was once used for its obtundant action and mild antimicrobial action. It is now considered as a periradicular tissue toxin and its use is no longer recommended.

The antimicrobial intracanal medicaments recommended in contemporary endodontic practice are given in **Box 15.8**.

I. CALCIUM HYDROXIDE

History

Calcium hydroxide, $Ca(OH)_2$, has been used by endodontists throughout the world since Hermann introduced it to dentistry in 1920.

Box 15.8

Commonly Recommended Intracanal Medicaments

- Calcium hydroxide
- Chlorhexidine digluconate
- Antibiotics
  - Triple antibiotic paste
  - Double antibiotic paste
- Steroids
  - Ledermix



Figure 15.16 Commercially available nonsettable $Ca(OH)_2$ intracanal medicament with intracanal delivery tips (UltraCal XS). (*Courtesy: Ultradent Products Inc.*)

Mechanism of Action

It is a highly alkaline substance with a pH of approximately 12.5.

Calcium hydroxide has antibacterial properties and has the ability to induce repair and stimulate hard-tissue formation. The bactericidal effect is conferred by its highly alkaline pH. The release of hydroxyl ions in an aqueous environment is related to the antimicrobial property. Hydroxyl ions are highly oxidizing free radicals that destroy bacteria by:

- Damaging the cytoplasmic membrane
- Protein denaturation
- Damaging bacterial DNA

Vehicles

The vehicle used to mix $Ca(OH)_2$ and the manner in which it is dispensed has a significant role to play in achieving maximum antibacterial effects as an intracanal medicament in endodontics. According to Fava and Saunders, the vehicles can be classified as follows:

- Aqueous—e.g., sterile water, normal saline
- Viscous—glycerine, polyethylene glycol, and propylene glycol

The other medicaments combined with $Ca(OH)_2$ in order to achieve synergistic antimicrobial effect include camphorated monochlorophenol (CMCP) and 0.12% chlorhexidine.

Commercially, calcium hydroxide for intracanal disinfection is available as a nonsettable form which can be removed with minimum instrumentation (**Figs 15.16–15.19**).



Figure 15.17 Intracanal placement of nonsettable $Ca(OH)_2$ in an infected root canal with serous drainage.

II. CHLORHEXIDINE DIGLUCONATE

CHX has been recommended both as a root canal irrigant and as an intracanal medicament. As a medicament, it can be used as:

- 2% CHX gel
- Mixture of CHX and $Ca(OH)_2$

CHX has been shown to be effective against both *E. faecalis* and *Candida albicans*.

III. ANTIBIOTICS

- Antibiotics have a limited role to play as an intracanal medicament due to the following reasons:
  - No antibiotic can completely eradicate the complex polymicrobial flora present inside an infected root canal.
  - Most antibiotics are bacteriostatic and depend on the host resistance for dealing with the infection. As the infected root canal space has no blood supply, the effect of many antibiotics is limited.
- Hence, a combination of antibiotics has been tried to overcome the above-mentioned limitations. The most popular intracanal antibiotic combinations used are:
  - *Triple antibiotic paste (TAP)*: Ciprofloxacin, metronidazole, and minocycline (1:1:1) in a macrogol/propylene glycol vehicle
  - *Double antibiotic paste*: Combination of ciprofloxacin and metronidazole
- The TAP is the recommended intracanal medicament in regenerative endodontic cases. (Refer Chapter 12 for more details.)

IV. STEROIDS

- Steroids have limited applications as intracanal medicament and are used exclusively in:
  - Internal resorption cases
  - Traumatic injuries of the teeth
- ***Ledermix***:
  - The most popular steroid-based intracanal medicament is Ledermix, developed by Schroeder in 1960.
  - Composition
    - *Corticosteroid*: 1% triamcinolone acetonide
    - *Antibiotic*: Demeclocycline

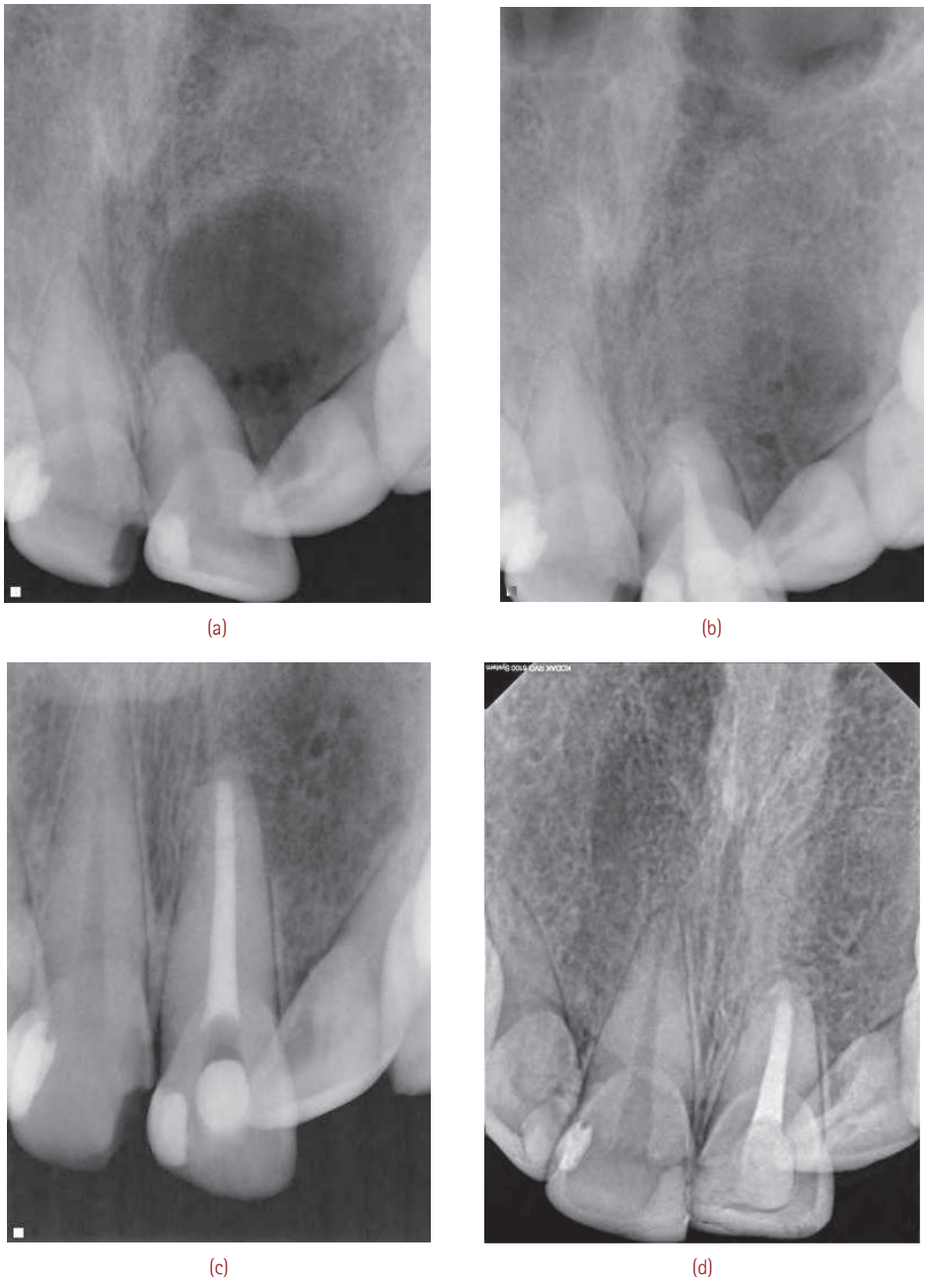


Figure 15.18 (a) Large periradicular radiolucency associated with a nonvital maxillary central incisor. (b) Calcium hydroxide used as an intracanal medicament for a period of 6 months. (c) Obturation was done after radiographic healing had taken place. (d) At 6-month recall, tooth was asymptomatic and functional with complete resolution of the lesion. (*Courtesy: Sashi Nallapati, Jamaica.*)

TEMPORARY FILLING MATERIALS

There are certain specific indications that demand the completion of the root canal treatment in multiple visits. In cases where the periradicular abscess drains through the root canal, endodontic therapy requires the placement of a temporary filling to seal the access cavity between visits to the endodontist. The purpose of the temporary filling is to seal the access cavity and thereby prevent the contamination of the root canal system by saliva, with its bacterial flora, food, and foreign materials, and prevent any intracanal medication from leaking.

The adequacy of temporary filling materials in sealing root canal dressings is just as important as of any other element in endodontic treatment. Leakage of the seal can counteract the most careful treatment. Temporary filling materials should meet certain requirements (**Box 15.9**).

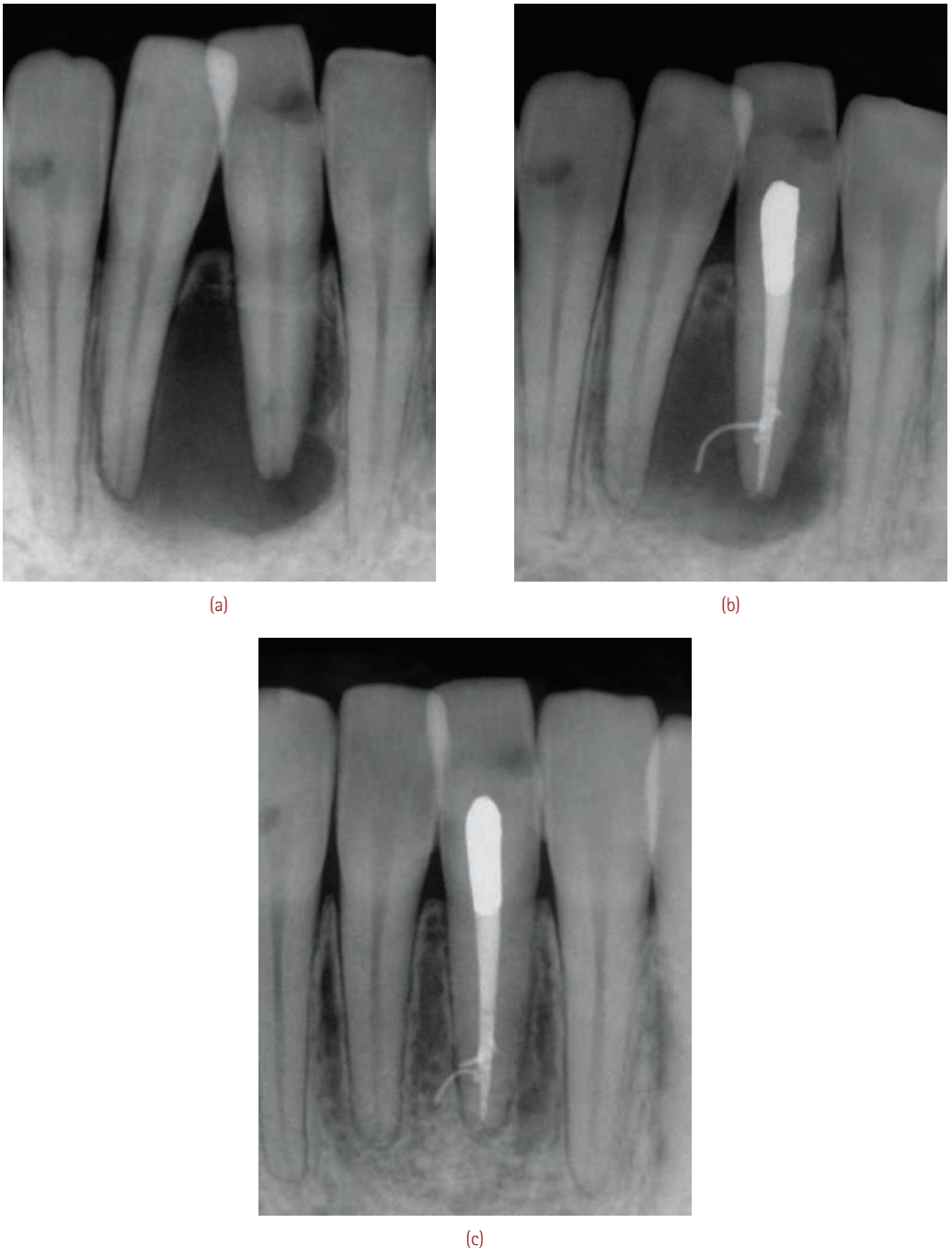


Figure 15.19 (a) Preoperative view: large periradicular lesion in mandibular central incisor. (b) Intracanal medication with calcium hydroxide medicament followed by subsequent obturation. (c) Follow-up X-ray demonstrating resolution of the periradicular lesion.

RECOMMENDED MATERIALS

- **Cavit-G** (ESPE, Seefeld, Germany) (**Fig. 15.20a**) is a premixed temporary filling material. It contains zinc oxide, calcium sulfate, zinc sulfate, glycoacetate, polyvinyl acetate resin, and triethanolamine. The hydrophilic nature of calcium sulfate allows absorption of moisture followed by expansion providing a superior seal. Care must be taken that there is a minimum thickness of at least 3.5 mm of the filling material.
- **IRM** (Dentsply International, Caulk Division, USA) (**Fig. 15.20b**) is a temporary filling material in a liquid and powder form that requires mixing. It is resin-reinforced zinc oxide–eugenol cement. Although the seal is inferior to that of Cavit, IRM is a recommended filling material in

Box 15.9

Ideal Requirements of a Temporary Filling Material

- Be impervious to fluids of the mouth and bacteria
- Hermetically seal the access cavity peripherally
- Not cause pressure on the dressing during insertion
- Harden within a few minutes after insertion
- Withstand the forces of mastication
- Be easy to manipulate and to remove
- Harmonize with the color of tooth structure



(a)

(b)

Figure 15.20 (a) Cavit-G. (*Courtesy: ESPE*). (b) IRM. (*Courtesy: Dentsply DeTrey.*)

areas under higher occlusal forces. The compositions of Cavit and IRM are given in **Box 15.10**.

- **TERM** (Dentsply International, Caulk, USA) is a composite resin interim filling material containing UDMA resin polymer, inorganic fillers, pigments, and initiators. The filling sets under visible light curing. It has an ability to provide good seal even in shallow filling depths of 1–2 mm.

Box 15.10

Composition of Cavit and IRM Temporary Restorative Materials

Cavit-G

- Zinc oxide
- Calcium sulfate
- Zinc sulfate
- Glycol acetate
- Polyvinyl acetate resins
- Polyvinyl chloride acetate
- Triethanolamine
- Pigments

IRM

- Powder
  - Zinc oxide
  - Polymethyl methacrylate (PMMA) powder
  - Pigment
- Liquid
  - Eugenol
  - Acetic acid

The clinician should be aware of the fact that all these materials are intermediate in nature and *leak invariably when left for more than 3 weeks*. Care must be taken to replace or complete the endodontic treatment before this critical period.

Two kinds of temporary seals are frequently used:

1. The *double seal* consists of a cotton pellet sealed in the pulp chamber by an inner seal of temporary stopping and an outer seal of Cavit or IRM cement.
2. The *single seal* consists of a medicated cotton pellet in the pulp chamber covered by another dry cotton pellet and sealed with Cavit or IRM cement.

Clinical Note

- Zinc oxide–eugenol cements were the most commonly employed temporary filling materials. Nevertheless, they are not the most ideal temporary filling materials as they are prone to leakage.
- Intracanal medicament dressings should preferably be renewed in a week and *not longer than 2 weeks* because dressings become diluted by periradicular exudate and are decomposed by interaction with the microorganisms.
- The ideal thickness of a temporary filling material should be *3–5 mm*.

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16 Obturation of the Radicular Space

Perfection is not attainable, but if we chase perfection we can catch excellence.
—Vince Lombardi

Definition: According to the American Association of Endodontists, *"Obturation is the method used to fill and seal a cleaned and shaped root canal using a root canal sealer and core filling material."*

The function of a root canal filling is to obturate the canal and eliminate all portals of entry between the periodontium and the root canal. The better the seal, the better the prognosis of the tooth. Achieving the ideal seal, however, is as complex as the anatomy of the root canal system itself. Because all root canal fillings must seal all foramina leading into the periodontium, an ideal filling must be well compacted, must conform and adhere to the shaped canal walls, and must end at the juncture of the root canal and the periodontium (**Box 16.1**).

Clinical Note

- Naidorf has stated that inadequate obturation of the root canal exposes it to periradicular tissue fluids, which provide material for growth of microorganisms or localization of bacteria in such dead spaces.
- According to a study by Ingle and Beveridge, 58% of endodontic failures can be attributed to incomplete obturation of root canals (**Fig. 16.1**).

Box 16.1

Grossman's Requirements for an Ideal Root Canal Filling Material

- The material should be easily introduced into the root canal.
- It should seal the canal laterally as well as apically.
- It should not shrink after being inserted.
- It should set slowly.
- It should be impervious to moisture.
- It should be bactericidal or, at least, should discourage the growth of bacteria.
- It should be radiopaque.
- It should not stain the tooth structure.
- It should not irritate periradicular tissues or affect the tooth structure.
- It should be sterile, or easily and quickly sterilized immediately before insertion.
- It should be easily removable from the root canal if necessary.

WHEN TO OBTURATE THE ROOT CANAL

A root canal may be obturated when the tooth is asymptomatic and the root canal is reasonably dry. Obturation after obtaining a negative culture and closure of an existing sinus tract have been suggested in the past. However, this concept is *no longer valid*. The clinical criteria for deciding the timing of



(a) (b)

Figure 16.1 (a) Incomplete shaping, cleaning, and obturation of a tooth leading to endodontic failure. (b) Proper shaping and cleaning of the root canals followed by a complete obturation ensures endodontic success.

Box 16.2

Clinical Criteria for Timing of Obturation

- Optimal shaping and cleaning of the canal can be easily achieved in a *single sitting in a tooth with vital pulp tissue*.
- Extra care and attention should be given while cleaning a canal with *necrotic and infected pulp*.
- The canal should be reasonably dry after completion of shaping and cleaning protocols, with *no "weeping" of fluids* in the form of bleeding or discharge of serous fluids. When seepage into the root canal is excessive, it can be treated and eliminated by reinstrumentation and enlarging the canal, and irrigating and sealing it with an intracanal medicament, such as calcium hydroxide paste.
- Failure of treatment is more common in teeth with *pre-existing periradicular radiolucency* than in teeth with no periradicular changes. Stringent shaping and cleaning protocols should be adhered to in such cases before deciding the timing of the obturation.
- In a multisitting root canal therapy case, care should be taken to ensure that there is *no breakdown or leakage of the temporary filling material* during the obturation visit.

Box 16.3

Clinical Criteria for Length of Obturation

- Kuttler demonstrated the following key observations:
  - The exit of the root canal (referred to as *major diameter*) should be around 0.5 mm short of the narrowest part of the root canal (referred to as *minor diameter or apical constriction*).
  - The minor diameter to major diameter distance *increases with age* due to the deposition of cementum.
  - The major diameter is not present at the anatomical apex of the canal and is deviated by more than 0.5 mm in 90% of cases.
  - The anatomical apex, radiographic apex, major diameter, and minor diameter (apical constriction) are not present at the same position.
- As the minor diameter is the narrowest part of the root canal closest to the exit of the canal, it is clinically recommended to limit the length of the obturation to this point. Refer **Box 14.3**; **Figs 14.22** and **14.23** for better understanding of this concept.
- The location of the minor diameter or apical constriction needs to be ascertained by a combination of using radiographs, electronic apex locator, and clinical judgment of the clinician.
- Hence, the most commonly recommended protocol for estimating the length of the obturation is as follows:
  - Using the reading of the *electronic apex locator*
  - To a distance of approximately *1 mm short of the radiographic apex* as determined by the IOPA radiograph
  - Combination of *both* of the above-mentioned techniques to improve the clinical decision making

obturation and length of obturation are given in **Boxes 16.2** and **16.3**, respectively.

SOLID CORE OBTURATING MATERIALS

Classification of obturating materials is provided in **Box 16.4**.

Box 16.4

Classification of Endodontic Obturating Materials

I. Historical solid core obturating material
   1. Silver points
II. Currently available solid core obturating materials
   1. Gutta-percha
   2. Mineral trioxide aggregate (MTA)
   3. Resilon

I. HISTORICAL SOLID CORE FILLING MATERIALS

Silver Points

Silver points were introduced in dentistry by Jasper in 1933 and have been used to fill root canals historically (**Fig. 16.2**). A silver point is stiffer than gutta-percha and can be easily inserted into a fine, tortuous canal.

However, silver points *are no longer recommended* in endodontic practice for the following reasons:

- Silver points are rigid and do not adapt to the internal anatomy of the root canal. Hence, the *canal is inadequately obturated* or filled mostly with sealer when a silver point is employed.
- Silver points start *corroding* when they come into contact with saliva or periradicular fluids. The corrosion products are toxic and lead to the failure of the endodontically treated teeth.



Figure 16.2 Silver points. (*Courtesy: Patterson Dental.*)

II. CURRENTLY USED SOLID CORE FILLING MATERIALS

1. Gutta-Percha

History

- *Hill (1847)*: Developed gutta-percha root canal filling known as "Hill's stopping"
- *Bowman (1867)*: Demonstrated the use of gutta-percha root canal filling
- *S.S. White Company (1887)*: Manufacture of gutta-percha points

Over the years, many different filling materials have been used to seal root canals. None have proved to possess all the ideal characteristics. Currently, gutta-percha is the most popular obturating material used in endodontics.

Composition

See **Box 16.5**.

Characteristics

- Gutta-percha is a rigid natural latex produced from the sap of rubber trees of genus *Palaquium gutta*.
- It is a *trans*-isomer of polyisoprene and exists in *alpha* (α) and *beta* (β) crystalline forms. The material is solid in the beta phase and does not shrink.
- On heating the material, the beta phase changes into the alpha phase which is tacky and flowable under pressure. The thermoplasticized alpha phase shrinks as it sets into a solid mass.
- The solid mass alpha-phase gutta-percha melts at a temperature above 65°C and turns into the beta phase on slow cooling. This exhibits less shrinkage and more dimensional stability than when the beta phase is heated.

Properties

Gutta-percha is a desirable filling material because of the following reasons:

- It does not shrink after insertion unless it is plasticized with a solvent or heat.
- It is easily sterilized prior to insertion and does not encourage bacterial growth.
- It is radiopaque, nonstaining, and impervious to moisture.
- It can be removed easily from the root canal if necessary.
- It is probably the least toxic and least irritating root canal filling material.

Box 16.5

Composition of Gutta-Percha Cones according to Friedman

- *20%:* Gutta-percha—matrix
- *65%:* Zinc oxide—filler
- *10%:* Heavy-metal sulfates—radiopacifier
- *5%:* Waxes or resins—plasticizer

Sizes and Tapers

Gutta-percha is available in *conventional* and *standardized* sizes.

The conventional sizes (**Fig. 16.3a**) include the following:

- Extra fine
- Fine
- Medium fine
- Fine medium
- Medium
- Large
- Extra large

The standardized sizes are designed to match the size and taper of the corresponding stainless steel or nickel–titanium instruments employed for shaping the canals:

- ISO 2% from size Nos. 15 to 140 (**Fig. 16.3b**)
- Greater taper gutta-percha cones such as 4 or 6% tapered (**Fig. 16.3c**)
- Variable taper gutta-percha points suiting the taper of variable taper shaping instruments such as the ProTaper F1, F2, and F3 (**Fig. 16.3d**)

Gutta-percha is also available as pellets that are used in thermoplastic obturation systems (to be explained later in this chapter).



Clinical Note

- Alpha-phase gutta-percha is more commonly employed in thermoplasticized techniques, while beta-phase gutta-percha is more popular in lateral condensation techniques.
- Due to the poor sealing property of gutta-percha, regardless of technique, it must be combined with a root canal sealer to ensure proper filling and sealing of the root canal.
- Gutta-percha sterilization—as the gutta-percha points cannot be heat sterilized, sterilization is recommended prior to use by *placing in 5.25% NaOCl for 1 minute.*

2. Mineral Trioxide Aggregate (MTA)

MTA can be used as a canal obturation material because of its superior physiochemical and bioactive properties.

Indications

According to Bogen et al., following are the indications for employing MTA as an obturating material:

- MTA obturation combined with root-end resection
- Teeth with open apices
- Retreatment with MTA obturation
- Internal resorption
- Dens in dente

Limitations

- Difficulty in retreatment following MTA obturation, especially in curved canals
- Potential for discoloration, especially when used in the anterior esthetic zone



Figure 16.3 (a) Conventional gutta-percha points (M, medium; FM, fine medium; F, fine; MF, medium fine; FF, fine fine). (b) ISO 2% tapered gutta-percha points. (*Courtesy: Diadent.*) (c) Greater taper gutta-percha cones. (*Courtesy: Meta Biomed.*) (d) Variable taper gutta-percha points. (*Courtesy: Dentsply Sirona.*)

3. Resilon

Resilon (Epiphany by Pentron Clinical Technologies or Real Seal by SybronEndo) is a high-performance polyurethane introduced as an alternative to gutta-percha.

Composition of Resilon

- It is a polycaprolactone core material with difunctional methacrylate resin, bioactive glass, bismuth and barium salts as fillers, and pigments.
- A resin sealer is always employed with the core filling material for obturation (**Fig. 16.4**).

Protocol for Use

- This system can be placed using lateral compaction, warm vertical compaction, or thermoplastic injection. The core material is available in the form of ISO-sized points and pellets for use with Obtura III (Obtura Spartan).
- *Resilon requires 150°C temperature for thermoplasticized techniques which is less when compared to the 200°C temperature required by normal gutta-percha.*
- Studies show that Resilon with Epiphany sealer and thermoplasticized gutta-percha with epoxy resin sealer have comparable sealing ability.
- Tay et al. evaluated the susceptibility of this material to hydrolytic enzymes and concluded that biodegradation of Resilon by bacterial and salivary enzymes needed further investigation.

Clinical Note

Currently, Resilon cannot be considered as a replacement for gutta-percha, due to the lack of long-term clinical outcome studies to demonstrate the clinical superiority of Resilon over gutta-percha.

GUTTA-PERCHA OBTURATION TECHNIQUES

Many methods are used to obturate the root canal with gutta-percha and a sealer. Some methods are old and tested, while the others are new, innovative, and awaiting final judgment. The techniques of gutta-percha obturation are given in **Box 16.6**.



Figure 16.4 Resilon (Real Seal System). (*Courtesy: SybronEndo.*)

Box 16.6

Techniques of Obturation

1. Cold lateral compaction
   a. Single-cone obturation technique
2. Warm compaction (warm gutta-percha)
   a. Warm vertical compaction technique
   b. Warm lateral compaction technique
3. Continuous wave compaction technique
4. Thermoplasticized gutta-percha injection
5. Carrier-based gutta-percha
   a. Thermafil thermoplasticized technique
   b. Guttacore thermoplasticized technique
   c. SimpliFill sectional obturation technique
6. McSpadden thermomechanical compaction technique
7. Chemically plasticized gutta-percha obturation technique
8. Custom cone obturation technique

All the methods use the physical characteristic of gutta-percha called property of *plasticity* or *flow*. Plasticity is inversely related to viscosity and can be defined as the ability to deform and to flow away from a force directed at its mass.

Each technique is designed to force the gutta-percha filling to flow into the root canal, compress against its walls, fill fine tortuous canals, seal the various foramina exiting into the periodontium, and, finally, compact into a solid core filling. The cold lateral compaction method of filling uses spreaders by inserting these instruments alongside the gutta-percha and compressing them laterally and apically.

Clinical Note

- All obturation techniques consist of using a solid core obturation material (usually gutta-percha that is used in either solid form or thermoplasticized form) in conjunction with a root canal sealer.
- Thermoplastic techniques use more heat to increase the plasticity of gutta-percha and thereby enable the operator to fill the root canal three dimensionally.

I. COLD LATERAL COMPACTION TECHNIQUE

This has been one of the most commonly practiced obturation techniques (**Fig. 16.5**). However, in contemporary endodontics, it is not the best technique to achieve a three-dimensional seal. The stepwise technique is given in **Box 16.7**.

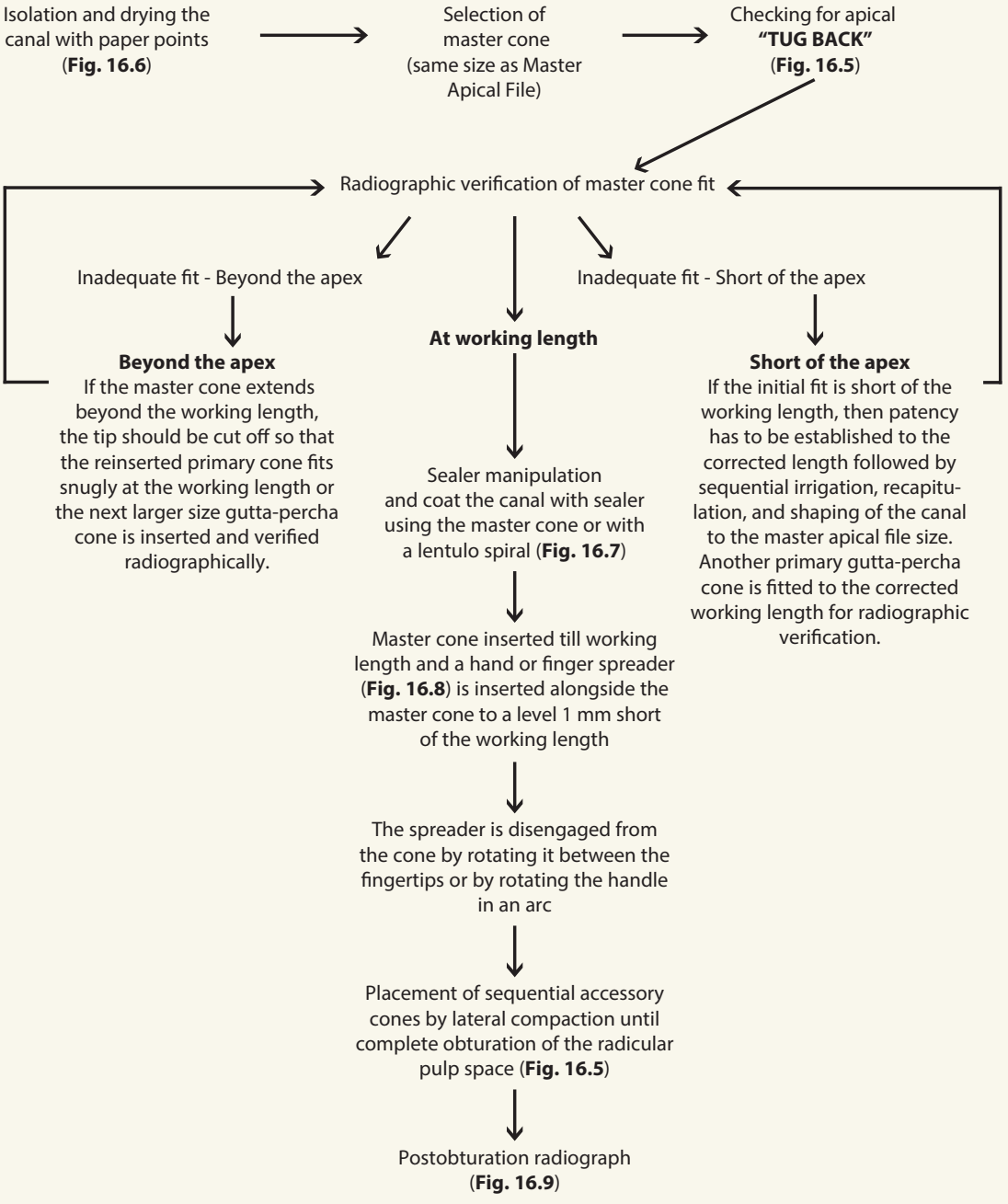
Clinical Considerations

- *Sealer considerations:* The root canal is first dried with absorbent paper points (**Fig. 16.6**) prior to the application of the root canal sealer. Sealer application on the canal walls can also be performed using a Lentulo spiral (**Fig. 16.7**) or with the master gutta-percha cone itself.
- *Spreader considerations (**Figs 16.8** and **16.9**)*
  - The size of the spreader is determined by the width of the prepared canal and the lateral fit of the primary cone; the greater the space between the canal wall and the butt end of the gutta-percha, the larger (wider) the spreader used.
  - The spreader size should reach within 1–2 mm of the working length in order to obtain optimal apical compaction. This can be ensured by placing a silicon stopper on the spreader.
- *Master cone considerations*
  - Selection of the master cone gutta-percha should be similar to the master apical file (MAF) size.
  - Minimal judicious force should be used on the spreader during the compaction process in order to avoid root fractures.
  - Additional secondary gutta-percha cones are inserted until the spreader cannot be reinserted, an indication that the root canal is fully compacted laterally.
  - A cement coating is not mandatory for secondary cones.

Several radiographs must be taken while one obturates the canal to check the accuracy of the procedure. The fit of the primary cone is verified by radiograph. Another radiograph should be taken when two or three secondary cones have been condensed in the root canal to determine the amount of flow and to avoid overfilling. Adjustment can still be made

Box 16.7

Technique of Cold Lateral Compaction



and the gutta-percha cone retrieved if overfilling occurs or if the primary cone does not flow to the apical foramen.

After verifying the fit of the obturated canal by radiograph, the butt end of the gutta-percha in the pulp chamber is cut off with a hot instrument, the chamber is cleaned, and a restoration is placed in the access cavity.

Limitations

- The presence of voids in between the filling
- An increased sealer:gutta-percha ratio when compared with the thermoplasticized techniques
- Studies have also shown that warm compaction techniques have a better ability to seal intracanal defects and lateral canals than cold lateral compaction

1. Single-Cone Obturation Technique

- Single-cone obturation technique is a commonly employed technique. This technique uses a single cone of gutta-percha

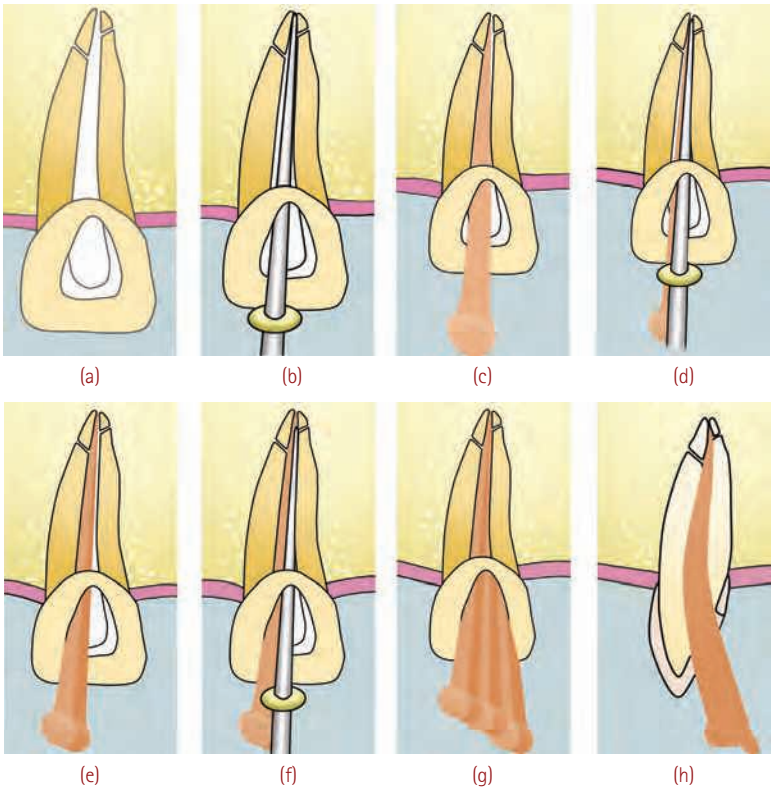


Figure 16.5 Cold lateral compaction technique: (a) Root canal after completion of cleaning and shaping. (b) Checking the fit of the spreader to be within 1 mm of the working length. (c) Placement of the master cone. (d) Placement of spreader alongside the master cone to a length 1 mm short of the master cone to compact the apical part of the cone. (e–h) Lateral compaction of additional cones sequentially.



Figure 16.6 Absorbent paper points. (*Courtesy: Meta Biomed.*)

that is of similar tip diameter and taper of the last shaping file used (MAF). The root canal is obturated with a single cone of gutta-percha along with an appropriate sealer.

Rationale

- The introduction of Ni-Ti shaping systems has led to the introduction of gutta-percha points that are matched in both tip diameter and taper to various MAF sizes that each rotary/reciprocal shaping system provides.
- Currently, gutta-percha points of ISO 20, 25, 30, and above sizes are available in not only 2% taper but also in 4 and 6% tapers (**Fig. 16.3c**).
- Variable taper rotary Ni-Ti systems (such as ProTaper Gold and Trunatomy) and variable taper reciprocal systems (such as Wave One Gold) provide clinicians with matching variable tapered gutta-percha points (**Fig. 16.3d**).

Clinical Note

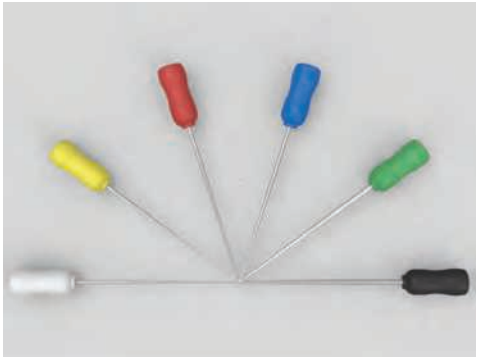
The single-cone obturation technique is frequently used by clinicians who use calcium silicate–based sealers (CSBS). This technique can also be used with other sealers such as Zinc oxide–eugenol-based sealers and epoxy resin–based sealers.



Figure 16.7 Lentulo spiral.



(a)



(b)

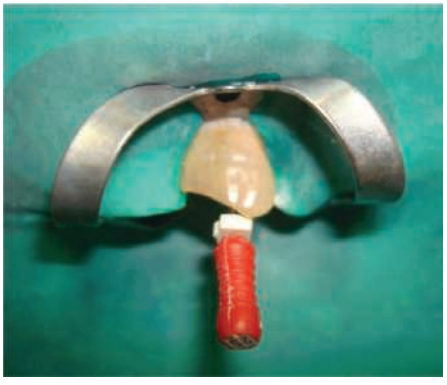
Figure 16.8 (a) Hand spreader. (b) Finger spreader.



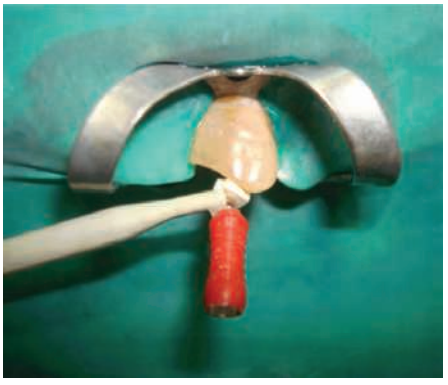
(a)



(b)



(c)



(d)

Figure 16.9 Cold lateral compaction technique: (a and b) Maxillary incisor requiring endodontic therapy. (c and d) Working length determination using an apex locator. *(continued)*

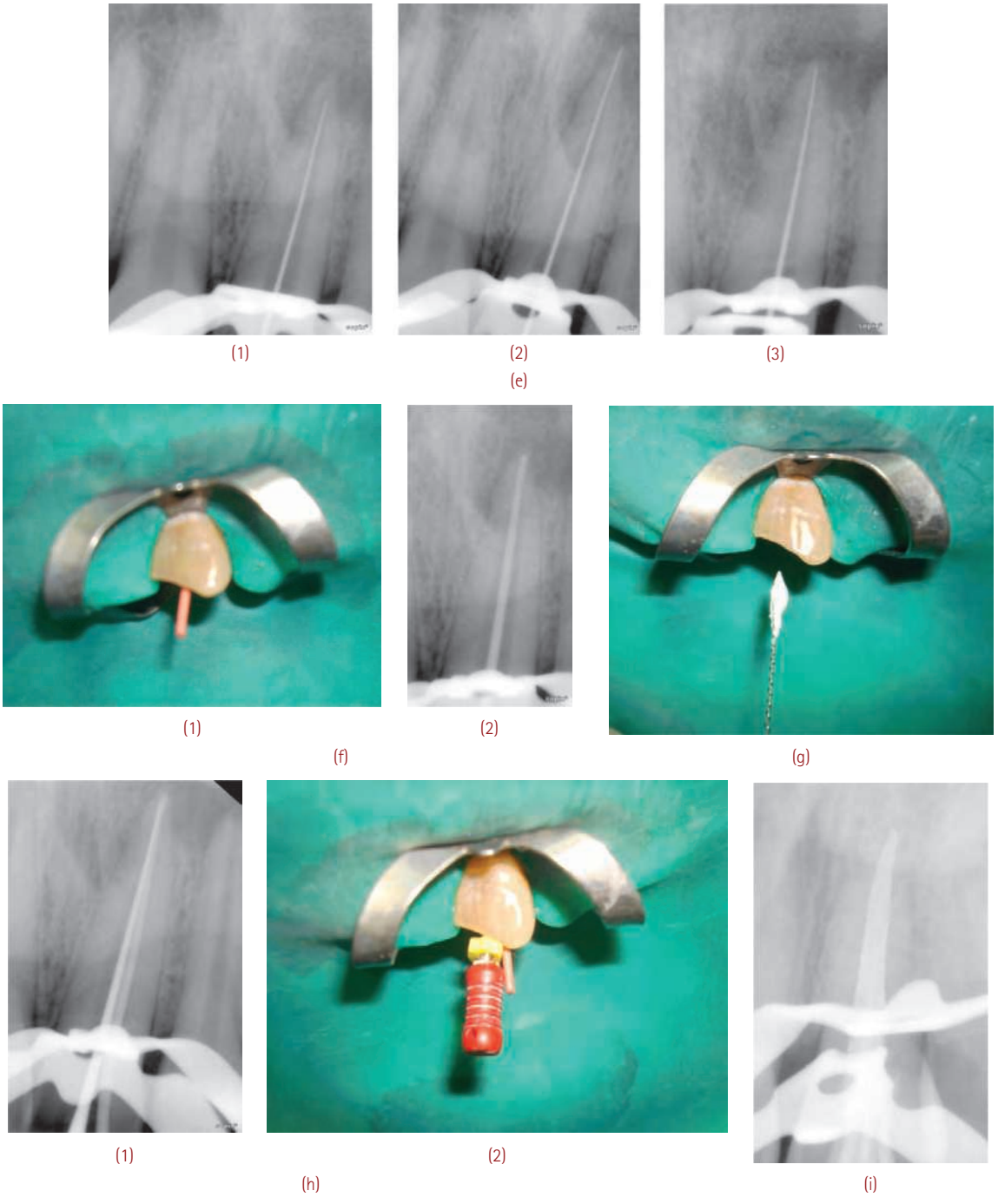


Figure 16.9 *(continued)* (e) (1) Working length 1 mm short of the apex, (2) working length 1 mm beyond the apex, and (3) working length 0.5 mm short of the apex. (f) Master cone radiograph. (g) Sealer placement with the help of a Lentulo spiral. (h) (1 and 2) Placement of initial spreader 1 mm short of the master cone. (i) Secondary gutta-percha cones inserted to fill the root canal laterally.

II. WARM COMPACTION METHOD (WARM GUTTA-PERCHA)

1. Warm Vertical Compaction

Principle

The warm vertical condensation or "warm gutta-percha" technique of filling root canals was introduced by ***Schilder*** with the objective of filling the main root canal as well as lateral and accessory canals. Using heated pluggers, one applies pressure in a vertical direction to the heat-softened gutta-percha and thereby causes it to flow and to fill the entire lumen of the canal (**Fig. 16.10**).

Schilder described the steps in shaping and cleaning of the root canal in preparation for obturation by the warm vertical compaction method. (Refer **Table 14.1**.)



Figure 16.10 Hand pluggers for warm vertical compaction (warm gutta-percha) technique. The condensers are graduated in size and have markings to judge the depth of penetration into the root canal.

Indications

- As an alternative to the cold lateral compaction technique
- When the fitting of a conventional master cone to the apical portion of a canal is impossible, as when there is a ledge formation, perforation, or unusual canal curvatures, internal resorptions, or large lateral canals

Technique

The steps in warm vertical compaction are as follows (**Fig. 16.11**):

- A primary nonstandardized or greater taper gutta-percha cone corresponding to the last instrument (MAF) used is fitted in the canal in the usual manner.
- The canal wall is coated with a thin layer of root canal sealer.
- The primary gutta-percha cone or master cone is inserted up to the working length.
- The coronal end of the cone is cut off with a heated instrument.
- Warm vertical compaction technique can be divided into two clinical steps:
  - *Step 1:* Down packing
    - A *"heat carrier,"* such as a root canal plugger (**Fig. 16.10**), is heated to redness and is immediately pushed into 3–4 mm of the coronal third of the gutta-percha. An alternative is to employ electric heat carriers (Down Pack systems) such as Touch n Heat (SybronEndo; **Fig. 16.12a**) or B&L Alpha 2 (B&L Biotech; **Fig. 16.12b**) as they permit temperature control of the heat carrier instrument.
    - The heat carrier is deactivated and removed after a pause of 2–3 seconds inside the canal. The sheared gutta-percha gets removed along with the heat carrier.

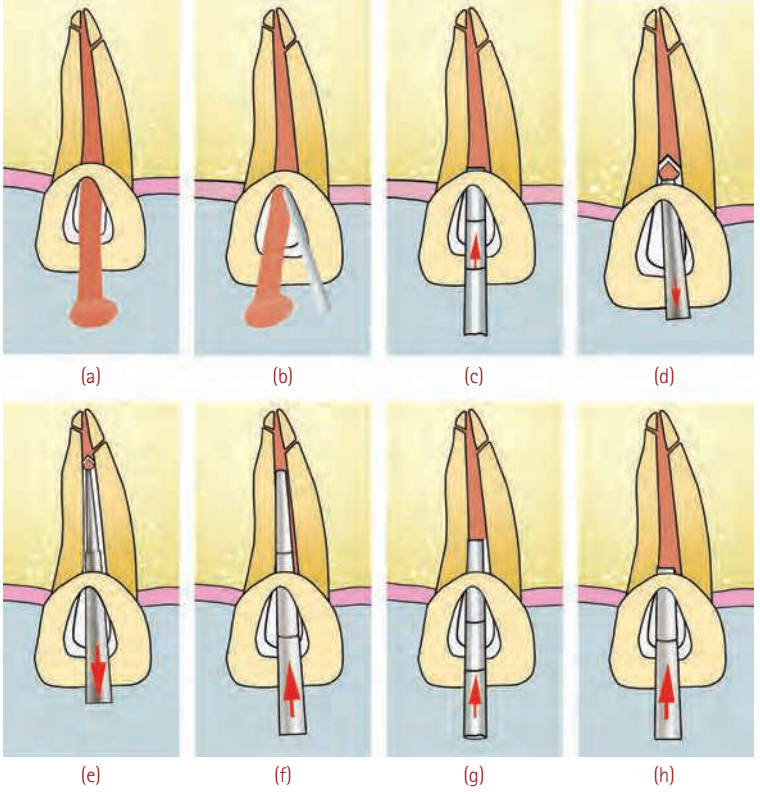


Figure 16.11 Warm vertical compaction technique: (a and b) Master cone adaptation in the prepared root canal. (c) Severing of the coronal portion of the master cone with a heated instrument. (d) Compaction of the master cone. (e) Sequential segments removed with the heat carrier followed by compaction. (f–h) Once the apical third is reached, the canal is backfilled with heated segments of gutta-percha followed by compaction with suitable pluggers.



(a) (b)

Figure 16.12 Electric heat carriers (Down Pack systems). (a) Touch N Heat heat carrier. (*Courtesy: SybronEndo.*) (b) B&L Alpha2. (*Courtesy: B&L Biotech.*)

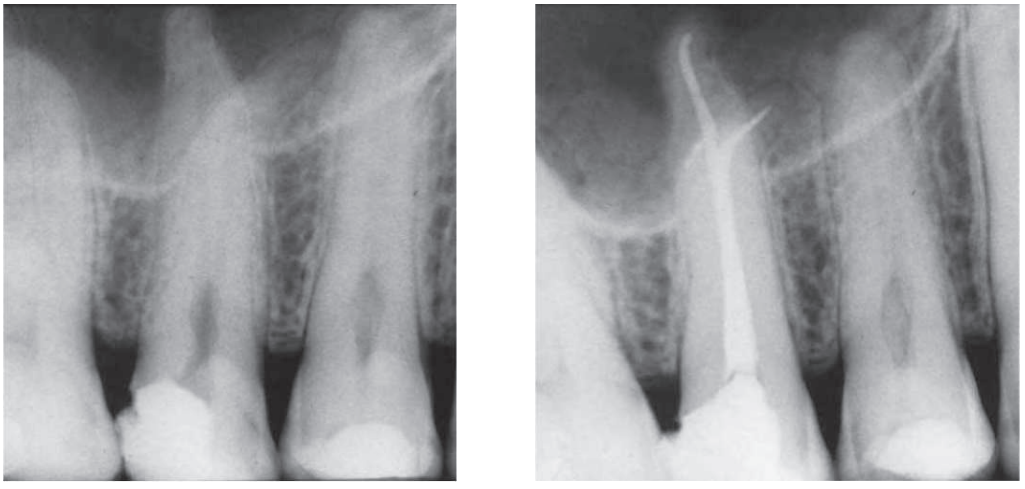
- A *vertical prefitted condenser or plugger* of suitable size (**Fig. 16.10**) is inserted, and vertical pressure is applied to the heated gutta-percha to force the plasticized material apically.
- The heat carrier is now again activated and placed to a further distance of 3–4 mm into the remaining gutta-percha. This is again followed by pausing and removing another segment of gutta-percha followed by compacting the remaining gutta-percha with the next narrower sized plugger as we proceed apically.
- This process of *"down packing"* or compacting of thermoplasticized gutta-percha segmentally using the alternate application of heat carrier and condenser is repeated until the smallest plugger compacts the gutta-percha to about *5 mm distance from the working length.*
- Care should be taken to *not remove the apical 5 mm of gutta-percha* during the down-packing procedure for the following reasons:
  - The apical "cold" gutta-percha prevents the inadvertent extrusion of the thermoplasticized gutta-percha beyond the working length.
  - The apical pressure created with the down packing to 5 mm short of working length is sufficient to seal the larger accessory canals and fills the lumen of the canal in three dimensions up to the apical foramen.
  - Thermal injuries to the periradicular tissues are prevented by limiting the depth of the heat carrier to 5 mm short of the working length.

– *Step 2:* Back filling
- Once the down packing is completed, the next step is to fill the remaining canal with thermoplasticized gutta-percha. This can be achieved in two ways:
  - *Schilder technique:* The remaining portion of the canal is plugged with additional pieces of gutta-percha that is heated with the heat carrier and then compacted with appropriate-sized pluggers (**Fig. 16.10**).
  - *Thermoplastic backfill technique:* This can be achieved with devices (**Fig. 16.13a–16.13c**) that heat gutta-percha to a specific temperature and allow the operator to extrude the thermoplastic gutta-percha into the canal apico-coronally. Once you fill 3–4 mm of the canal, the backfill device is



(a) (b) (c)

Figure 16.13 Thermoplastic backfill obturation systems. (a) Obtura III thermoplasticized injection technique. (*Courtesy: Obtura Spartan.*) (b) Beta 2. (*Courtesy: B&L Biotech.*) (c) Elements Free Obturation System. (*Courtesy: SybronEndo.*)



(a) (b)

Figure 16.14 Warm vertical compaction obturation in a maxillary premolar.

removed and the plugger is used to compact the gutta-percha. This is repeated till you completely obturate the canal till the canal orifice (**Fig. 16.14**).

Popular backfill devices include Obtura III (Obtura Spartan), Elements Free Obturation System (SybronEndo), and B&L Beta (**Fig. 16.13a–16.13c**).

Advantages

- Excellent seal of the canal apically and laterally
- Obturation of the larger lateral and accessory canals

Disadvantages

- The amount of time it takes
- The risk of vertical root fracture resulting from undue force
- Periodic overfilling with gutta-percha or sealer that cannot be retrieved from the periradicular tissues

Clinical Note

- Heating gutta-percha to 200°C in warm vertical compaction technique does not exceed the critical external root surface temperature and hence is considered to be a safe technique.
- An increase of 10°C at the root surface for a period of more than 1 minute is required to produce irreversible bone damage.

2. Warm Lateral Compaction

This technique provides the advantages inherent to thermoplastic techniques as well as length control during obturation. The technique involves placement of the master cone and lateral compaction using heat carriers such as *Endotec II tips* (Medidenta) and *EndoTwinn tips* (Hu-Friedy).

The device is placed beside the master cone and activated followed by placement of an unheated spreader in the space previously occupied by the heat carrier. Accessory cones are then placed and the process is repeated until the canal is filled.

III. CONTINUOUS WAVE COMPACTION TECHNIQUE

Principle

This is a variation of the warm vertical compaction technique introduced by Buchanan. The technique employs the use of gutta-percha cones and pluggers that mimic the tapered preparation, thereby permitting the application of greater hydraulic force during warm compaction (**Fig. 16.15**).

Clinical Technique

Continuous wave compaction uses tapered nickel–titanium systems to prepare the canal. Pluggers are selected in consistence with the size of the shaping instruments used. Tapered pluggers #.06, #.08, #.10, and #.12 with a tip diameter similar to the tapered gutta-percha points, respectively, are employed (**Fig. 16.16**). The procedure is carried out with an electric heat carrier system (**Fig. 16.12**).

IV. THERMOPLASTICIZED GUTTA-PERCHA INJECTION TECHNIQUES

Principle

This technique comprises a pressure apparatus consisting of an insulated electrically heated syringe barrel and a selection of needles ranging from 18 to 25 gauge size. The plunger is designed to prevent backward flow of the gutta-percha. The degree of heat is regulated to provide proper extrusion of the gutta-percha according to the size of the needle.

Technique

The thermoplastic backfill systems (**Fig. 16.13**) are used in this technique. They can heat the gutta-percha to 200°C. The canal preparation is similar to any other technique. After drying the canal, sealer is coated on to the canal walls. The

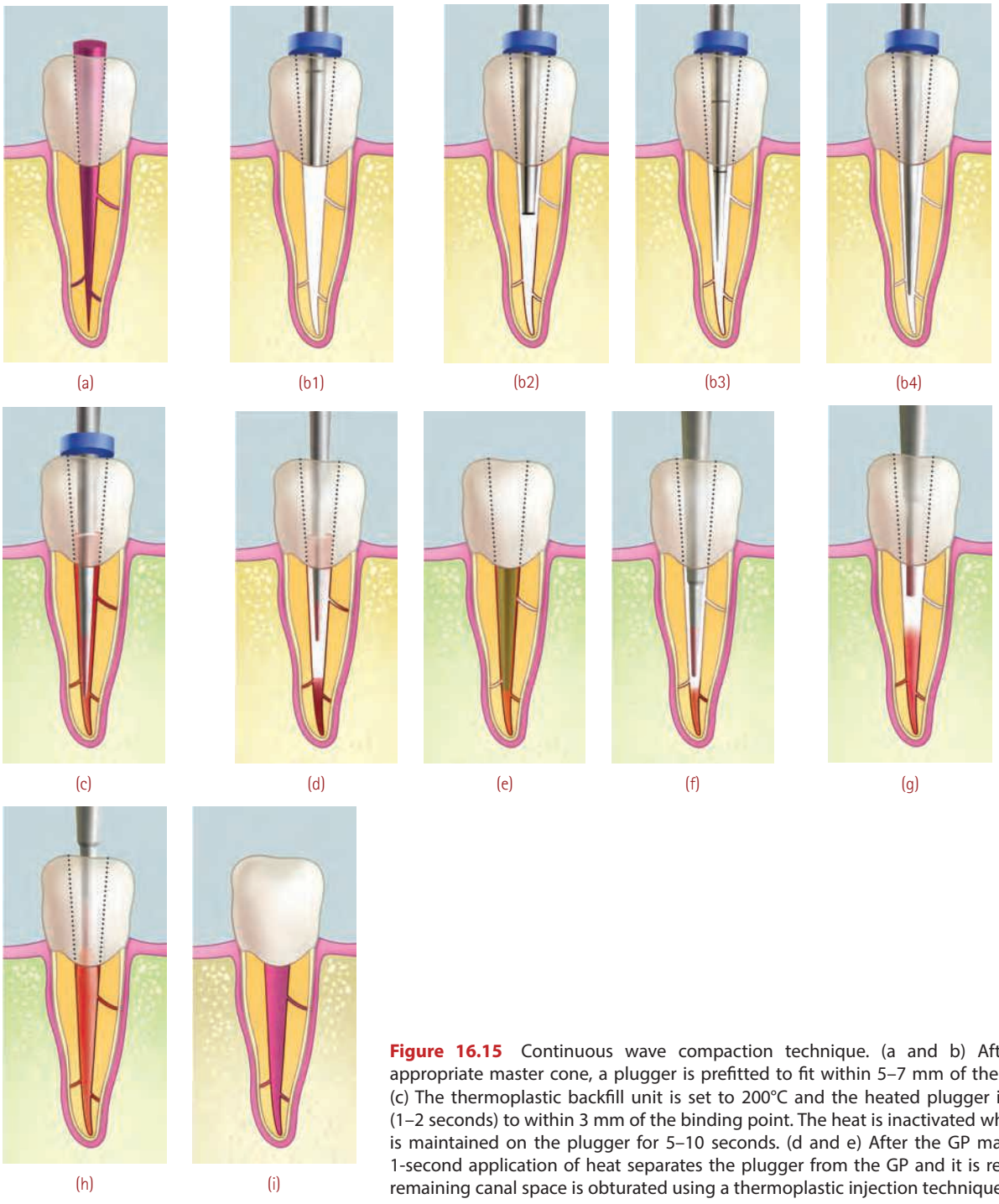


Figure 16.15 Continuous wave compaction technique. (a and b) After selecting an appropriate master cone, a plugger is prefitted to fit within 5–7 mm of the working length. (c) The thermoplastic backfill unit is set to 200°C and the heated plugger is moved rapidly (1–2 seconds) to within 3 mm of the binding point. The heat is inactivated while firm pressure is maintained on the plugger for 5–10 seconds. (d and e) After the GP mass has cooled, a 1-second application of heat separates the plugger from the GP and it is removed. (f–i) The remaining canal space is obturated using a thermoplastic injection technique.

gutta-percha is electrically heated in a handheld gun that contains a chamber surrounded by a heating element where the gutta-percha pellets are loaded.

A suitable gauge needle is selected to be positioned at *3–5 mm short of the working length*. Gutta-percha is gradually injected by squeezing the trigger of the gun and the needle is gradually withdrawn as the canal gets filled apically. The gutta-percha is then compacted using pluggers of appropriate size. The rest of the canal can be filled in one to two increments using the same technique (**Figs 16.17** and **16.18**).

In the injection method, the canal preparation is restricted apically with flaring of the body of the canal toward the access opening. Torabinajed and colleagues found that injection of plasticized gutta-percha from a pressure syringe produced satisfactory obturation as compared to cold lateral compaction.



Figure 16.16 Buchanan system B heat pluggers for warm vertical compaction. (*Courtesy: SybronEndo.*)

Limitations

- One common defect in all injection techniques is the *lack of precision* in delivering the gutta-percha near the apical foramen and not beyond, though it may fill the canal laterally in all its interstices. The injection technique relies on the heated and plasticized gutta-percha to flow apically with minimal compression, when compared to the force or pressure used in lateral and vertical compaction.
- Unless vertical pressure is combined with the injection method of obturation, the interface seal between the gutta-percha and the canal wall is weakened and voids occur in the final set filling.

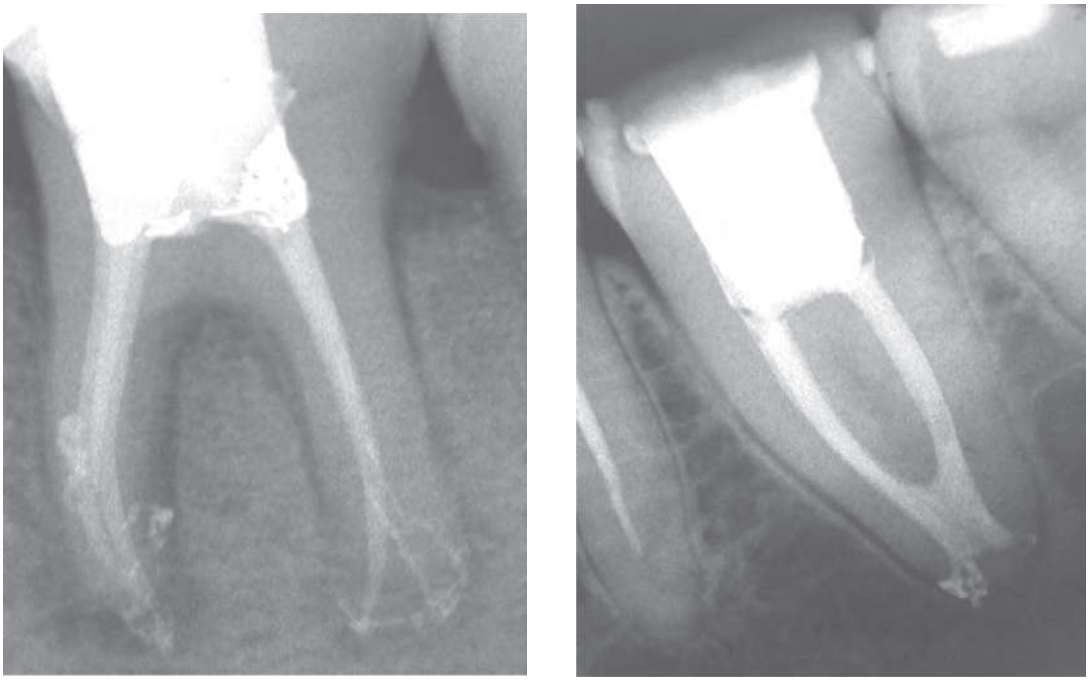
V. CARRIER-BASED GUTTA-PERCHA TECHNIQUES

1. Thermafil Thermoplasticized Technique

This technique was developed by Ben Johnson in 1978. Thermafil is a carrier-based gutta-percha obturation system comprising a plastic core carrier coated with alpha-phase gutta-percha. Thermafils are available in ISO standardized sizes as well as variable tapered sizes suitable for canals prepared with nickel–titanium tapered instruments (**Fig. 16.19**). These obturators are used in conjunction with a heating device known as the ThermaPrep Plus Oven (**Fig. 16.20l**).

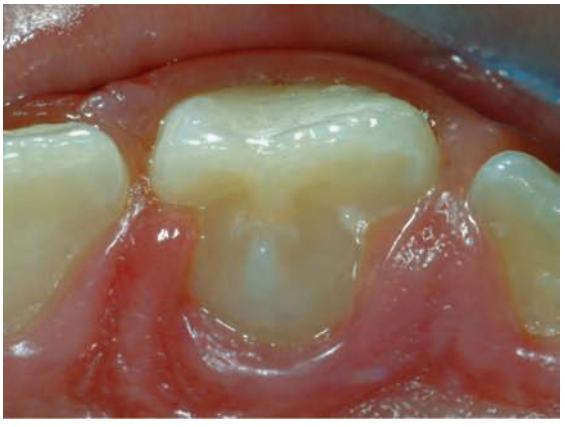
- After preparation of the canal with suitable instruments, the size of the canal is assessed with a Thermafil verifier instrument which helps in the selection of the appropriate-sized obturator.
- The canals are dried and a light coat of sealant is applied.
- The silicon stopper on the carrier is adjusted to the working length and the carrier is loaded into the ThermaPrep Plus Oven for approximately 10 seconds.
- The carrier is then inserted into the canal and placed up to the working length with a firm uniform apical pressure without rotating.
- The position of the carrier is verified radiographically and the gutta-percha is allowed to cool for 2–4 minutes before resecting the carrier at the level of the canal orifice.

This technique has been described in **Figure 16.20**.



(a) (b)

Figure 16.17 Mandibular molars obturated with thermoplasticized injection technique.



(a)



(b)



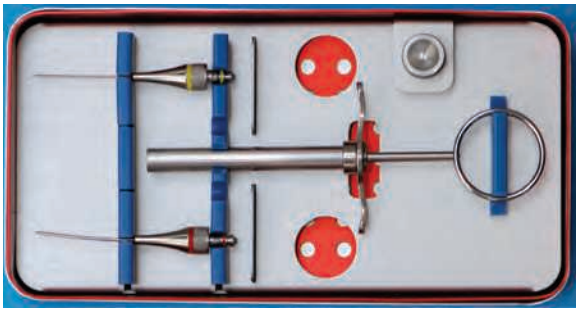
(c)



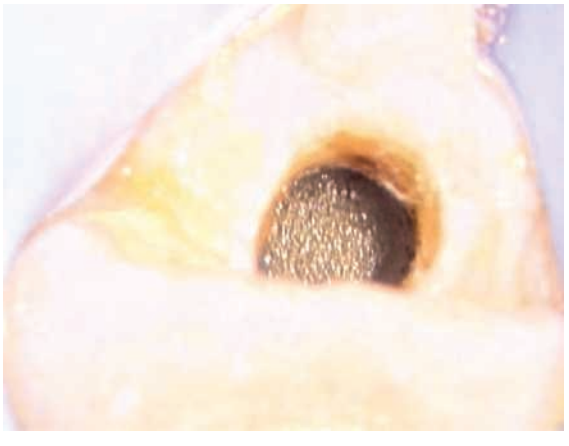
(d)



(e)



(f)

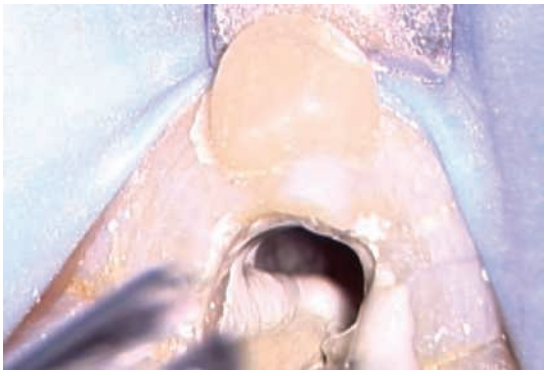


(g)

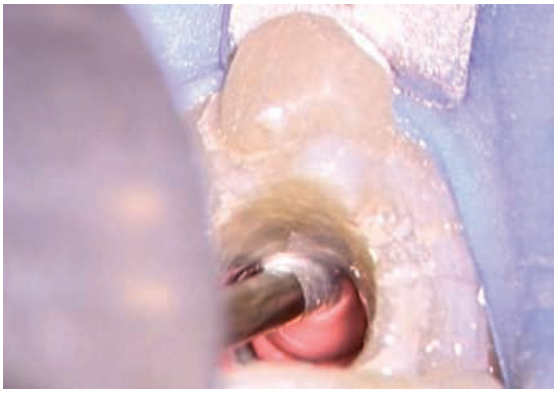


(h)

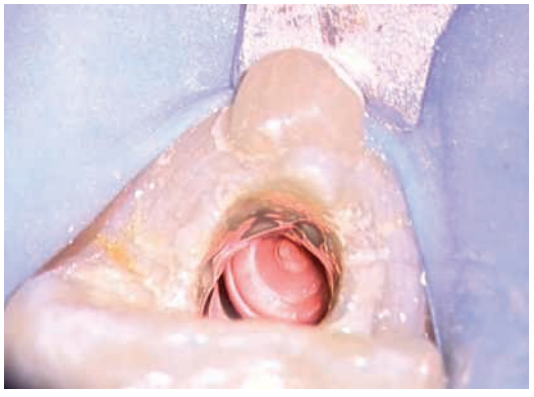
Figure 16.18 Obturation of a maxillary central incisor with a complex root canal anatomy with an MTA apical barrier and thermoplasticized injectable gutta-percha technique: (a) Clinical view of the crown of the maxillary right central incisor. (b) Preoperative radiograph. Note the periapical radiolucency, the unusual anatomy, and the wide open apex. (c) The main (central) root canal has been medicated with calcium hydroxide. (d) The calcium hydroxide has been removed and a thin layer of MTA has been used for the direct pulp capping of the pulp exposure of the distal canal. (e) The apical foramen as seen through the operating microscope (20×). (f) The MAP System, specifically designed carrier for placement of MTA (Quality Aspirators). (g) Three millimeters of MTA has been placed in the apical one-third of the canal. (h) Intraoperative radiograph. Note the thickness of MTA without any overfilling. *(continued)*



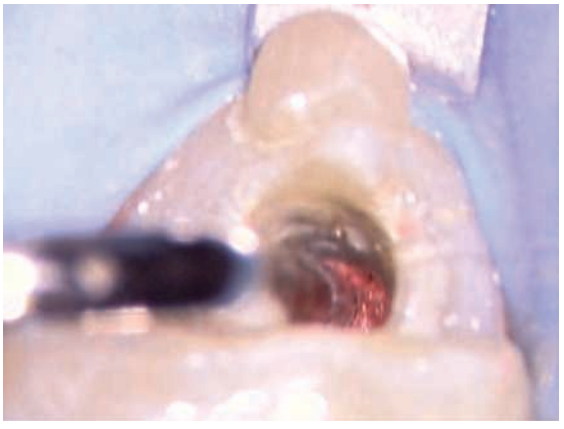
(i)



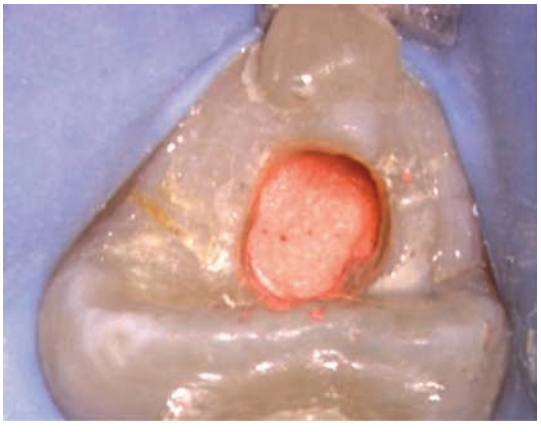
(j)



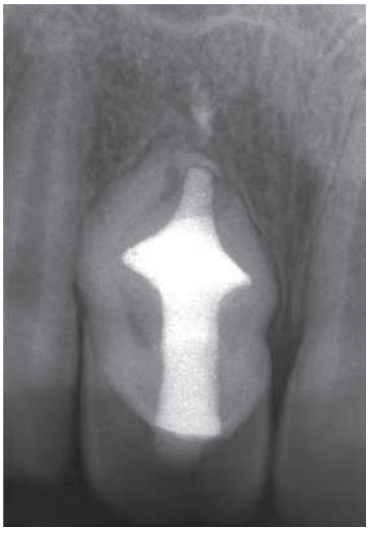
(k)



(l)



(m)



(n)

Figure 16.18 *(continued)* (i) The canal walls are coated with Kerr Pulp Canal Sealer carried with a paper point. (j–m) The canal is obturated with thermoplastic injectable gutta-percha. (n) Two-year recall radiograph. (*Courtesy: Arnaldo Castelluci, Italy.*)



Figure 16.19 Thermafil obturators. (*Courtesy: Dentsply Sirona.*)

2. GuttaCore Thermoplasticized Technique

GuttaCore is the newer generation of carrier-based gutta-percha obturation system that uses *crosslinked gutta-percha* as the carrier for the outer thermoplasticized carrier (**Figs 16.21** and **16.22**). This is a significant innovation as it overcomes the limitation of the previous-generation Thermafil obturators that employ metal or plastic carriers.

Advantage

GuttaCore overcomes the drawback of Thermafil obturators, as in cases of retreatment, it would be clinically more easier to remove the crosslinked gutta-percha core than the plastic core of Thermafil obturators.

3. SimpliFill Sectional Obturation Technique

SimpliFill (Lightspeed Technology Inc.) is a carrier-based sectional gutta-percha obturation system used in conjunction with the light-speed rotary instruments. The SimpliFill carrier has an apical 5-mm plug of gutta-percha which performs cold sectional obturation of the root canal (**Fig. 16.23**).

The carrier size is chosen according to the diameter of the MAF. After drying the canal and applying the sealant, the carrier is introduced up to the working length. The handle of the carrier is rotated quickly in the counterclockwise direction three to four times to disengage the apical plug of gutta-percha from the carrier. The remaining coronal space can be filled with lateral compaction or thermoplasticized gutta-percha methods described earlier.

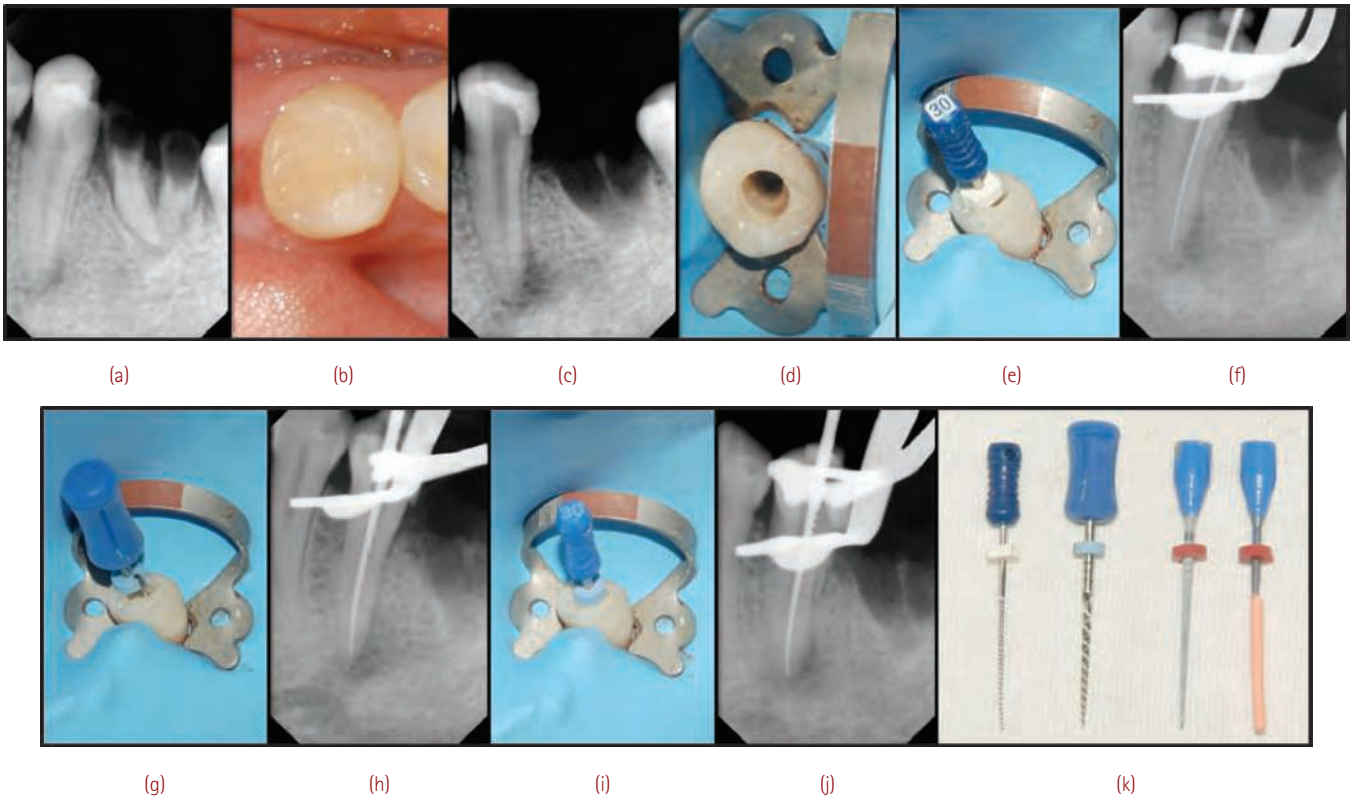


Figure 16.20 Thermafil obturation technique: (a) Preoperative radiograph of tooth 35. (b) Pre-endodontic restoration done using composite resin. (c) Radiograph showing pre-endodontic restoration. (d) Access opening performed through restored tooth. (e) ISO No. 30 K-file placed to working length. (f) Radiographic verification of file. (g) Master file ProTaper Universal F3 placed to working length. (h) Radiographic verification of master file. (i) Thermafil verifier No. 30 placed to working length. (j) Radiographic verification of Thermafil verifier. (k) From left: ISO 2% file, ProTaper F3, Verifier Stripped Thermafil Carrier, and Thermafil Carrier (apical diameter 30# for all files). *(continued)*

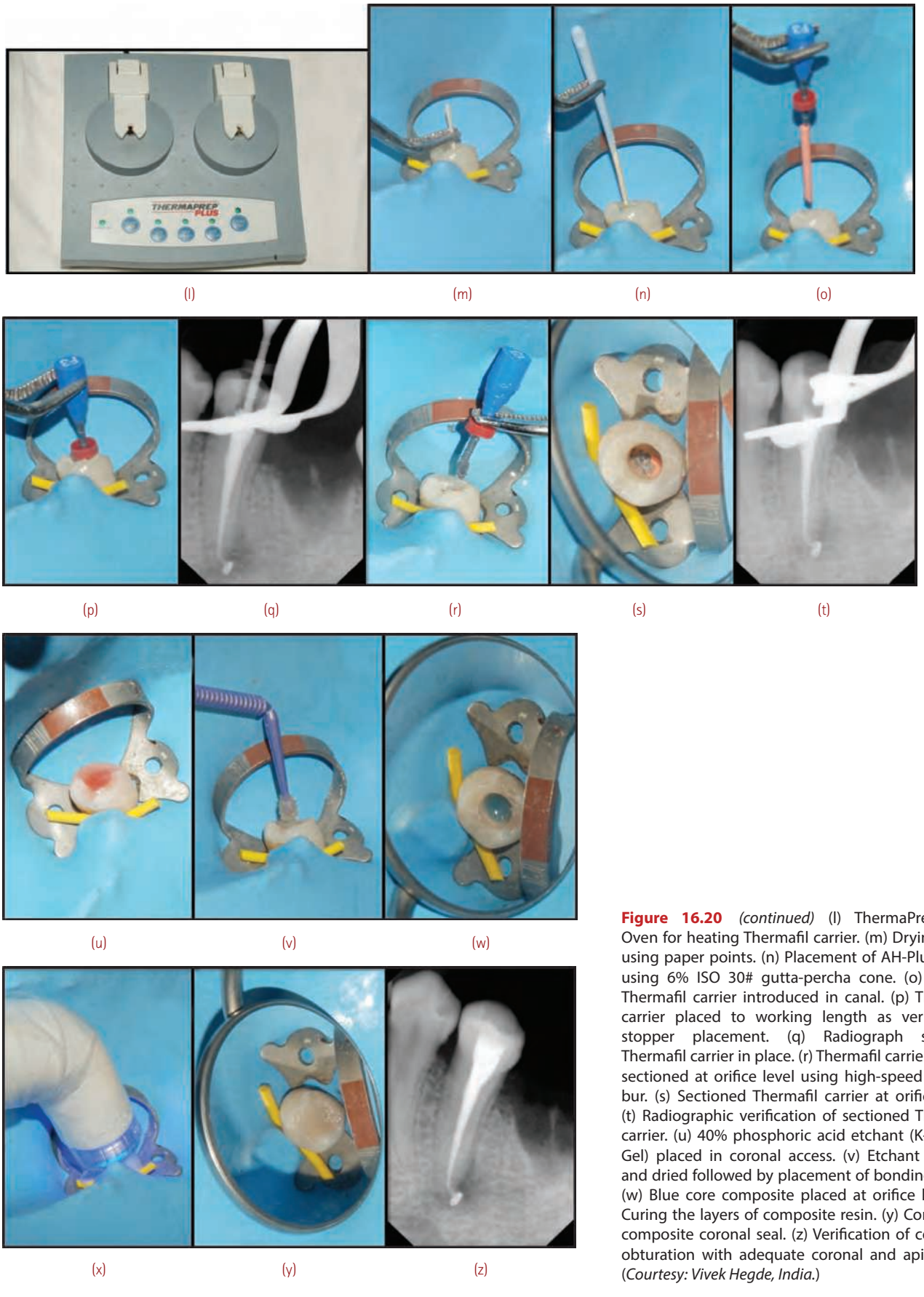


Figure 16.20 *(continued)* (l) ThermaPrep Plus Oven for heating Thermafil carrier. (m) Drying canal using paper points. (n) Placement of AH-Plus sealer using 6% ISO 30# gutta-percha cone. (o) Heated Thermafil carrier introduced in canal. (p) Thermafil carrier placed to working length as verified by stopper placement. (q) Radiograph showing Thermafil carrier in place. (r) Thermafil carrier handle sectioned at orifice level using high-speed carbide bur. (s) Sectioned Thermafil carrier at orifice level. (t) Radiographic verification of sectioned Thermafil carrier. (u) 40% phosphoric acid etchant (K-Etchant Gel) placed in coronal access. (v) Etchant washed and dried followed by placement of bonding agent. (w) Blue core composite placed at orifice level. (x) Curing the layers of composite resin. (y) Completed composite coronal seal. (z) Verification of complete obturation with adequate coronal and apical seal. (*Courtesy: Vivek Hegde, India.*)

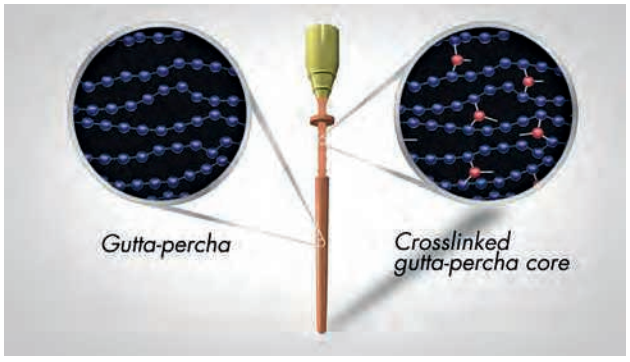


Figure 16.21 GuttaCore obturators. (*Courtesy: Dentsply Sirona.*)



Figure 16.22 ThermaPrep 2 Oven for heating carrier-based obturators such as GuttaCore. (*Courtesy: Dentsply Sirona.*)

VI. McSPADDEN THERMOMECHANICAL COMPACTION METHOD

The compaction method, introduced by McSpadden, uses heat to decrease gutta-percha viscosity and increase its plasticity. The heat is created by rotating a compacting instrument in a slow-speed contra-angle handpiece at 8,000–10,000 RPM alongside gutta-percha cones inside the root canal. The

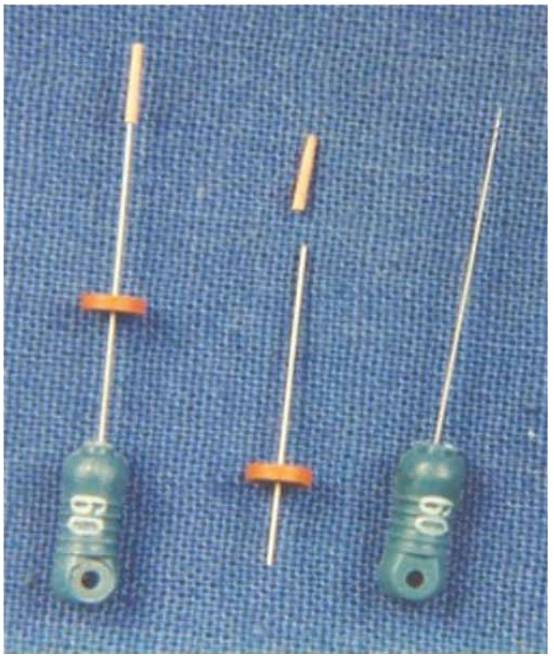


Figure 16.23 SimpliFill sectional obturation system.

compactor whose spiraled 90° flutes are similar to the flutes on a Hedstrom file, but in reverse, forces the softened gutta-percha apically and laterally (**Fig. 16.24**).

As the compactor blade breaks easily if it binds, this method should be used to fill straight canals only. Using the step-back method, the canal should be enlarged to at least the size of a No. 45 instrument. Gutta-percha cones are inserted in the prepared canal short of the root apex, and a compactor blade, selected according to the width and length of the prepared canal, is inserted between the gutta-percha and the canal wall.

With a stop on the compactor blade, the rotating tip of the blade is guided to within 1.5 mm of the root apex. Restriction of the blade within the canal prevents the forcing of thermoplasticized gutta-percha through the root apex. The plastic gutta-percha moves laterally and apically because the reversed flutes on the compactor blade push the softened



Figure 16.24 McSpadden compactor.

gutta-percha forward and sideways even when one is withdrawing the rotating blade from the canal.

Advantages

- Ease of selection and insertion of gutta-percha cones
- Economy of time
- Rapid filling of canals apically and laterally, including irregular spaces within the canal if one uses a sealer

Disadvantages

- Inability to use the technique in narrow canals
- Frequent breakage of compactor blades
- Frequent overfilling of the canal
- Shrinkage of the cooled, set filling

VII. CHEMICALLY PLASTICIZED GUTTA-PERCHA TECHNIQUE (EUCAPERCHA, CHLOROPERCHA)

Gutta-percha can be plasticized by chemical solvents such as chloroform, eucalyptol, or xylol. The disadvantage of using a chemical-solvent filling material is its inability to control overfilling, with resultant periapical tissue reaction and shrinkage of the filling after setting, resulting in a poor apical and lateral seal.

Clinical Note

Chemically plasticized gutta-percha technique is *no longer recommended*.

VIII. CUSTOM CONE TECHNIQUE

Custom cone technique is a chair-side procedure employed for customizing the gutta-percha in wide canals where traditional master cone cannot be adapted. The clinician has to customize a gutta-percha point to achieve a tug back.

Technique

- Soften an appropriate-sized gutta-percha with one or more accessory cones with the help of heat and roll together between two glass slabs. A spatula may also be used as an alternative. A single master cone of increased diameter is created which is then sized within the canal.
- Soften the tip of the master cone with chloroform, eucalyptol, or halothane for few seconds and gently place it to the working length with a locking plier. On removal, the softened gutta-percha carries the impression of the canal and this process is repeated till a snug fit is achieved. Ensure that the gutta-percha remains semirigid during this process.
- A radiograph is exposed to verify proper fit and position before obturating the canal with the custom cone along with an appropriate root canal sealer.

Clinical Note

- Warm vertical compaction is the most popular obturation technique globally among endodontists. It is usually performed along with a Zinc oxide–Eugenol-based or epoxy resin-based sealer. However, to follow this technique, the clinician needs a have a heat carrier (for down packing) and a thermoplastic obturation unit (for backfilling).
- Cold lateral condensation has historically been popular due to its ease of clinical technique. It is still popular among segments of general dentists practicing endodontics.
- The single-cone obturation technique with calcium silicate–based obturation systems is gaining popularity.

ROOT CANAL SEALERS

Definition: *Root canal sealers are used in conjunction with biologically acceptable semisolid or solid obturating materials to establish an adequate seal of the root canal system.*

Grossman's ideal criteria for a root canal sealer are given in **Box 16.8** and the classification of currently employed root canal sealers is given in **Box 16.9**.

Box 16.8

Grossman's Criteria for an Ideal Root Canal Sealer

- Provide an excellent seal when set
- Produce adequate adhesion between itself, the canal walls, and the filling material
- Be radiopaque
- Be nonstaining
- Be dimensionally stable
- Be easily mixed and introduced into the canals
- Be easily removed if necessary
- Be insoluble in tissue fluids
- Be bactericidal or discourage bacterial growth
- Be nonirritating to periradicular tissues
- Be slow setting to ensure sufficient working

Box 16.9

Classification of Currently Employed Root Canal Sealers

I. Commonly used sealers
1. Zinc-oxide–eugenol-based sealers
2. Epoxy resin-based sealers
3. Calcium silicate–based sealers (CSBS)

II. Other available sealers
1. Calcium hydroxide sealers
2. Silicone sealers
3. Glass ionomer–based sealers
4. Other resin-based sealers
5. Medicated sealers (not recommended)

I. COMMONLY USED SEALERS

1. Zinc Oxide–Eugenol-Based Sealers

- They have a long history of having been used successfully in endodontics.

Grossman developed a nonstaining cement that meets most of the ideal requirements for a root canal sealer. The composition is given in **Box 16.10**.

- Most of the sealers in common use contain zinc oxide resin as a base ingredient of the powder. The liquid usually consists of eugenol alone or in combination with other liquids such as Canada balsam. Included in this group are the following:
  - Grossman's cement: ***Roth's 801 sealer*** (Roth International)
  - Rickert's sealer: ***Pulp Canal Sealer*** (SybronEndo)
  - ***Tubli-Seal*** (SybronEndo; **Fig. 16.25**)

Grossman's cement hardens in approximately 2 hours at 37°C and 100% relative humidity. Its setting time in a canal is less. It begins to set in the root canal within 10–30 minutes because of the moisture present in dentin. The setting time is also influenced by the quality of the zinc oxide and the pH of the resin used, the care and technique in mixing the cement to its proper consistency, the amount of humidity in the atmosphere, and the temperature and dryness of the mixing slab and spatula.

The sealer is mixed on a sterile glass slab with a sterile spatula. Depending on the number of canals to be filled, one uses two or three drops of root canal cement liquid. Slowly, small increments of cement powder are added to the liquid while one spatulates it to a smooth, creamy mix. The spatulation time depends on the number of drops of liquid used, a minute per drop.

Tissue tolerance of this sealer is satisfactory, with little inflammation and no inhibition of repair. Langeland and coworkers have stated that all root canal cements are irritating in their freshly mixed state, but on setting, most become relatively inert.

Box 16.10

Grossman's Formula of a Nonstaining Sealer

Powder	Parts
Zinc oxide, reagent	42
Staybelite resin	27
Bismuth subcarbonate	15
Barium sulfate	15
Sodium borate, anhydrous	1
Liquid	
Eugenol	



Figure 16.25 Tubli-Seal zinc oxide–eugenol sealer. (*Courtesy: SybronEndo.*)

Clinical Note

Zinc oxide–eugenol sealers have a long and successful history of being an effective root canal sealer in endodontics.

2. Epoxy Resin–Based Sealers

- ***AH26*** (Dentsply DeTrey) is an epoxy resin containing a nontoxic hardener. Radiopacity is imparted to it by bismuth oxide. It has strong adhesive properties and contracts slightly while hardening. However, it was found to release formaldehyde during setting.
- ***AH Plus*** (Dentsply DeTrey; **Fig. 16.26**) is a modified formulation of AH26 with a working time of approximately 4 hours and setting time of 8 hours. This sealer does not release formaldehyde and is currently one of the most commonly used endodontic root canal sealer.
  Box 16.11 presents the formula of AH Plus sealer.

Advantages

- Good sealing ability
- Biocompatibility to periapical tissues
- Moderate antimicrobial activity
- Dentinal adhesion
- Long working time and ease of manipulation



Figure 16.26 AH Plus epoxy resin sealer. (*Courtesy: Dentsply Sirona.*)

Box 16.11

Composition of AH Plus Epoxy Resin Sealer

Paste A
- Epoxy resin
- Calcium tungstate
- Zirconium oxide
- Silica
- Iron oxide

Paste B
- Adamantaneamine-N
- Calcium tungstate
- Zirconium oxide
- Silica–silicone oil

Clinical Note

Epoxy resin–based sealers are currently the most recommended and popular sealers used in contemporary endodontics.

3. Calcium Silicate-Based Sealers (CSBS)

Tricalcium silicate is one of the main components of MTA and is now the focus of the newer generation of bioceramic sealers.

The examples of popular calcium silicate sealers are:

- ***BioRoot RCS*** (Septodont) (**Fig. 16.27a**)
  - *Composition*: Zirconium oxide, dicalcium silicate, tricalcium silicate, calcium phosphate monobasic, calcium hydroxide, filler and thickening agents
- ***TotalFill BC Sealer*** (FKG) (**Fig. 16.27b**)
  - *Composition*
    - *Powder*: Tricalcium silicate, zirconium oxide, povidone
    - *Liquid*: Aqueous solution of calcium chloride and polycarboxylate

Clinical Characteristics

- Tricalcium silicate sealers set by reaction with water to form a matrix of calcium silicate hydrates and calcium hydroxide (alkaline pH of 12). This reaction is followed by the precipitation of calcium phosphate.
- CSBS have sealing properties comparable to those of epoxy resin sealers.
- They are biocompatible and have the potential to provide a bioactive surface with stimulation of hard-tissue formation.
- They also exhibit antibacterial properties.
- They are recommended to be used along with cold lateral condensation or single-cone obturation techniques.

Clinical Note

- Epoxy resin–based sealers along with zinc oxide–eugenol-based sealers are the most popular conventionally used endodontic sealers.
- Calcium silicate–based sealers (CSBS) are currently becoming popular due to their favorable biological characteristics.



(a) (b)

Figure 16.27 Calcium silicate-based sealers: (a) BioRoot RCS. (*Courtesy: Septodont.*) (b) TotalFill BC Sealer. (*Courtesy: FKG.*)

Table 16.1 Comparative Assessment of Most Commonly Used Contemporary Endodontic Sealers

Sealer	Popular Examples	Important Properties
I. Zinc oxide–eugenol based sealer	Grossman's Sealer: Roth 801 (Roth International) Pulp Canal Sealer (SybronEndo) Tubli-Seal (SybronEndo)	• Earliest sealer developed. • Popular and economical • They exhibit slow setting time • Can be used with both cold and thermoplasticized techniques
II. Epoxy resin–based sealer	AH Plus (Dentsply Sirona)	• Most popular of the currently used endodontic sealers • Excellent sealing ability and does not resorb • Does not contain eugenol • Can be used with both cold and thermoplasticized techniques
III. Calcium silicate–based sealers (CSBS)	*BioRoot RCS* (Septodont) *TotalFill BC Sealer (FKG)*	• Most biocompatible sealer currently available • Bioceramic hydrophilic sealer utilizes moisture within the canal to complete the setting reaction and it does not shrink on setting • Also exhibits antimicrobial properties on setting

A comparative assessment of most commonly used contemporary endodontic sealers, namely, zinc oxide–eugenol based, epoxy resin-based, and CSBS, is given in **Table 16.1**.

II. OTHER AVAILABLE SEALERS

1. Calcium Hydroxide–Based Sealers

Some zinc oxide–eugenol cements have been modified by incorporating calcium hydroxide.

- ***Sealapex*** (SybronEndo; **Fig. 16.28**) has been described as noneugenol, calcium hydroxide polymeric resin root canal sealer available in a base catalyst system. The base contains zinc oxide, calcium hydroxide, butyl benzene, sulfonamide, and zinc stearate. The catalyst contains resin, isobutyl salicylate, barium sulfate, titanium dioxide, and aerosol.
- Another zinc oxide–type cement containing calcium hydroxide is *Calcibiotic Root Canal Sealer* (***CRCS***). Set CRCS contains 14% by weight of calcium hydroxide.
- ***Apexit Plus*** (Ivoclar Vivadent) is a two-paste sealer system with the base paste containing calcium hydroxide and the activator paste comprising disalicylate, bismuth hydroxide/bismuth carbonate, and fillers.



Figure 16.28 Calcium hydroxide sealer (Sealapex). (*Courtesy: SybronEndo.*)

Clinical Note

Calcium hydroxide sealers were developed for their antimicrobial and osteogenic–cementogenic potential; however, these actions have not been clinically demonstrated.

2. Silicone Sealers

- ***RoekoSeal*** (Coltène/Whaledent, Germany) is a polyvinylsiloxane that has been reported to expand slightly on setting.
- ***GuttaFlow*** (Coltène) has a cold flowable matrix that is triturated. It consists of gutta-percha added to RoekoSeal. The material is provided in capsules for trituration. The technique involves injection of the material into the canal, followed by placement of a single master cone.

III. GLASS IONOMER–BASED SEALERS

Glass ionomers have been advocated as root canal sealers for their dentin-bonding ability.

- ***Ketac Endo*** (3M ESPE) is an example of a glass ionomer sealer.
- ***Activ GP*** (Brasseler) consists of a glass ionomer–impregnated gutta-percha cone with a glass ionomer external coating and a glass ionomer sealer.

Clinical Note

Glass ionomer sealers are not popular because of the difficulty in removing the sealer from root canal walls during retreatment. Solvents are ineffective against them.

IV: OTHER RESIN SEALERS

- ***EndoREZ*** (Ultradent Products) is a methacrylate resin with hydrophilic properties. When used with EndoREZ resin-coated gutta-percha cones, the dual-cure EndoREZ sealer bonds to both the canal walls and the core material.
- ***Diaket***, a polyvinyl resin (3M ESPE), consists of a powder composed of bismuth phosphate and zinc oxide and a liquid consisting of dichlorophen, triethanolamine, propionylacetophenone, and copolymers of vinyl acetate, vinyl chloride, and vinyl isobutyl ether.
- ***Epiphany*** (Pentron Clinical Technologies) and ***RealSeal*** (SybronEndo) have been introduced for use with a new core material, Resilon (Pentron Clinical Technologies). The manufacturers claim that these sealers can bond to both the canal wall and the core Resilon core material to create a "monoblock effect."

V: MEDICATED SEALERS (NOT RECOMMENDED)

Medicated sealers are no longer indicated in routing endodontic practice. These include paraformaldehyde sealers such as Endomethasone, N2, and Reibler's paste.

SEALER CONSISTENCY

- Root canal sealer should be mixed according to the manufacturer's instructions.
- The completed mix can be tested for proper consistency by raising the flat blade of the spatula up from the mixed mass. The cement should "*string out*" for at least 10 cm before breaking.
- Another test for consistency is that the suspended mix should cling to the inverted spatula blade for 10–15 seconds before dropping from the spatula. The cement is now coated into the dried root canal (**Fig. 16.29**).
- As moisture accelerates the set of many sealers, the pulp chamber and canals should be thoroughly dried before inserting the cement.
- Small amount of cement is carried into the canal using a Lentulo spiral or the master cone. This procedure prevents air bubbles from being trapped in the cement. Coat the walls of the canal with a thin layer of cement by means of a lateral or rotary motion. Avoid forcing any cement into the periradicular tissues.



(a) (b) (c)

Figure 16.29 (a) Proper consistency of sealer. (b) Increased liquid content in sealer makes the sealer thin. (c) Grainy mix due to excessive powder.

PERIRADICULAR REACTIONS TO OBTURATING MATERIALS

The reaction of connective tissue to root canal cements and filling materials has been studied by many investigators. No root canal cementing medium or core is entirely innocuous. In fact, any foreign body, such as cement or core, extruded into the periradicular tissue can be highly irritating and may reduce the probability of healing by as much as 25%.

The zinc oxide–eugenol type of cements is probably irritating because of the eugenol, while epoxy resin sealers are more compatible, and CSBS are the most biocompatible sealers available. Fortunately, the irritation caused by overfilling is generally mild for most of the filling materials.

Nevertheless, *all filling materials should be confined within the root canal.*

SINGLE-VISIT ENDODONTICS

Completion of endodontic therapy in a single visit is not a new concept. Literature reviews of single-visit endodontics can be traced back to almost 100 years. Later, as endodontic procedures became more precise, sophisticated, and demanding, multiple-visit endodontics gained popularity. In recent years, with the advent of rotary nickel–titanium instruments, single-visit endodontics has gained increased acceptance as the treatment of choice for most of the endodontic cases.

The clinical experience and ability of the clinician is the most important factor. A clinician who is experienced in single-visit endodontics can perform the majority of cases in a single visit. However, for a clinician who is starting to make the transition from single-visit endodontics to multiple-visit endodontics, the following indications and contraindications may prove useful.

INDICATIONS

- Vital teeth
- Physically compromised patients who have to make an effort to come to the dental clinic
- Medically compromised patients who require antibiotic prophylaxis and sometimes alteration in the medication they take
- Fractured anteriors where esthetics is a concern
- Apprehensive but cooperative patients
- Patients who require sedation or an operation room
- Nonvital teeth with sinus tract

CONTRAINDICATIONS

- Patients with temporomandibular joint (TMJ) disorders and inability to keep open the mouth for long periods
- Teeth with limited access
- Nonsurgical retreatment cases

Criteria for single-visit endodontics are given in **Box 16.12**.

Box 16.12

Decision-Making Criteria for Single-Visit Endodontics

Favorable Criteria	Unfavorable Criteria
• Clinically experienced operator	• Relatively inexperienced operator
• Patient is cooperative for the longer procedure	• Patient is noncooperative
• Accessibility and mouth opening is good	• Poor accessibility and mouth opening
• Normal root canal anatomy	• Anatomical variations such as extra roots/canals
• Patent root canals	• Calcifications/ledges/canal obstructions
• Easily negotiable curvatures	• Acute canal curvatures
• Absence of periradicular lesion	• Presence of a periradicular lesion
• Complete pulpal anesthesia easily achieved	• Hot tooth
• Primary endodontic treatment	• Retreatment cases

Clinical Note

- The significance of coronal seal following canal obturation is to prevent microleakage. According to Torabinajed et al., lack of a coronal protection seal leads to canal reinfection with *Staphylococcus* species following 19 days of obturation in an in vitro study.
- Thus, following obturation, the access cavity should be restored ***immediately*** with an appropriate core buildup material to prevent microleakage.

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17 Procedural Errors: Prevention and Management

Experience is what we get, when we don't get what we want ....

Procedural errors during endodontic therapy occur not only with students and beginners but also with skilled and experienced clinicians in spite of taking all possible precautions. Adhering to the fundamental biological and mechanical guidelines of endodontics can prevent such iatrogenic complications and produce predictable outcomes even in complex root canal anatomies (**Fig. 17.1**).

A clinician should have the ability to:

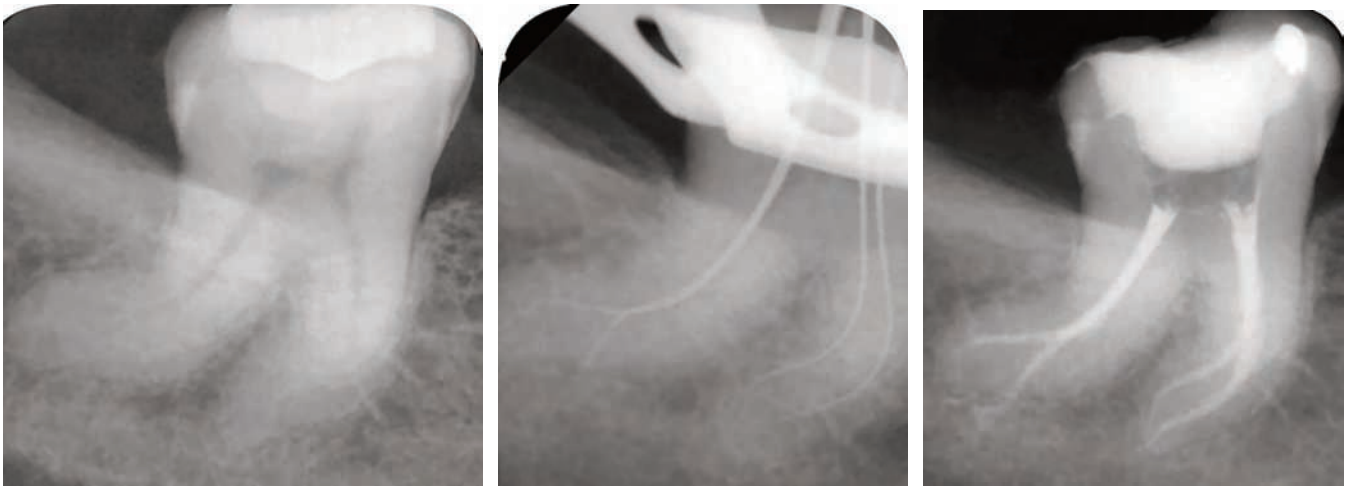
- Assess and inform the patient about the prognosis of a case before initiating the treatment
- Identify the given clinical problem with diagnostic acumen
- Anticipate problems in challenging cases
- Use appropriate materials and modifications in routine techniques in order to prevent procedural errors
- Identify clinical problems the moment they occur during the procedure and manage them positively

Before commencing a procedure, the endodontist (or a general practitioner), trained in endodontics, must do a sincere introspection of his/her capabilities in handling an endodontic situation. If it is not within the purview of the attending clinician, then he/she should either call in a peer consultant or refer the case to one who can handle the situation.

CLINICAL GUIDELINES

Procedural errors can be avoided to a larger extent by following these guidelines:

- Establish a proper communication and rapport with the patient. The patient has a moral and legal right to be informed about every step of the treatment procedure.
- Complete a thorough history and meticulous clinical examination of the tooth or teeth in question before commencing the treatment.
- Ascertain the periodontal status, prosthodontic restorability, and prognosis of the tooth in question.
- Aspiration of an endodontic hand instrument happens only when the rubber dam is not in place. Grossman had aptly stated in 1955 that if an instrument is swallowed by the patient, the dentist is likely to be confronted with a lawsuit. He further stated that in the eyes of the court, when an endodontic instrument escapes from the endodontist's fingers and is ingested or aspirated, expert opinion is not necessary to justify the claims of negligence. Even today, this statement signifies the **importance of application of rubber dam during endodontic treatment**.



(a) (b) (c)

Figure 17.1 (a) Preoperative radiographic view of a mandibular molar with acute curvature. (b) Negotiating the root canal curvatures and respecting the original canal anatomy. (c) Postobturation view. (*Case Courtesy: Ahmed Ibrahim Salim, Egypt.*)

- High-power suction is synonymous with rubber dam application. There are quite a few reported cases of endodontic instrument ingestion or aspiration. This is definitely a preventable procedural error. Aspiration or ingestion of endodontic instruments can be a clinical disaster ending up in life-threatening situations or ending up in the need for major surgery to remove the instrument.
- One must have thorough knowledge of the internal anatomy of the pulp space and variations in the root canal configuration. Also required is complete knowledge of the apical terminus of root canals, especially apical foramen, apical constriction, and anatomical apex. In addition, one must know approximately at what age the root apex would be complete in different teeth in the arch. A beginner can learn to anticipate these variations by observing cross and vertical ground sections of all teeth at various levels.
- Obtain an intraoral periapical radiograph for every step of endodontic therapy. These include one before commencing the treatment, one during working length determination, one during master apical gutta-percha cone selection, and one following the completion of the obturation.
- One must be well trained in applying the various endodontic instruments, materials, and techniques being employed.
- Knowledge of the microbiota of the pulp space and methods, medicaments, and techniques to disinfect the pulp space is essential.
- Application of rubber dam and high-power suction is the standard of care in endodontics.
- The working length must be estimated by more than one method.
- The basic rules of hand and rotary instruments have to be followed.
- Recapitulation has to be done at every phase of cleaning and shaping irrespective of the instrument design employed.
- Irrigation with appropriate irrigants is necessary to ensure proper cleaning of the root canal. The use of sodium hypochlorite is recommended but with care and precision.
- Use of chelating agents is recommended, and if a canal block cannot be negotiated, then alternative treatment modalities have to be employed.
- Intracanal medicaments have to be used with care and caution.
- Shaping and cleaning of the crucial apical third followed by obturating the canal should be done without damaging the periradicular tissues.

TYPES OF PROCEDURAL ERRORS

Procedural errors can be broadly categorized as follows:

I. Procedural errors related to access opening of the pulp space
II. Procedural errors related to canal shaping and cleaning
III. Procedural errors related to obturation

I. PROCEDURAL ERRORS RELATED TO ACCESS OPENING OF THE PULP SPACE

The main errors and challenges faced during access opening procedures are as follows:

- Treating the wrong tooth
- Incomplete removal of caries
- Inability to locate extra canals (missed canal orifices)
- Iatrogenic perforations (cervical perforations)

A. Treating the Wrong Tooth

Arriving at a diagnosis and designing a treatment plan before beginning any procedure can definitely bring down the number of procedural mishaps that can occur during endodontic therapy. A significant factor in diagnosis and treatment planning is making pre-endodontic notes. This will help in identifying the tooth in question.



Clinical Note

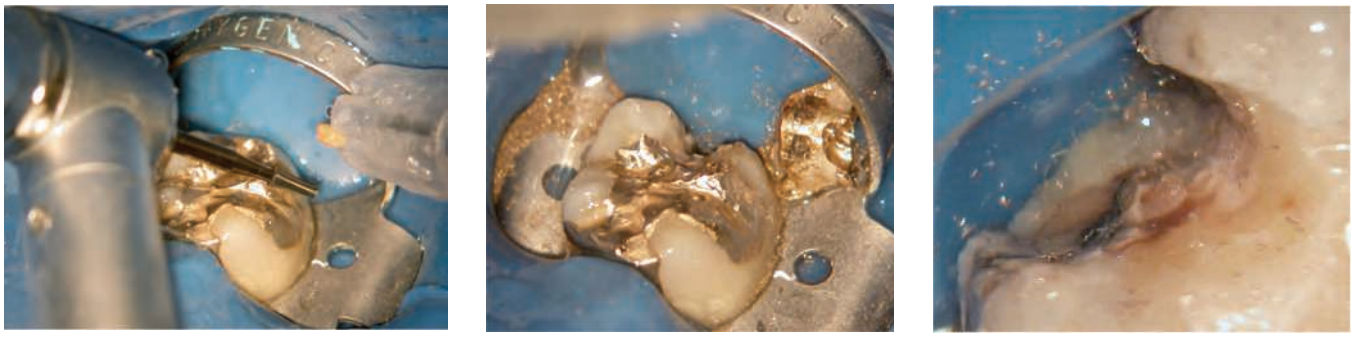
- Make a suitable marking on the radiograph and also on the tooth in question in the oral cavity before the application of a rubber dam. This will help to avoid treating the wrong tooth.
- Alternatively, as an option, it is suggested that the initial access cavity into the enamel or dentinoenamel junction can be completed before the rubber dam application.

B. Incomplete Removal of Caries

Secondary caries under the existing restorations is one of the reasons for the need of endodontic therapy in certain cases. One must study the preoperative radiographs under magnification, and if any doubt exists about the presence of secondary caries, the entire filling must be removed and the access has to be redesigned accordingly.

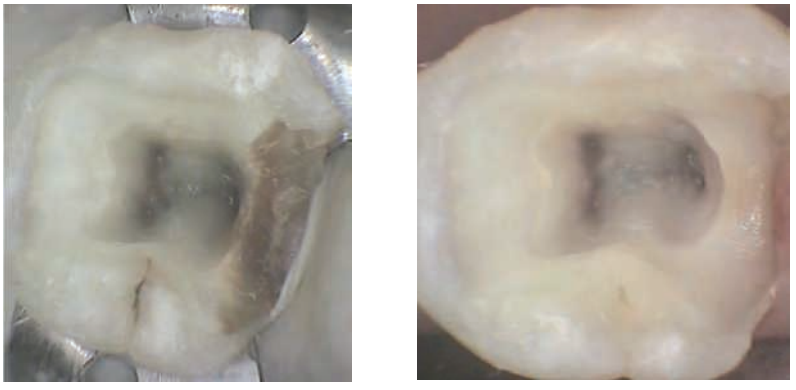
It is recommended that an existing old restoration, especially involving occlusoproximal areas, should be removed in total and access cavity designed accordingly. This will prevent any chances of secondary caries being left behind when an endodontic procedure is completed. All caries must be removed from a tooth receiving endodontic treatment (**Fig. 17.2**).

The other common error occurs in distal carious lesions involving the pulp. The clinician might concentrate on the access opening in the mesial part of the tooth and cause incomplete removal of dental caries (**Fig. 17.3**). Such teeth will get reinfected in future and ultimately fail. The clinician should remember that secondary caries in an endodontically treated tooth ultimately leads to coronal leakage and ultimate endodontic failure. Complete removal of the carious process should be the first principle of access opening before focusing on canal orifice location.



(a) (b) (c)

Figure 17.2 (a) Access opening of a mandibular molar with caries lesion under the existing restoration. (b) Undermined distal margin of the tooth and restoration breakdown easily during initial access opening. (c) Evidence of caries under the margins of the old restoration.



(a) (b)

Figure 17.3 (a) Incomplete removal of caries in the distal gingival margin after access opening. (b) Caries removal completed in the same tooth.

Clinical Note

- A proper access opening is the key to ensure an errorless procedure during cleaning and shaping. In endodontics, the idiom "access is success" should be kept in mind always. If access is not properly gained, it would be the beginning of a procedural failure.
- The preoperative diagnostic radiograph provides vital information regarding the root canal configuration, calcifications, unusual morphology, and angulations of the tooth. Failure to "*read the radiograph*" invariably leads to procedural errors. Visual enhancement aids such as the dental operating microscope (DOM) are not only helpful in challenging cases but also recommended routinely to ensure the highest levels of endodontic care.

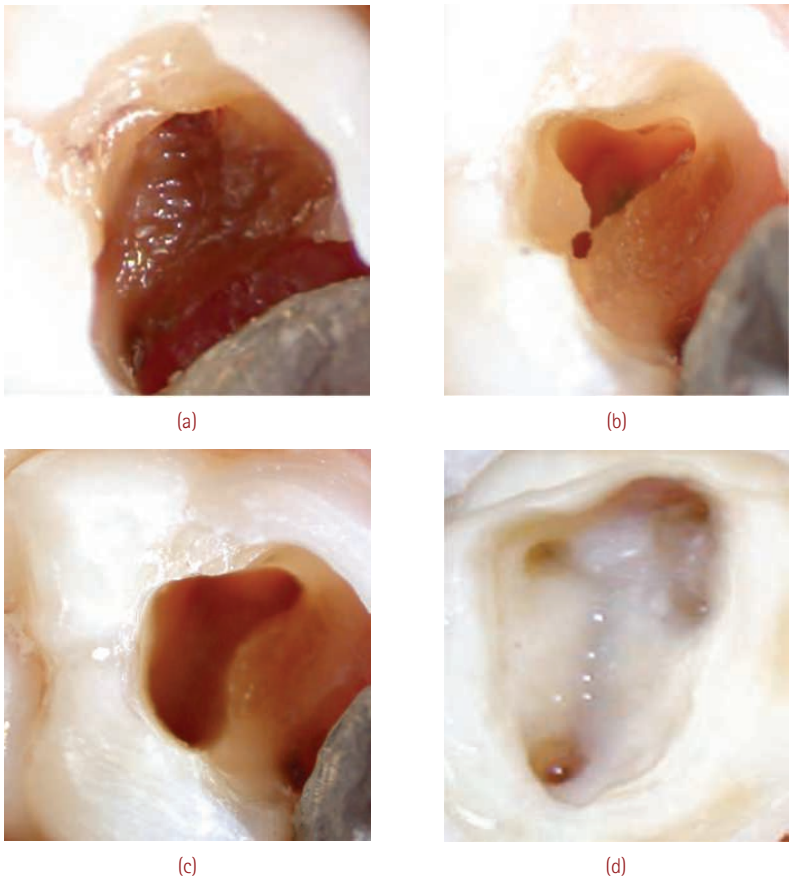
C. Missed Canal Orifices

Causes

- Failure to externalize the internal anatomy while studying the preoperative radiograph
- Lack of knowledge pertaining to root canal anatomy, configuration, and its variations
- Improper access and not observing the basic cavity design features
- Incomplete deroofing of the pulp chamber (**Fig. 17.4b**)
- Incomplete removal and shaping of the lateral walls of the pulp chamber
- The access openings in both maxillary and mandibular molars are always on the mesial half of the occlusal surface rarely extending across the midline
- In maxillary premolars, the opening is always buccolingual with one canal under buccal cusp and one under palatal cusp
- A case report of the mandibular first molar with a middle mesial canal (**Fig. 17.5**)

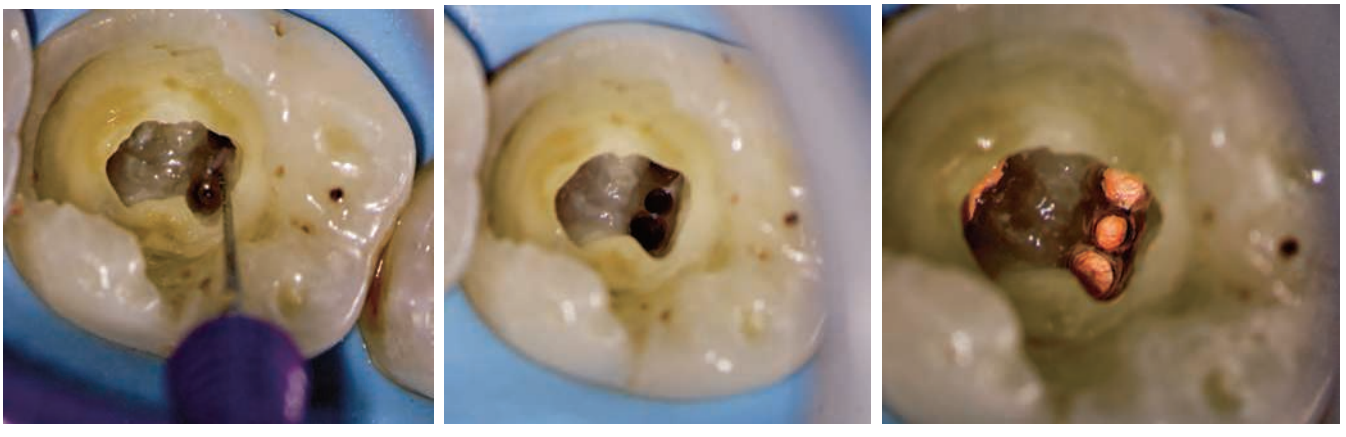
Prevention and Action

- Good periapical radiographs preoperatively and during root canal cleaning and shaping. Observe radiographs under magnification.
- Multiple radiographs in varying angulations help the clinician to better understand the morphology of the tooth and aid in tracing extra canals (**Fig. 17.6**).
- Use DG16 explorer or size 06/08/10 ISO K-file instruments to locate the orifices (**Fig. 17.7**). The other files which work effectively in such situations are the C+ file and Profinder files.



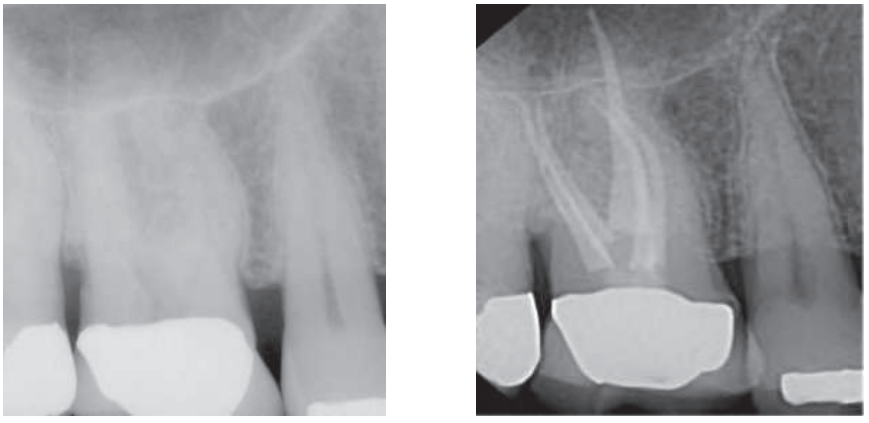
(a) (b) (c) (d)

Figure 17.4 (a) Distal carious exposure of pulp in a maxillary first molar. (b) Caries removed and the triangular opening seen is the access entry into the pulp chamber through the roof. Note the incomplete removal of the roof of the pulp chamber. (c) Access modified to remove the roof and facilitate straight-line access to all the canals. (d) Access refined and the second mesiobuccal canal traced.



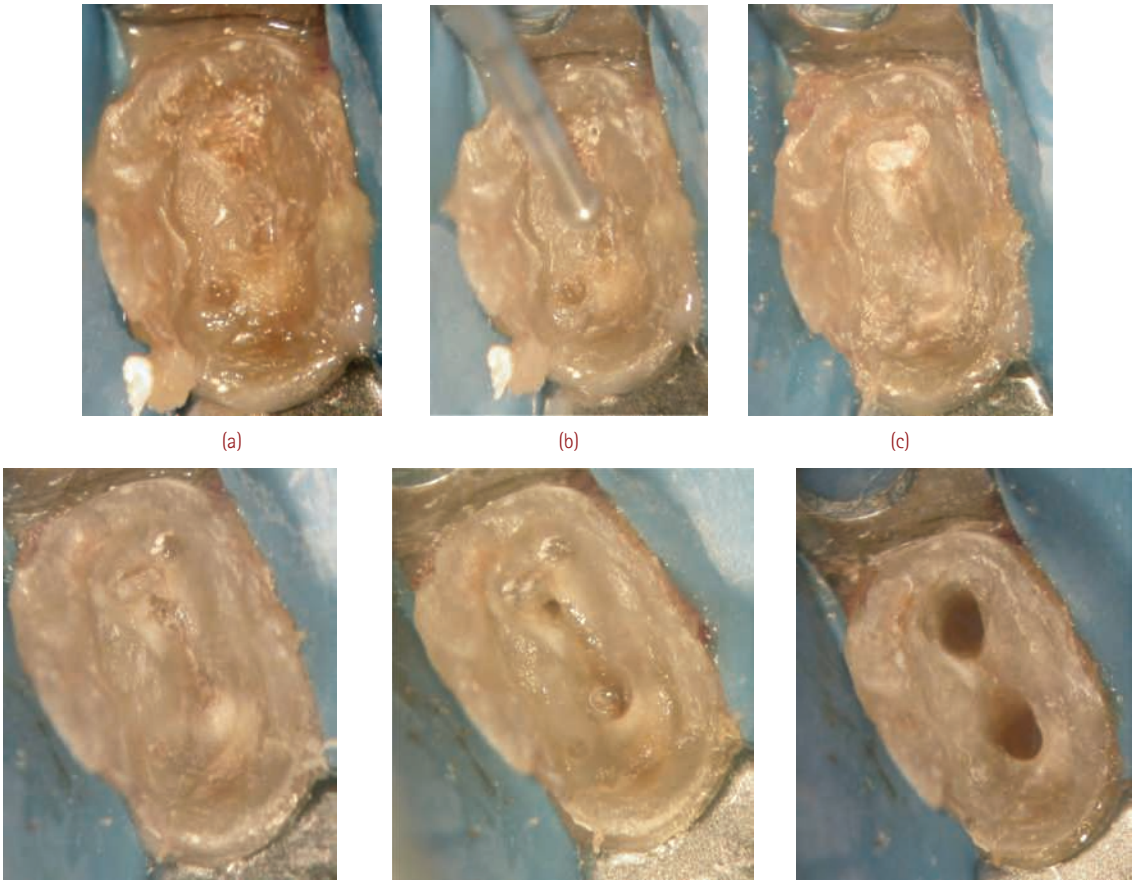
(a) (b) (c)

Figure 17.5 (a) Thin strip of tissue evident between the developmental groove connecting the mesiobuccal and mesiolingual canals. (b) Middle mesial canal traced and the orifice is distinct and located midway between the other two mesial canals. (c) All the three mesial canals negotiated and obturated. (*Courtesy: Reuben Joseph, India.*)



(a) (b)

Figure 17.6 (a) Preoperative radiograph of the maxillary first molar indicative of the possibility of extra canals. (b) Postoperative radiograph showing evidence of five canals with two canals each in the mesiobuccal and distobuccal roots. (*Courtesy: Julian Webber, England.*)



(a) (b) (c)

(d) (e) (f)

Figure 17.7 (a) Maxillary premolar with a calcified pulp chamber. (b) Troughing of the floor of the chamber with a Munce access refinement bur. (c) Canal orifices are becoming evident on deeper troughing. (d) Buccal and palatal canal orifices located. (e and f) Canals negotiated followed by shaping and cleaning. (*Courtesy: Siju Jacob, India.*)

Clinical Note

Knowledge of canal anatomy and of the laws of access opening is crucial in preventing such errors related to access opening. (*Refer to* **Box 13.3**.)

D. Iatrogenic Cervical Perforations

Causes

- Failure to preoperatively interpret the internal pulp space anatomy accurately
- Lack of clinical acumen
- Calcification of the pulp chamber
- Crown root angulation
- Crowding and rotation of tooth

Cervical perforations (**Figs 17.8–17.10**) usually occur due to excess removal of coronal dentin in the form of gouging which leads to crown perforation.

Management of Nonfurcal Cervical Perforations

The primary protocol is hemorrhage control with 1:50,000 epinephrine followed by perforation repair with tricalcium silicate cements/mineral trioxide aggregate (MTA). Keep periodontal treatment options open.

Prevention

- One must study the crown root angulations of maxillary lateral incisors and mandibular first premolar teeth before proceeding with the treatment. In fact, these are teeth which normally exhibit significant crown root angulations.
- Removing all caries is the basic rule in endodontics and restorative dentistry. But in an effort to remove all caries, care must be taken in not removing healthy dentin and undermining the crown tooth structure which might result in a perforation.
- Repeated and thorough evaluation of radiographs is mandatory to avoid any mishaps such as perforations.

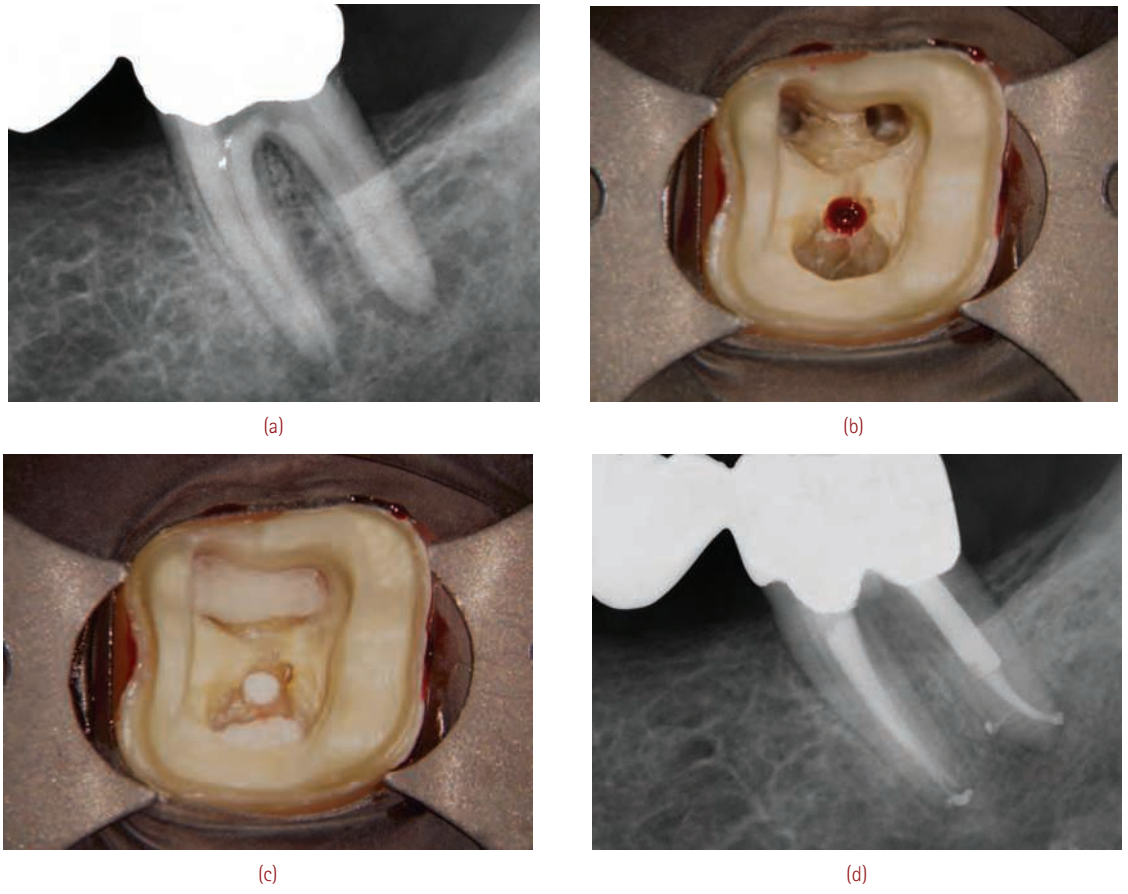
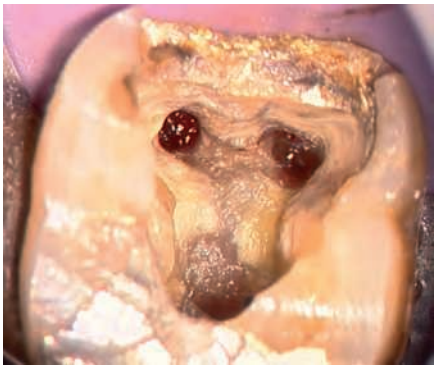


Figure 17.8 (a) Perforation of the furcal floor of the mandibular second molar. (b) Perforations evident as bleeding spots in the floor of the pulp chamber. (c) Perforation repair completed with white MTA. (d) Postobturation view. (*Courtesy: Clifford Ruddle, USA.*)



(a)



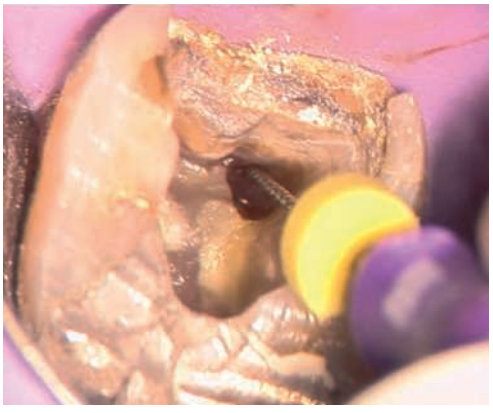
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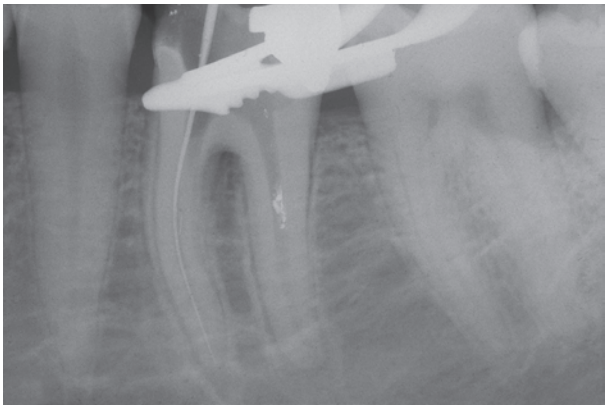
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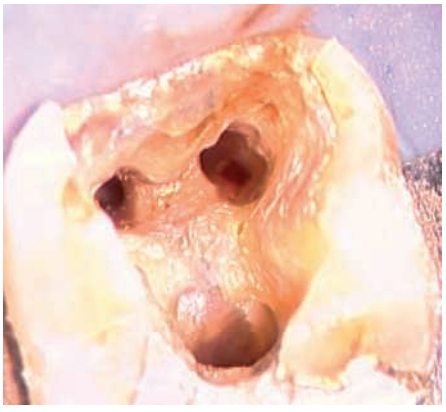


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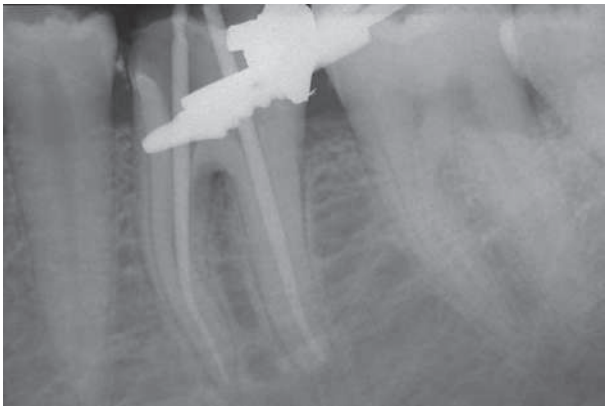


(f)

Figure 17.9 (a) In an attempt to find the mesiobuccal canal, a perforation was made in the floor of the pulp chamber. Preoperative radiograph. (b) Clinical aspect of the access cavity. The bleeding is seen from the perforation near the orifice of the buccal canal. (c) A small file has been introduced in the bleeding area and has been connected to an electronic apex locator to confirm the diagnosis of a perforation. (d) On the mesial aspect of the perforation is now visible the orifice of the canal. (e) A #10 K-file is negotiating the original mesiobuccal canal. (f) Working length of the mesiobuccal canal. *(continued)*



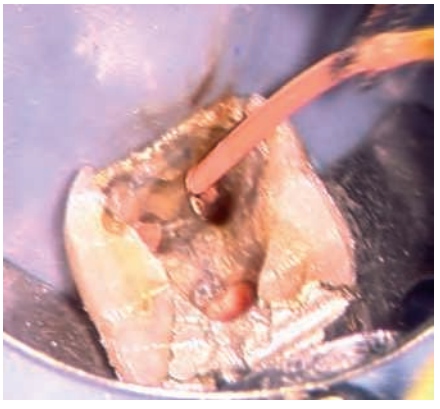
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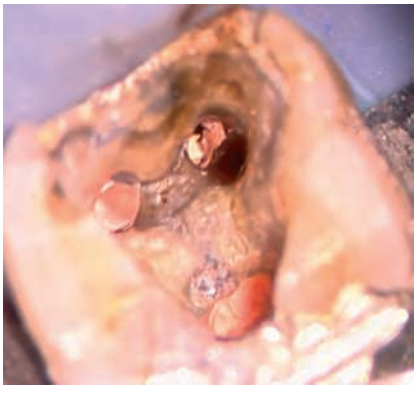
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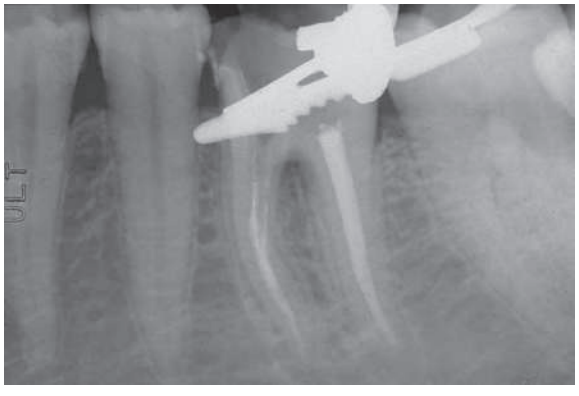
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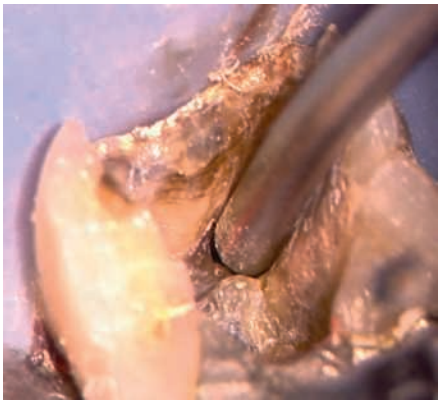
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(k)

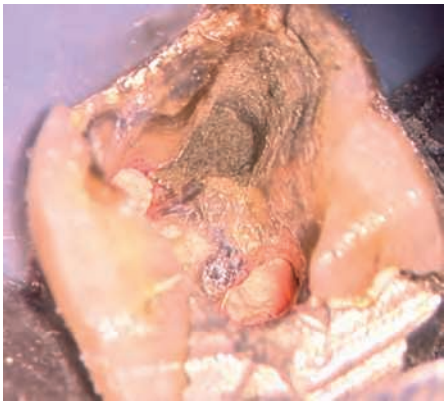


(l)

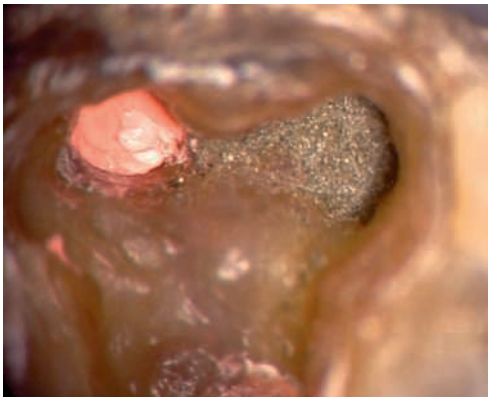


(m)

Figure 17.9 *(continued)* (g) After shaping and cleaning, now the perforation is the little opening about 7 mm below the canal orifice. (h) Fitting the gutta-percha cones. (i) The gutta-percha cone of the mesiobuccal canal has been partially presectioned apical to the perforation, bended, and coated with a sealer before being introduced in the canal. (j) Because of the partial cut, the gutta-percha point is separated in two fragments: one apical, which remains in the canal apically to the perforation, and one coronal, which is removed. (k) The canal has been obturated with the Schilder technique only apically to the perforation. (l) Deepest packing point in the mesial canals. (m) Positioning the MTA with the Dovgan carrier. *(continued)*



(n)



(o)



(p)



(q)

Figure 17.9 *(continued)* (n) The canal has been filled with MTA up to the orifice. (o) At the follow-up visit, the material is completely set. (p) Postoperative radiograph. (q) Two-year recall radiograph showing good healing. (*Courtesy: Arnaldo Castellucci, Italy.*)



Figure 17.10 Failure to recognize the mesial drift in this mandibular premolar has resulted in the operator error of almost creating a perforation during access preparation.

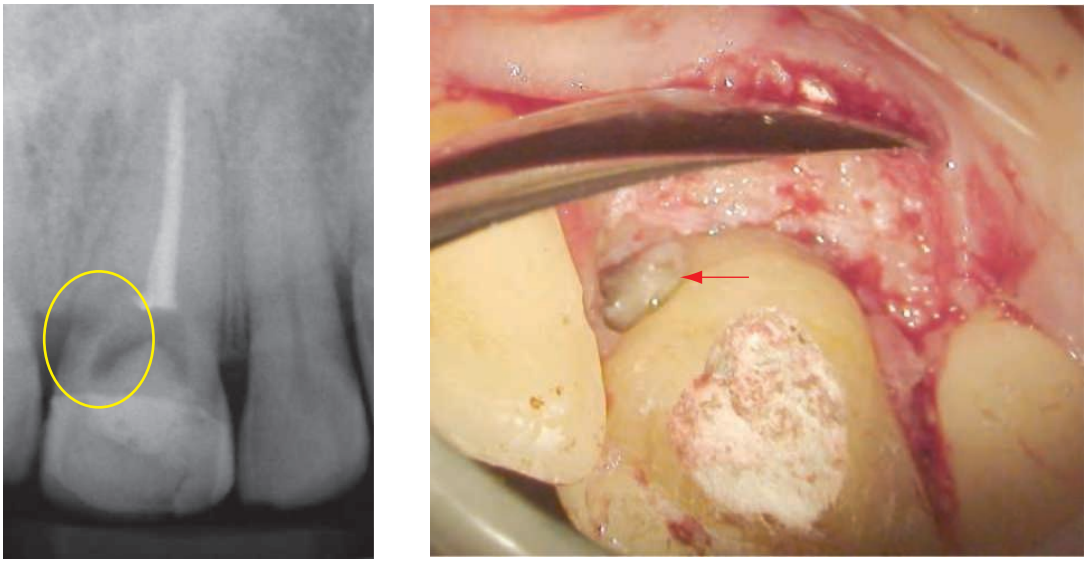
Management of Cervical Perforation in the Furcation Area

Once there is flooding of blood into the pulp chamber, one must suspect a perforation likely into periodontal tissues or into the furcation. This must immediately be confirmed with a radiograph. An electronic apex locator is very useful in differentiating a bleeding canal from a perforation.

Tricalcium silicate cements/MTA is the material of choice for sealing perforations. The patient should be informed that a procedural error has occurred, and a guarded prognosis is communicated to the patient.

Prevention

- Study the preoperative radiographs and meticulously evaluate the pulp chamber morphology.
- Access bur penetration for depth and angulation should be confirmed before proceeding with designing access cavity.
- Straight-line access is an important consideration in all access preparations.
- With maxillary lateral incisor and mandibular first premolar, always follow "stay lingual rule."
- While preparing access cavities if a ceramic crown or a metal crown is already present, it is better to remove the crown and proceed with endodontic access and treatment.
- When there is an existing restoration, it is safer to remove the old restoration to rule out any secondary caries at the floor or axial wall.
- In dealing with calcifications in the chamber or pulp space, the endodontist must externalize the internal



(a) (b)

Figure 17.11 (a) Mesial perforation at the cervical level in a maxillary central incisor. (b) Surgical exposure of the cervical perforation. (*Courtesy: Venkat Canakapalli, New Zealand.*)

anatomy of pulp space. The geometric patterns of orifices of root canals are found at the entry point. Pulp space must be mentally projected with consideration for direction of canals as they leave the pulp chamber and orifices. According to Guttman et al., this requires an astute integration of two-dimensional radiographic findings with three-dimensional tooth anatomy coupled with a safe and dexterous movement of the rotary or ultrasonic tip on the pulpal floor.

- A dental operating microscope (DOM) is recommended to be an integral part of an endodontic practice as the greater magnification and illumination enable a clinician to prevent and manage procedural errors.
- Gouging and perforation of the crown are caused by directing the bur nonparallel to the long axis of the tooth after initial preparation (**Fig. 17.11**). Ledge and perforation occur routinely due to the nonobservance of basic ground rules in preparing an access followed by shaping and cleaning. Discoloration of the crown also occurs due to the same reason.

II. PROCEDURAL ERRORS IN CANAL SHAPING AND CLEANING

The common procedural errors encountered during cleaning and shaping are as follows:

- Canal blockage
- Deviation from normal canal anatomy
  - Ledge formation
  - Transportation
  - Zipping
- Separation of instruments
- Strip perforation

A. Canal Blockage

Blockage of the canal is basically because of inadvertent packing of dentinal debris into the middle and apical third of the root canal during shaping procedures.

Prevention of Canal Blockage

- Always use the smaller sized instruments first (size 10 or size 08 K-files).
- Use the instruments in a sequential order.
- Always precurve stainless steel (SS) hand instruments.
- Use reproducible reference points and stable silicon stoppers on instruments while cleaning and shaping.
- Use copious amounts of irrigants and always work in a wet canal.
- Recapitulate repeatedly. If there is a loss of working length at this step, take a radiograph and confirm. Use smaller sized instruments to dislodge the debris and again flush before proceeding with the next phase of cleaning and shaping.

B. Deviation from Normal Canal Anatomy

Root canal anatomy is always multiplanar curved and not as simple as is visualized in a radiograph. One of the most common operator errors during shaping of root canals is in causing deviation of the canal from the natural anatomy.

i. Ledge Formation

Definition: *Ledge is an artificially created deviation of the root canal wall that prevents the passage of an instrument to the apex of an otherwise patent canal* (**Fig. 17.12**).



Figure 17.12 Ledge formation in the buccal canal of a maxillary premolar.

Causes of Ledging

According to Jafarzadeh and Abbott, the common causes for ledging of a canal are as follows:

- Not extending the access cavity sufficiently to allow adequate access to the shaping instruments to enter the root canal easily
- Complete loss of control of the instrument if the endodontic treatment is attempted through a proximal surface cavity or through a proximal restoration
- Incorrect assessment of the root canal curvature
- Erroneous root canal length determination
- Forcing and driving the instrument into the canal
- Using a noncurved SS instrument that is too large for a curved canal
- Failing to use the instruments in a sequential order
- Rotating the file at the working length (i.e., overuse of a reaming action)
- Inadequate irrigation and/or lubrication during instrumentation
- Overrelying on chelating agents
- Attempting to retrieve broken instruments
- Removing root filling materials during endodontic retreatment
- Attempting to prepare calcified root canals
- Inadvertently packing debris in the apical portion of the canal during instrumentation (i.e., creating an apical blockage)

Prevention of Ledge Formation

- A preoperative radiograph is taken to assess and anticipate the unusual root canal curvature.
- Patency of the canal should be maintained throughout the cleaning and shaping procedure.
- Recapitulation with smaller instruments in between each change of instrument is the recommended method to prevent ledge formation.
- Work passively without forcing the instruments into the canal.
- Never force an instrument apically. If resistance exists, confirm whether there is blockage due to other causes.
- Work sequentially by increasing the sizes of instruments without jumping to large numbers.

Clinical Note

- Early recognition of having created a ledge is significant.
- Ledges created by smaller instruments are easier to bypass and make the pathway to the main canal easier, while larger instruments tend to create a table.
- Precurve or overcurve the apical 3–4 mm of the file with the same curvature as seen in the radiograph and tease the file until it is able to bypass the ledge.
- If the ledge is closer to apical terminus, complete the canal shaping and cleaning and obturate with an injectable thermoplastic obturation technique.

ii. Transportation

If the instrument remains within the confines of the root canal, the elliptic preparation will produce *internal transportation* of the foramen, and if the instrument is outside the confines of the root canal, it will produce *external transportation* of the foramen (**Fig. 17.13**).

iii. Zipping

Definition: *Zipping is defined as the apical transportation of a curved canal caused due to improper shaping technique.*

Clinical Note

- Always precurve the initial small-sized hand instruments.
- Do not skip sizes of instruments while cleaning and shaping.
- Never rotate the instruments in curved canals.

When a file is rotated in a curved canal at the apical area, a biomechanical defect results in the form of an *elbow*. Less-flexible instruments may overcut the outer surface of the curved canal and may produce an elliptic preparation in the apical third that is difficult to obturate. This elliptic preparation is cone shaped, with the apex or elbow toward the middle third of the canal and the base or "zip" toward the cementum surface (**Fig. 17.14**).

Elbow

Definition: *Elbow is the narrowest portion of the zipped canal.* A zipped canal is apical to the elbow and usually obturation ends at the elbow.

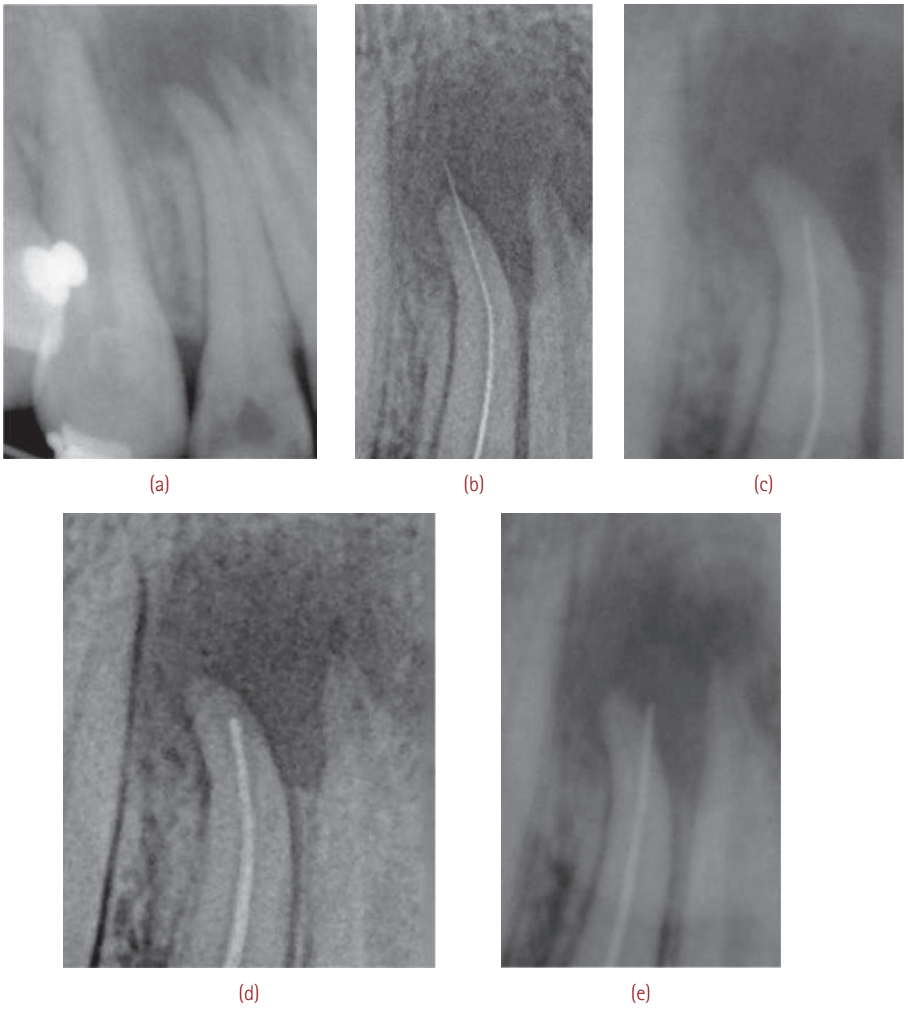


Figure 17.13 (a) Maxillary lateral incisor with apical curvature requiring endodontic therapy. (b) Initial file is able to follow the curvature in the apical third. (c) Shaping and cleaning with a bigger sized file starts to transport the canal. (d) Loss of working length along with zipping of the canal evident. (e) Zipping causing external transportation and apical perforation.

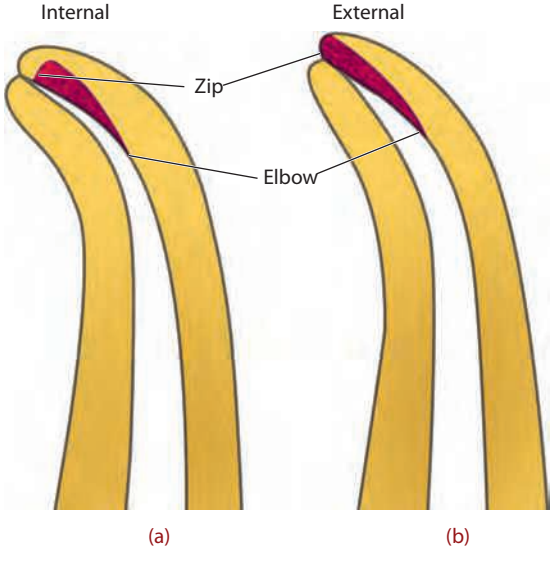


Figure 17.14 (a) Internal transportation of a root canal. (b) External transportation of a root canal.

Creation of an "elbow" is associated with zipping and describes a narrow region of the root canal at the point of maximum curvature as a result of the irregular widening that occurs coronally along the inner aspect and apically along the outer aspect of the curve.

Management

Prevention is the best form of management of canal transportation. Adhering to the principles of root canal instrumentation and appreciation of canal anatomy and instrument dynamics would help in the prevention of this form of procedural error.

In cases of a zip or transportation, any type of obturation can be used but thermoplasticized obturation techniques are the preferred method of obturation.

C. Instrument Separation in the Canal

Refer Chapter 21 for details regarding instrument separation and clinical management of the same.

D. Strip Perforation

Definition: Strip perforation is defined as a perforation due to inappropriate shaping technique causing severe deviation from the normal root canal anatomy and leading to pathologic communication with the surrounding periodontal tissues.

Management

- Strip perforation can be clinically recognized when bleeding occurs during shaping even after the complete removal of the pulpal tissue within the root canal.
- Clinical management is in achieving hemostasis followed by sealing the perforation with tricalcium silicate–based cements/MTA.
- These procedures are always recommended to be performed using a DOM.



Clinical Note

- The use of stainless steel (SS) instruments of larger sizes above ISO 20 is normally associated with increased probability of shaping errors that cause canal deviation. A common operator error is in using larger sized SS instruments in an aggressive manner. As SS instruments are stiffer, operator errors are increased when using larger sized SS instruments.
- The use of nickel titanium instruments in the right protocol is the safest and most predictable method to shape complex root canals without causing any canal deviation.
- Avoid reusing endodontic instruments and preferably follow a single-use philosophy for shaping instruments.

III. PROCEDURAL ERRORS WITH OBTURATION

A. Underfilling of gutta-percha
B. Overfilling of gutta-percha

A. Underfilling of Gutta-Percha: Inability to Seat the Master Cone to Estimated Full Working Length

This happens mainly due to loss of working length as a result of packing dentinal mud into the pulp space without recapitulation or insufficient irrigation. The use of small-sized files to dislodge the packed dentinal mud and irrigation with sodium hypochlorite frequently is recommended.

Obtain a radiograph after this procedure and reposition the master cone. Take a confirmatory radiograph and proceed with obturation after using a suitable sealer depending on the technique chosen.

B. Overfilling of Gutta-Percha: Shaping of Canal Beyond the Working Length

Instrumenting beyond constriction during root canal therapy should not routinely happen if the basic biological and mechanical principles are observed as cardinal rules.

Apart from other basic tenets, the following are to be observed:

- A continuous tapered funnel preparation is a mandatory requirement for all canals receiving gutta-percha as obturating material by any technique.
- Accurate estimation of the working length.
- Reproducible reference points.
- Verify working length frequently with radiographs and electronic apex locators.
- Adhere to the cardinal rules of shaping and cleaning.
- An apical stop is mandatory while shaping and cleaning is done. It is also important that if an apical stop is not present, we have to obtain an artificial apical stop to limit the flow of sealant and to obtain a stop against which softened gutta-percha can be condensed comfortably.
- When placing a master cone to the estimated working length, obtain more than one radiograph.
- The master cone is sometimes placed slightly short of the working length, especially in wide canals, so that the gutta-percha when compacted thermally will flow into the constriction and apical ramifications.

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18 Prosthodontic Considerations in Endodontically Treated Teeth

Our objective should be the perpetual preservation of what remains than the meticulous restoration of what is missing.
—M. M. De Van

A successful endodontic treatment has to be complemented with an adequate postendodontic restoration to make the pulpless tooth function indefinitely as an integral part of the oral masticatory apparatus. Endodontically treated teeth fail principally due to one of the following two reasons:

1. Persistent intraradicular infection
2. Postendodontic restorative difficulties

Careful postendodontic restoration is required, as the cumulative loss of tooth structure due to caries, trauma, and endodontic procedures combined with the loss of structural integrity contributes to the fracture of the tooth. Ideally, the final restoration should be planned before the root canal treatment is begun, although the restorative plan may be modified as the treatment progresses.

ASSESSMENT OF RESTORABILITY

An endodontically treated tooth must be evaluated before definitive restorative procedures are initiated. Evaluation factors (**Fig. 18.1**) are used to determine whether the endodontically treated tooth is restorable, unrestorable, or restorable after successful retreatment. Definitive restorative treatment should not be initiated if the treated tooth exhibits any of the following:

- Poor root canal filling
- Active inflammation
- Pressure sensitivity
- Exudate
- Fistula (or parulis)
- Periodontal disease (moderate or severe periodontitis)
- Severe loss of sound tooth structure (tooth would not benefit from crown lengthening or orthodontic extrusion)

In short, seven categories of infection, trauma, inflammation, unacceptable endodontics, or lack of restorability, as listed, can delay or end up in no definitive restorative treatment (**Figs 18.2** and **18.3**).

The choices of treatment for such cases include the following:

- Retreatment: Endodontic retreatment (can reverse inflammation, permitting the tooth to receive restorative treatment)
  - Nonsurgical endodontic retreatment
  - Surgical endodontic retreatment
- Periodontal treatment (tooth will require stabilization)
- Monitoring (time to assess progressive healing)
- Extraction (unrestorable)

If none of the aforementioned problems exist, a definite restorative treatment may be initiated. The treatment guidelines for anterior and posterior teeth are slightly different as they differ both morphologically and functionally.

ANATOMICAL, BIOLOGICAL, AND MECHANICAL CONSIDERATIONS IN RESTORING ENDODONTICALLY TREATED TEETH

There is scientific information to support the contention that endodontically treated teeth have special needs that exceed the requirements of the teeth with viable pulp.

This is because endodontically treated teeth are associated with unique structural and functional challenges. These include the following:

- The role of moisture loss and the nature of dentin
- Alterations in strength caused by architectural changes in the morphology of the teeth
- Concepts of the biomechanical behavior of tooth structure under stress
- Biological width
- Protecting the remaining coronal tooth tissue—creating the ferrule

MOISTURE LOSS

- In 1972, Helfer et al. determined the moisture content of vital and pulpless teeth. This study demonstrated 9% less moisture in the calcified tissues of pulpless dog teeth than that in vital teeth. This was the first investigation lending credence to the empirical assumption that pulpless teeth may have increased brittleness from moisture loss, but there is still sparse additional evidence to support this concept. It was thought that the dentin in endodontically treated teeth was more brittle due to loss of collagen cross-linking and loss of water.
- In 1991, Huang et al. proved that neither endodontic treatment nor dehydration caused degradation of the physical or mechanical properties of dentin.
- Sedgley and Messer also proved that the hardness levels of both vital and nonvital teeth are comparable.

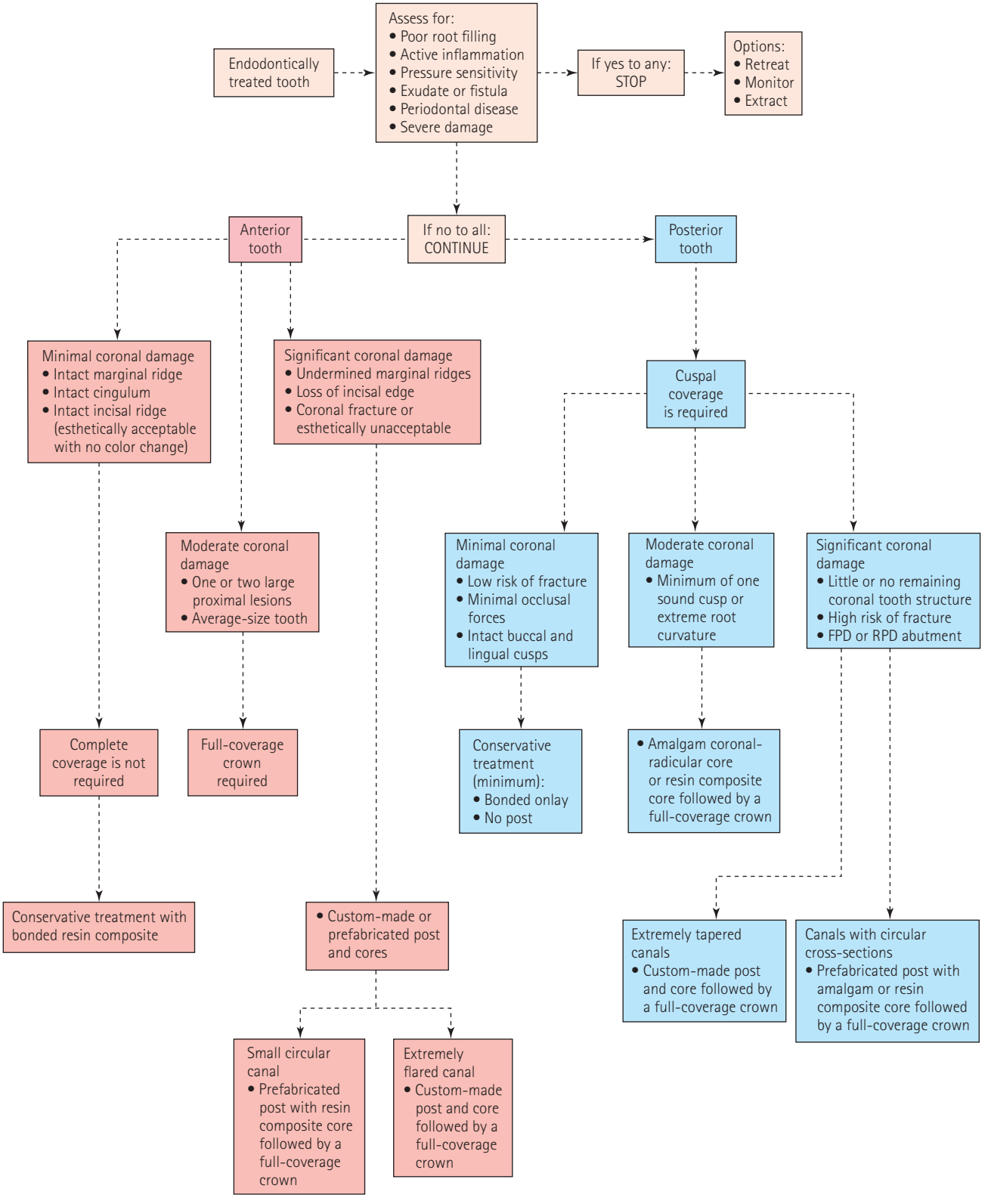
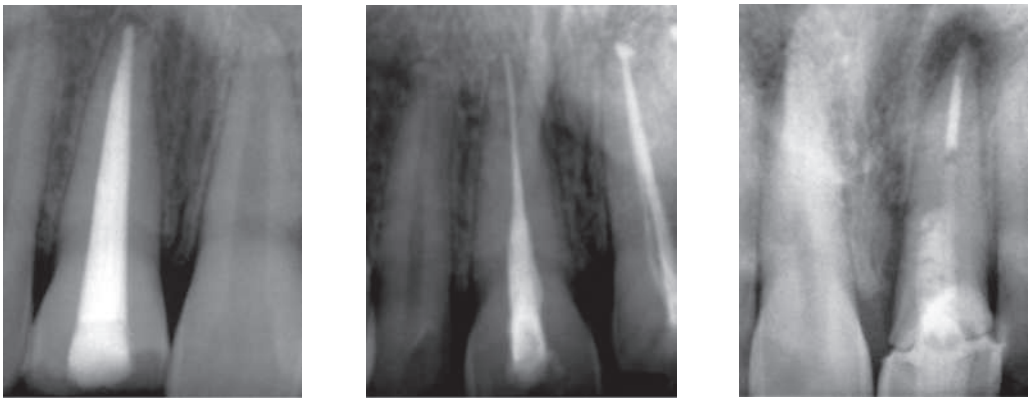
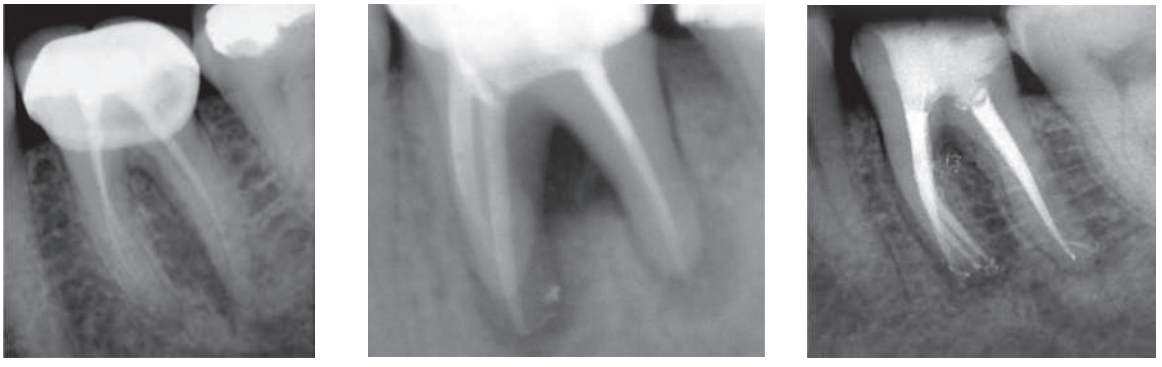


Figure 18.1 Restorative decision-making chart. FPD, fixed partial denture; RPD, removable partial denture; MOD, mesio-occlusal-distal.



(a) (b) (c)

Figure 18.2 (a) Anterior endodontically treated tooth with clinical and radiographic signs of healing. This tooth can proceed for a definitive prosthodontic restoration. (b) Poorly obturated maxillary central incisor necessitating the need for retretreatment prior to prosthodontic restoration. (c) Maxillary central incisor with a post and core exhibiting clinical signs of failure along with radiographic periradicular changes. This tooth has a guarded prognosis.



(a) (b) (c)

Figure 18.3 (a) Poorly obturated mandibular first molar necessitating the need for retreatment prior to a prosthodontic restoration. (b) Endodontically treated molar with persisting periradicular and periodontal lesion necessitating the need for periodontal therapy and monitoring before planning for a definitive prosthodontic restoration. (c) Well-obturated molar with clinical and radiographic signs of healing. This tooth can proceed for a definitive prosthodontic restoration.

Clinical Note

Dehydration of dentin and degradation of collagen are no longer considered to be a cause for endodontically treated teeth requiring specific restorative procedures.

ARCHITECTURAL CHANGES

- The decrease in the strength of endodontically treated teeth due to altered coronal structure has been documented. A mesio-occlusal-distal (MOD) cavity preparation *reduced tooth stiffness* by more than 60%, with the *loss of the marginal ridge contributing to greatest loss of tooth strength*. This compromise of architectural integrity has been the object of research with respect to cuspal anatomy, flexure, and strength.
- The *loss of tooth structure* due to a combination of dental caries, trauma, previous restorative procedures, and endodontic access cavity preparation contributes to the reduction in structural integrity of a tooth (**Fig. 18.4**).

BIOMECHANICAL BEHAVIOR

- The biomechanical behavior of endodontically treated teeth has been found to be *functionally different* from that of vital teeth. Tidmarsh described an intact tooth as a hollow, laminated structure that deforms under load but exhibits complete elastic recovery after physiologic loading.
- It has been reported that teeth have a *proprioceptive feedback mechanism* that is lost when the pulp is removed.

This loss might contribute to the endodontically treated teeth to be subjected to greater loads than normal vital teeth and ultimately leading to failure.



Figure 18.4 Clinical picture of a structurally compromised tooth after removal of previous restoration and endodontic treatment.

BIOLOGICAL WIDTH

Definition: The term *biological width* refers to the combined vertical dimension of the *junctional epithelium* and the *supra-alveolar connective tissue*.

Adequate space is required between the margin of the restoration and the crest of bone to have a healthy gingival attachment apparatus. Gargiulo et al. found the dimensions of the attachment apparatus to range from 1.77 to 2.43 mm. This means that there should be an *absolute minimum of 2.5 mm between the restoration margin and the crest of bone* (**Fig. 18.5**). This width is referred to as the *biological width*.

- The **mean biological width** was found to be **1.91 mm**, which consisted of:
  - Junctional epithelium (1.14 mm)
  - Connective tissue attachment (0.77 mm)
- The **mean sulcus depth** was found to be **1.32 mm**.

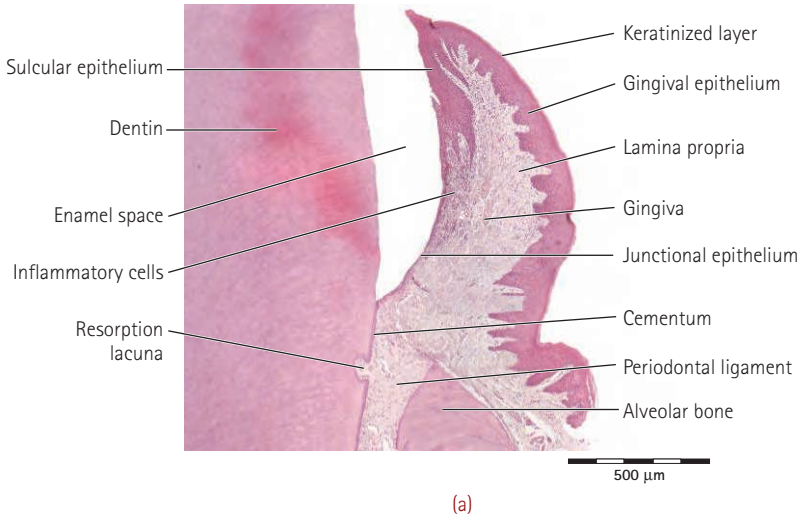


Figure 18.5 (a) Tooth and its supportive structures. Longitudinal section: periodontal ligament and the gingiva. Stain: H + E. (*Courtesy: Mathias Nordvi, University of Oslo, Norway.*) (b) Schematic diagram illustrating the biological width in millimeter.

Clinical Note

- The biological width is preserved when the restoration is placed allowing for approximately 2 mm for the connective tissue and junctional epithelium and 1 mm for the sulcus.
- **Three to four mm is the minimum necessary distance from the gingival margin to the alveolar crest** that ensures periodontium healing after tooth preparation with quick reestablishment of the junctional epithelium and connective tissue integrity.

An adequate bulk of tooth coronal to the restoration margin is required to restore the tooth. The amount of coronal tooth structure, along with the position of the tooth in the arch, will dictate the type of core indicated, whether a prefabricated post or a cast post and core is indicated, and whether a crown is needed.

Clinical Note

The clinician should ensure that the restoration margin does not impinge onto the biological width as it would cause periodontal breakdown.

CROWN FERRULE

Definition: *A ferrule is defined as a band of extracoronal material at the cervical margin of a crown preparation that encompasses the tooth and provides resistance form to the tooth. This is usually provided by the crown that is placed over the post and core system.*

- It is of paramount importance that as much coronal or supragingival tooth tissue is preserved as possible, as this significantly improves the prognosis of the tooth and restoration.
- *One to 2 mm of tooth tissue coronal to the finish line of the crown preparation significantly improves the fracture resistance of the tooth* and is more important than the type of core and post material (**Fig. 18.6**).
- The word *ferrule* is thought to be derived from the Latin word *ferrum*, meaning iron, and *viriola*, meaning bracelet. Thus, the ferrule effect occurs because of the crown bracing against the remaining supragingival tooth tissue (**Fig. 18.7**).

Clinical Note

- Various studies comparing restored teeth prepared with and without a ferrule have shown that the *ferrule reduced the incidence/possibility of vertical root fracture by one-third*.
- When failure occurred in teeth with a ferrule, it was most commonly due to horizontal fracture compared to the vertical root fracture seen in teeth with no ferrule. Thus, the teeth were more likely to be retrievable.
- A study by Libman and Nicholls investigating the effect of cyclic loading on cast post and cores with ferrules 0.5, 1, 1.5, and 2 mm high has shown that the **1.5- and 2-mm ferrules are clinically recommended**.

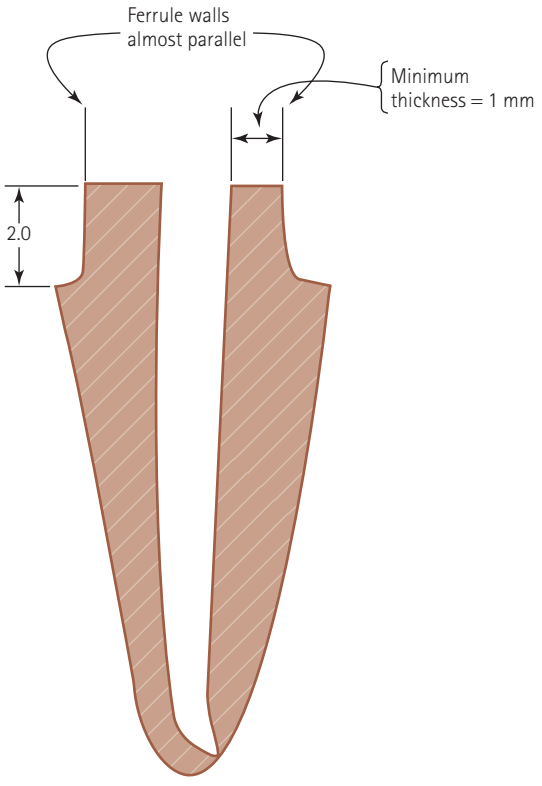


Figure 18.6 Schematic diagram illustrating the ferrule.

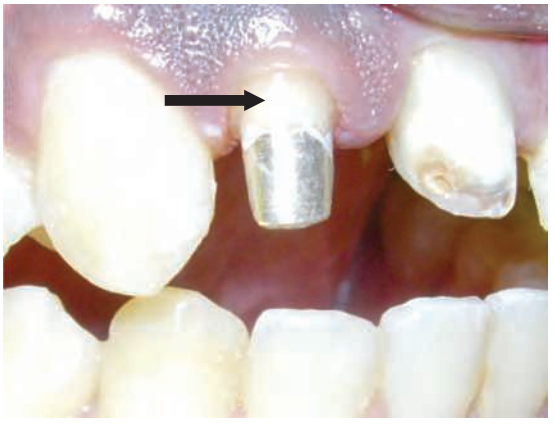


Figure 18.7 Cast post and core in the maxillary lateral incisor with sufficient crown ferrule.

The height of the ferrule at different locations around the circumference of the tooth may also be important due to functional occlusal loading.

Clinical Note

- A 1.5- to 2 mm ferrule can be recommended labially and lingually, whereas a shorter 1-mm ferrule could be accepted mesially and distally due to decreased stress in these directions
- Maxillary incisor → Longer ferrule on the palatal aspect
- Mandibular incisor → Longer ferrule on the labial aspect

RESTORATIVE TREATMENT PLANNING OF NONVITAL TEETH

Restorative treatment decisions depend on the following:

- Amount of the remaining tooth structure
- Functional demands that will be placed on the tooth
- Need for the tooth as an abutment in a larger restoration

Posterior teeth carry greater occlusal forces than anterior teeth, and restorations must be planned to protect posterior teeth against fracture. The horizontal and torquing forces endured by abutments for fixed or removable partial dentures dictate more extensive protective and retentive features in the restoration. Teeth with minimal remaining tooth structure face the following challenges:

- They have an increased risk for fracture.
- They provide decreased retention for the restoration.
- They are in jeopardy for invasion of the periodontal attachment.

As the remaining tooth structure decreases and functional forces increase, greater restorative control is needed. Extensively damaged or missing tooth structure fundamentally alters the use of restorative procedures and the need for adjunctive treatment from the other specialties. Misunderstanding or misuse of integrated therapy can lead to an ever-shortening cycle of treatment, breakdown, and retreatment.

CORE

The core consists of restorative management of the coronal portion of a tooth after the completion of endodontic treatment.

This material replaces carious, fractured, or otherwise missing coronal structure and retains the final crown. If sufficient coronal tooth structure remains to provide retention to the core, then a post may not be required.

The core is anchored to the tooth by extending into the coronal aspect of the canal or through the endodontic post. The attachment between the tooth, post, and core is mechanical, chemical, or both, as the core and post are usually fabricated of different materials. The remaining tooth structure can also be altered to augment the retention of the core or to provide resistance to core rotation under function. Pins, grooves, and channels can also be placed in the dentin in a position remote from the post space.

However, these modifications increase the core retention and resistance to rotation at the expense of the tooth structure. In most cases, the irregular nature of the residual coronal tooth structure and the normal morphology of the pulp chamber and canal orifices eliminate the need for these tooth alterations.

Using restorative materials that bond to the tooth structure enhances retention and resistance without the need to remove valuable dentin. Therefore, if additional retentive or antirotation form of the core is deemed necessary, dentin removal should be kept to a minimum.

The desirable physical characteristics of a core include the following:

- High compressive strength
- Dimensional stability
- Ease of manipulation
- Short setting time
- An ability to bond to the tooth (and post if a post is indicated)

Unfortunately, an ideal core material does not exist. The most commonly used core materials are as follows:

- *Dual cure resin-based composite* offers an esthetically pleasing material, especially in the anterior region under an all-porcelain restoration. It has good strength characteristics and low solubility and is the recommended material of choice for core buildups for both anterior and posterior teeth.
- *Silver amalgam* has good mechanical properties (high strength and low solubility) and can be employed as a core buildup material alone or in conjunction with pins or posts. However, silver amalgam used as a core material is diminishing due to concerns over mercury toxicity and the advent of composite core buildup material.
- *Cast gold* has been used successfully for many years, as it exhibits high strength and low solubility. Placing cast gold post and core, however, is an indirect procedure requiring two visits. Both gold and amalgam are not esthetically pleasing, especially under newer all-ceramic restorations.
- *Glass ionomer cement (Type IX)*, on the other hand, has been shown to be weak in tensile and compressive strengths, and it has low fracture resistance as a core. It also exhibits a low modulus of elasticity, poor condensability, and high solubility. Therefore, *the use of glass ionomer cement as a core material should be avoided.*



Clinical Note

- The most ideal and recommended core buildup material to be used in contemporary endodontics is **dual-cure resin-based composite**.
- The use of *amalgam is diminishing* with the call to restrict the use of mercury due to its environmental impact.
- *Glass ionomers should not be used as a core buildup material.*

POSTENDODONTIC EVALUATION OF TEETH

Anterior and posterior teeth function much differently; therefore, they must be evaluated separately.

ANTERIOR TEETH

The anterior tooth receives predominately *shear forces*, which act on both the clinical crown and the root. Although some laboratory studies have indicated that a post strengthens an intact anterior endodontically treated tooth, the majority of studies have suggested that the fracture resistance of these teeth is not affected by, or is decreased with, placement of a post.



(a) (b)

Figure 18.8 (a) Retention of a core in endodontically involved maxillary central incisor is possible without the need for a post. (b) Extensive loss of the tooth structure necessitates the placement of a post prior to the placement of the core and final coronal restoration.

Therefore, when a complete coverage restoration is not required for esthetic or functional reasons (e.g., to serve as an abutment for a fixed or removable partial denture), a post is not indicated. However, if a complete coverage restoration is indicated in an endodontically treated anterior tooth for esthetics or function, a post may be indicated. This is especially true for maxillary lateral incisors and mandibular incisors.

With maxillary central incisors and canines, the decision to place a post should be based on:

- Amount of the remaining coronal tooth structure (**Fig. 18.8**)
- Occlusion and function of the tooth

If there is a significant amount of remaining coronal tooth structure, the crown preparation should be accomplished before the decision regarding post placement is made. Once the axial preparation is completed and the access preparation is cleaned, the dentist can make the decision as to whether the remaining coronal tooth structure and core needs the retention of a post.

If the remaining coronal tooth structure is adequate to support the core and crown, based on the functional requirements of the tooth, the resin composite core can be bonded into the access preparation. However, if there is doubt regarding the adequacy of the resistance form of the coronal portion of the tooth, then a post and core is indicated.

Clinical Note

- A full-coverage crown is *not mandatory* for every endodontically treated anterior tooth.
- The clinical decision is based on the extent of loss of tooth structure and esthetics:
  - Only access cavity preparation with no discoloration → Etched resin composite core buildup restoration
  - Loss of one or both the proximal walls and/or significant discoloration that cannot be managed by bleaching → Etched resin composite core buildup restoration followed by full-coverage crown
  - Extensive loss of tooth structure → Post and core followed by full-coverage crown

POSTERIOR TEETH

For the posterior tooth, the decisions are clearer. The forces on posterior teeth are predominantly vertical. *Endodontically treated posterior teeth should receive cuspal coverage*, but in most cases do not require a post. A post is indicated in a posterior tooth only when other more conservative retention and resistance features cannot be used for the core. These features include chamber retention, which is shown to be exceedingly effective.

In 1980, Nayyar and Walton described the *amalcore*, or *coronal–radicular*, restoration. This technique advocates the removal of gutta-percha (2.0–3.0 mm) from the coronal third of the obturated root canals followed by core buildup into this space along with the pulp chamber space. These intraradicular extensions of the core material act as effective retentive aids. The coronal–radicular buildup has proved to be a predictable and cost-effective restorative modality for posterior endodontically treated teeth.

Although a post is not commonly required to retain the core in a posterior tooth, it is indicated when:

- There is extensive loss of the coronal tooth structure, *or*
- The tooth is to serve as an abutment for a removable or fixed partial denture. In this circumstance, the forces that play on the tooth are not physiologic, and coronal reinforcement may be necessary.

Clinical Note

In posterior teeth, posts are most commonly placed in:

- Palatal canal of maxillary molars (**Fig. 18.9**)
- Distal canal of mandibular molars
- Palatal canal of maxillary premolars

Maxillary premolars are a unique subset of posterior endodontically treated teeth. Because these teeth are subjected to a mixture of shear and compressive forces, a post and core in a maxillary premolar is needed in the following cases:

- If the remaining coronal tooth structure is inadequate, the clinical crown is tall in relation to its diameter at the point where it enters the alveolar bone.

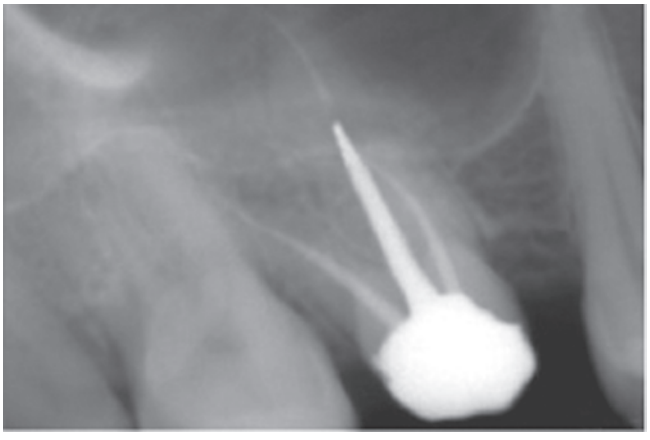


Figure 18.9 Post in the palatal canal of a maxillary first molar.

- If the tooth receives significant lateral stress, a post may be indicated.
- In addition, if the premolar serves as an abutment for a removable or fixed partial denture, a post and core may be indicated.

Clinical Note

- The primary function of a post is to provide *retention* of the core material.
- A post does not strengthen or increase the fracture resistance of a tooth.

FACTORS DETERMINING POST SELECTION

An ideal post system should have the features as given in **Box 18.1**.

The clinician should be knowledgeable in selecting the right type of post and core systems to meet the biological, mechanical, and esthetic needs for each individual tooth. The principles which are to be taken into consideration during treatment planning for a post and core restoration are provided in **Box 18.2**.

Box 18.1

Ideal Features of an Endodontic Post

- Provide maximal retentiveness to the core
- Physical properties compatible to dentin
- Maximum retention with minimal removal of dentin
- Even distribution of functional stresses along the root surface
- Esthetic compatibility with the definitive restoration and surrounding tissue
- Minimal stress during placement and cementation
- Resistance to displacement
- Easy retrievability
- Material compatibility with core
- Ease of use, safety, and reliability
- Reasonable cost

Box 18.2

Clinical Factors Influencing Post and Core Restorations

I. Post length
II. Tooth anatomy
III. Post width
IV. Canal configuration and post adaptability
V. Post design
VI. Luting cement

I. POST LENGTH

- The length and shape of the remaining root determines the length of the post. It has been suggested that root length should be considered for the selection of the ideal post length.
- It has been demonstrated that *the greater the post length, the better the retention and stress distribution*. However, it may not always be possible to use a long post, especially when the remaining root is short or curved.
- Several studies suggest that it is important to *preserve 4–6 mm of apical gutta-percha* to maintain the apical seal. Also, the post length should be equal to the length of the crown or two-thirds the length of the root, whichever is greater (**Figs 18.10** and **18.11**).
- When the root length is short, the clinician must decide whether to use a longer post or to maintain the recommended apical seal and use a parallel-sided cemented post. For molars with short roots, the placement of more than one post will provide additional retention for the core foundation restoration.
- The clinical considerations to be taken while selecting the length of a post are given in **Box 18.3**.

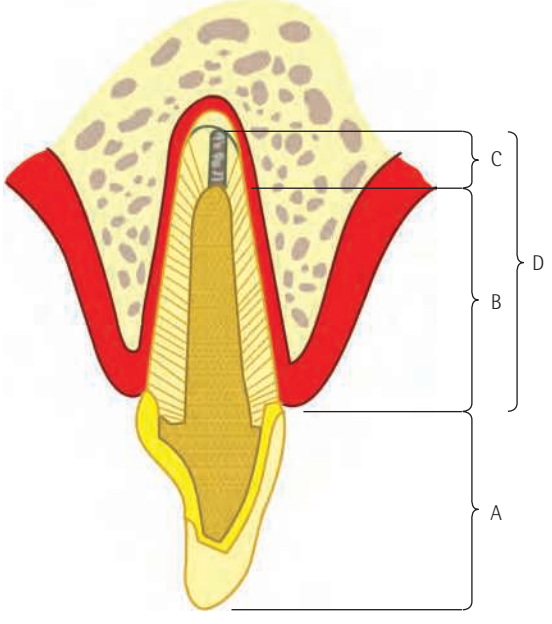


Figure 18.10 To provide optimal retention, the post should equal the crown in length (A = B), or be two-thirds the length of the root (B = D), whichever is greater. The length of gutta-percha remaining at the apex (C) should be a minimum of 4 mm.



Figure 18.11 Ideal length of a post with 5 mm of apical seal.

Box 18.3

Clinical Considerations on Post Length

In long-rooted teeth	The post can be *as long as possible* without disturbing the apical gutta-percha seal (even three-fourths the length of the root).
In average to short-rooted teeth	The post length is determined by retaining *at least 4 mm of apical gutta-percha in order to ensure apical biological seal*. The remaining canal space is utilized as the post length.
In teeth with horizontal bone loss periodontally	It is desirable to extend the length of the post to at least *4 mm apical to the crest of the bone* or *halfway between the crestal bone and the root apex*.

II. TOOTH ANATOMY

Each tooth in the arch exhibits anatomical characteristics such as root curvature, mesiodistal width, and labiolingual dimension. Hence, root anatomy dictates post selection. Teeth may have anatomical variations, which may adversely affect the post placement. A consideration of the root size and length is important, because improper post space preparation and use of large-diameter posts present the risk of apical or lateral perforation. Moreover, an active post can initiate cracks in the thin dentinal wall.

Gutmann reviewed the anatomical considerations in detail and stated that roots of maxillary centrals, laterals, and also mandibular premolars have sufficient bulk to accommodate most post systems. This knowledge aids the dentist in determining the post suitable for a given root.

Clinical Note

Molar posts *should never extend more than 7 mm into the root canal from the canal orifice.*

III. POST WIDTH

The criteria in the selection of the post width are as follows:

- Preserving the tooth structure
- Reducing the chances of perforation
- Permitting the restored tooth to resist forces

Various investigators have recommended different approaches regarding the selection of the post diameter. These approaches were summarized by Lloyd and Palik into three categories (**Fig. 18.12**):

1. *Conservationist* approach advocates minimal canal preparation and maintaining as much residual dentin as possible, thereby suggesting restriction of the post diameter in an effort to conserve the remaining tooth structure.

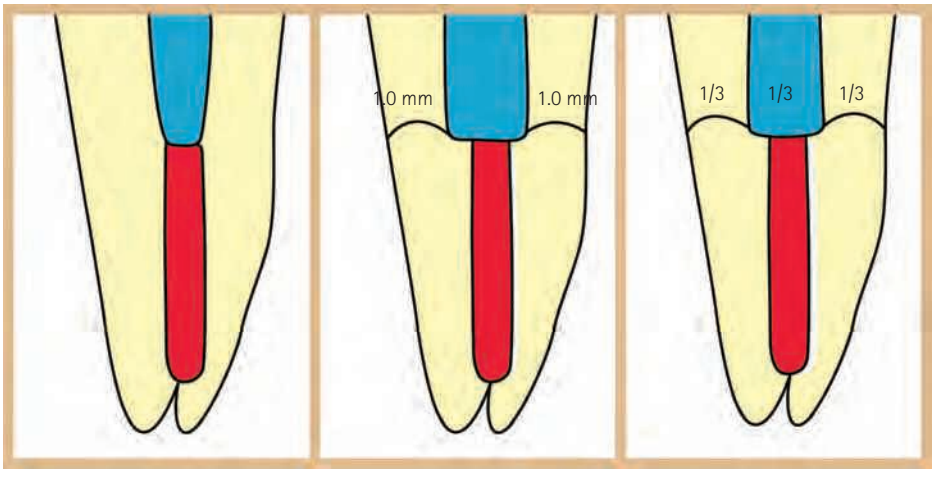


Figure 18.12 Post diameter philosophies: (a) conservationist, (b) preservationist, and (c) proportionist.

Box 18.4

Recommended Post Widths

	Maxillary (mm)	Mandibular (mm)
Central incisor	1.1	0.7
Lateral incisor	0.9	0.7
Canine	1.0	0.9
Premolars and molars	0.9	0.9

2. *Preservationist*—the post should be surrounded by a minimum of 1 mm of sound dentin.
3. *Proportionist*—Stern and Hirshfeld suggested that the post width should not be greater than the root width at its narrowest dimension. This proportionist approach was advocated with the intent of saving sufficient tooth structure.

The influence of the post width on its retention and fracture resistance has also been studied. *It was shown that an increase in the post width has no significant effect on its retention.* The tooth restored with larger-diameter posts is reported to provide the least resistance to fracture with a decrease in the width of the remaining dentin.

Tilk et al. evaluated maxillary and mandibular teeth and recommended a range of post widths (**Box 18.4**).

IV. CANAL CONFIGURATION AND POST ADAPTABILITY

- Canal configuration aids in making a choice between a custom-designed post and a prefabricated post. If the selected post closely fits or conforms to the canal size, it may be a more conservative option because less dentin removal is required, thus enhancing the resistance of the tooth, as well as retention of the post.
- Often, a dilemma arises in funnel-shaped canals, whether to use a parallel-sided post and fill the remaining post space with cement or to use a tapered post that closely adapts to the canal wall.
- It has been suggested that if a canal requires extensive preparation, a *well-adapted cast post and core restoration will be more retentive than a prefabricated post that does not match the canal shape*. A recent investigation regarding custom-cast posts reported a success rate of more than 90% after 5 years in function.
- In vitro studies have demonstrated that a well-adapted tapered post on fracture resulted in an extensive loss of the tooth structure compared with teeth restored with well-adapted, passively cemented, parallel-sided posts. Clinically, tapered custom-cast posts are recommended only in canals with irregular anatomy.

V. POST DESIGN

The available post design classification is provided in **Box 18.5**.

Box 18.5

Classification of Endodontic Posts

A. Based on shape
   (i) Parallel
   (ii) Tapered
   (iii) Parallel and tapered
B. Based on surface characteristics
   (i) Active
   (ii) Passive
C. Based on fabrication methods
   (i) Custom-cast post and cores
   (ii) Prefabricated post and cores
      - Metal post and core
      - Zirconia post and core
      - Fiber-reinforced composite post and cores

A. Based on Shape

(i) *Parallel*: Parallel-sided post designs have been shown to increase retention and produce uniform stress distribution along the post length. Concentration of stress has been reported to occur at the apex of the post, especially in a narrow and tapering root end. The various commercially available parallel posts include the following:
- Parallel-sided serrated and vented posts
- Parallel-sided threaded posts
- Parallel-sided threaded split-shank posts

(ii) *Tapered*: Several studies have implicated the active post design as a cause of failure of the post- and core-restored teeth. Of the designs studied, the tapered post conforms to the natural root form and canal configuration, thus permitting optimal preservation of the tooth structure at the post apex. However, this design is reported to produce a *wedging effect*, stress concentration at the coronal portion of the root, and lower retentive strength. The various commercially available tapered posts include the following:
- Tapered smooth-sided posts
- Tapered self-threading posts

(iii) *Parallel and tapered combination*: In the parallel-tapered design, the post is parallel throughout its length except for the most apical portion, where it is tapered. The coronal parallel design provides retention while the apical tapered design permits preservation of dentin in the apical part of the root canal.

Clinical Note

- Parallel posts are clinically recommended due to their better stress distribution and improved retention abilities.
- The only tapered post design that is clinically recommended is the custom-cast post and core system.

B. Based on Surface Characteristics

- *Active posts*: They mechanically engage the dentin with threads.

- *Passive posts*: They depend on the cement and its close adaptation to the canal wall for their retention.

The surface characteristics of the post also change the retentive and fracture resistance values. The highest retention is observed in the threaded post, followed by the post with a serrated surface. The least retention is seen with smooth-surface posts. Unfortunately, the threaded post engages in the dentin and may lead to increased undesirable stresses within the root.

An analysis of the available clinical studies suggests that the performance of a threaded post is inferior to that of a custom-cast post. Of all the designs studied, the *threaded tapered screw post exerts a greater amount of stress and was considered the least desirable* (**Fig. 18.13**). The parallel-sided, serrated, and vented posts were found to exert the least amount of stress.

Clinical Note

- Active posts have better retentive abilities but are clinically not recommended as they decrease the fracture resistance of the root.
- Passive cemented posts are clinically recommended.

C. Based on Fabrication Method

(i) Custom-Cast Post and Core

The custom-cast post has the advantage of conforming closely to the configuration of the prepared canal (**Fig. 18.14**). This is especially significant when the canal is severely flared. The retentive and protective characteristics of custom-cast posts are such that they are less retentive than the parallel-sided posts with little or no stress associated with their installation. However, they might act as wedges during occlusal load transfer resulting in vertical fracture of the roots (**Table 18.1**).

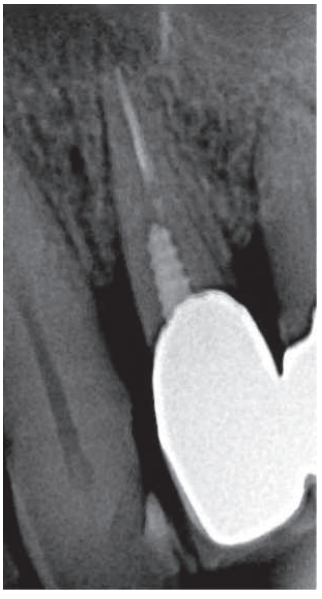
Cast Post and Core Fabrication Technique

Cast post and core restorations can be fabricated with either direct or indirect techniques:

- *Direct technique:* The direct technique of making a custom post and core is a chair-side procedure wherein the fabrication of the resin or wax pattern on the prepared tooth is done in the patient's mouth. Some form of plastic dowel or thin metal post is used as the central reinforcement around which the resin or wax pattern is formed. This post and core pattern is then invested and cast to form the direct custom-cast post and core.
- *Indirect technique:* An impression is made of the post core preparation and the resin or wax pattern is fabricated on



(a)



(b)

Figure 18.13 (a) Active threaded posts. (b) Vertical root fracture attributed to the active threaded post in this tooth.

Table 18.1 Merits and Demerits of Cast Post and Core Systems

Advantages	Disadvantages
• Are custom fit to the root configuration • Are adaptable to large, irregularly shaped canals and orifices and are ideal when the core has to be angled to the post in cases of misaligned teeth • Can be efficiently fabricated when multiple teeth require posts • Are strong with the post and core forming a single unit with no interface between them • Have considerable documentation to support their effectiveness	• Require two appointments and involve additional laboratory fee • Are less retentive than parallel prefabricated posts • Temporization between appointments is more difficult • Corrosion can occur due to the casting process or because of the use of dissimilar alloys • There is risk of casting inaccuracies

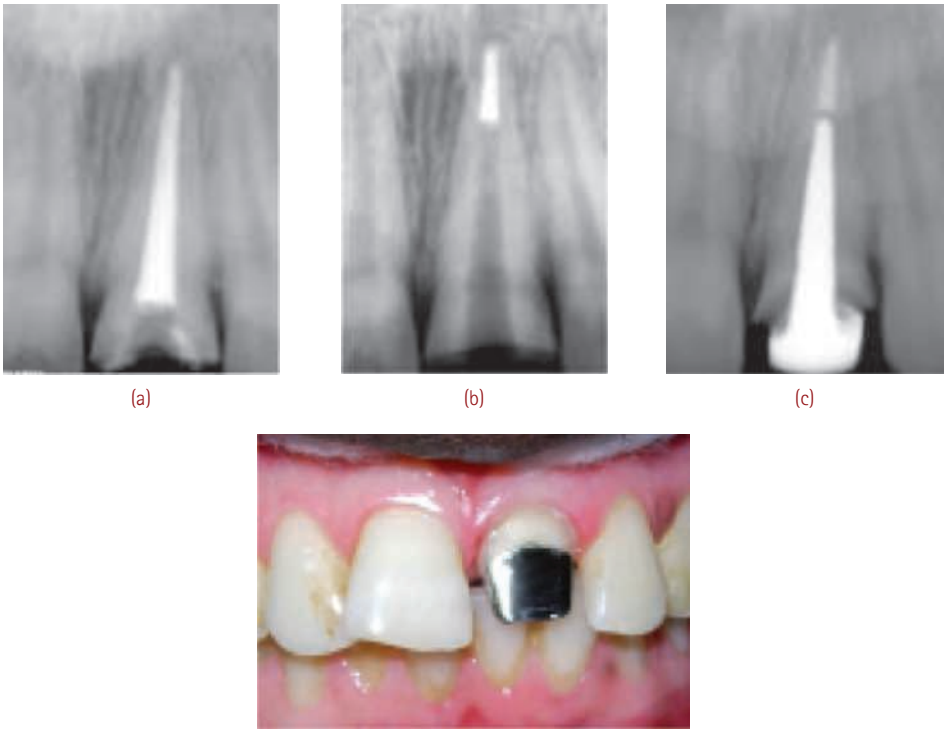


Figure 18.14 Custom-cast post and core: (a) Postobturation view in a maxillary central incisor with an oblique crown fracture. (b) Post space preparation completed with apical 5 mm of remaining gutta-percha. (c) Cast post and core seated in the post space. (d) Cemented cast post and core.

the dental stone cast which is then invested and cast to form the indirect custom-cast post and core.

Posterior teeth can also be restored with custom-cast post and cores. Mandibular premolars are treated in the same way as the anterior teeth. When they are used on molars, largest canals such as the palatal canal are used on maxillary molars (**Fig. 18.9**) and distal canals on mandibular molars.

Clinical Note

- The custom-cast post and core is recommended whenever more than *three-fourth* of the coronal tooth structure is lost.
- The prefabricated post and core systems are recommended when the loss is restricted between *one-half* and *two-third* of the coronal tooth structure.

(ii) Prefabricated Post Systems

Metal Post

Traditionally, posts were made of metal alloys. The most commonly used alloys are nickel chromium alloy, stainless steel, and titanium alloy. Active metal posts are not advocated due to their predilection for causing root fractures (**Fig. 18.15a**). Passive metal posts which are tapered in design offer least retention but allow minimal removal of radicular dentin. Hence, the *commonly advocated metal posts are passive and parallel in design* (**Fig. 18.15b**).

Ceramic Post

Theoretically, ceramic posts and cores should have good esthetic and biological properties, and these newer, reinforced ceramic posts will work clinically as an alternative to metal posts. The main disadvantage of ceramic materials has been principally associated with their low flexural strength compared with that of metals, and in function, ceramic materials have a record of frequent failure in high-stress situations.



Figure 18.15 (a) Active threaded metal post. (b) Passive serrated metal post.

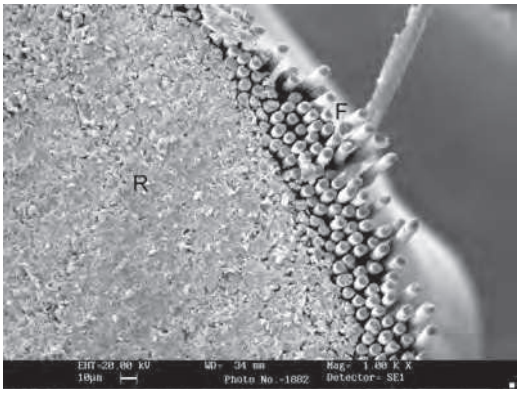
These post and core systems are *not recommended* because of the following reasons:

- In a study, preformed ceramic posts were reported to be significantly more rigid than the parallel-sided stainless steel posts. The metal posts were also significantly more retentive than the ceramic posts bonded using a variety of luting and bonding agents and surface preparation techniques.
- The most common failure of metal posts is *post loosening* while the most common failure of ceramic posts is *post fracture*. This is a disadvantage as removal of a fractured ceramic post is difficult.

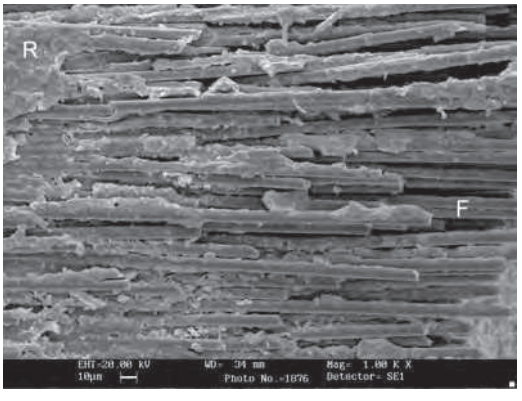
Glass Fiber–Reinforced Epoxy Resin Posts

The addition of fibers to an epoxy polymer matrix can result in a significant improvement in the mechanical properties of strength, fracture toughness, stiffness, and fatigue resistance of the resultant material. Fibers may be composed of glass or carbon.

Carbon fiber posts are no longer recommended due to their poor esthetics (**Fig. 18.16**).



(a)



(b)

Figure 18.16 Scanning electron microscope (SEM) micrographs from a carbon fiber post: (a) Cross-section of the carbon fibers covered with resin matrix (magnification 1000×). (b) Long-axis section of the carbon fibers (magnification 1000×). (*Courtesy: Carlos Jose Soares et al., Federal University of Uberlândia, Brazil.*)



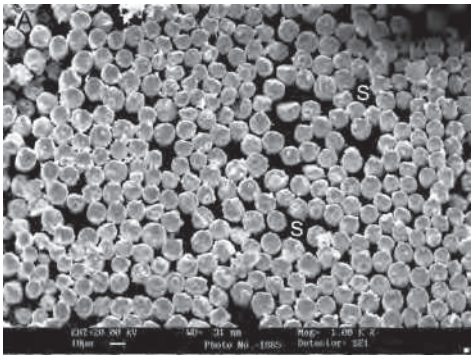
Figure 18.17 Quartz fiber posts.

Glass fiber posts are esthetic and clinically popular and can be made of:

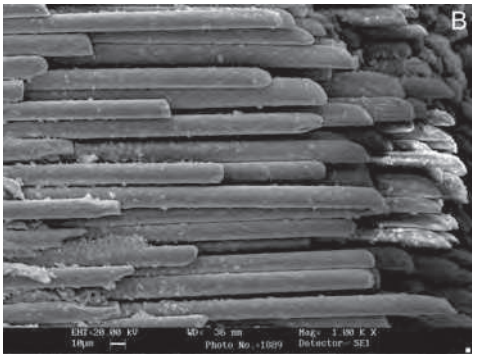
- Electrical glass (E-glass)
- High-strength glass (S-glass)
- Quartz fiber (this is pure silica in a crystallized form and provides better esthetics; **Figs 18.17** and **18.18**)

These post systems can be in one of the following shapes:

- Cylindrical
- Cylindrical–conical
- Conical



(a)



(b)

Figure 18.18 SEM micrographs from a glass fiber post: (a) Cross-section of the glass fibers (magnification 1000×). (b) Long-axis section of the glass fibers (magnification 1000×). (*Courtesy: Carlos Jose Soares et al., Federal University of Uberlândia, Brazil.*)

Glass fiber posts are popular for the following reasons:

- Post, core, and cement are resin based and constitute a homogenous ensemble
- More homogenous stress distribution than other metallic post systems (**Fig. 18.19**)
- Better biomechanical performance with greater fracture loads
- Mode of failure is favorable allowing repair and restoration
- Excellent esthetics when compared to other that of post systems
- Good adhesion to the cementing medium

These posts are the most commonly employed prefabricated system in contemporary clinical practice. The chair-side technique for using these posts is shown in **Figures 18.20** and **18.21**.

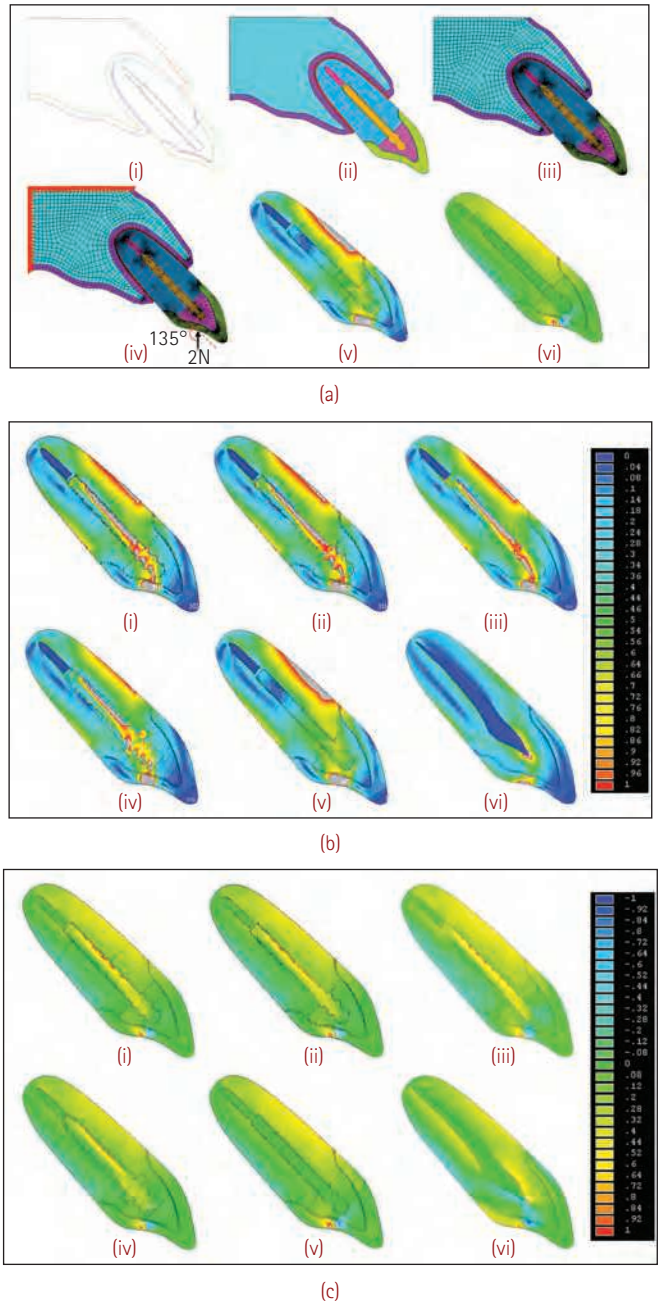
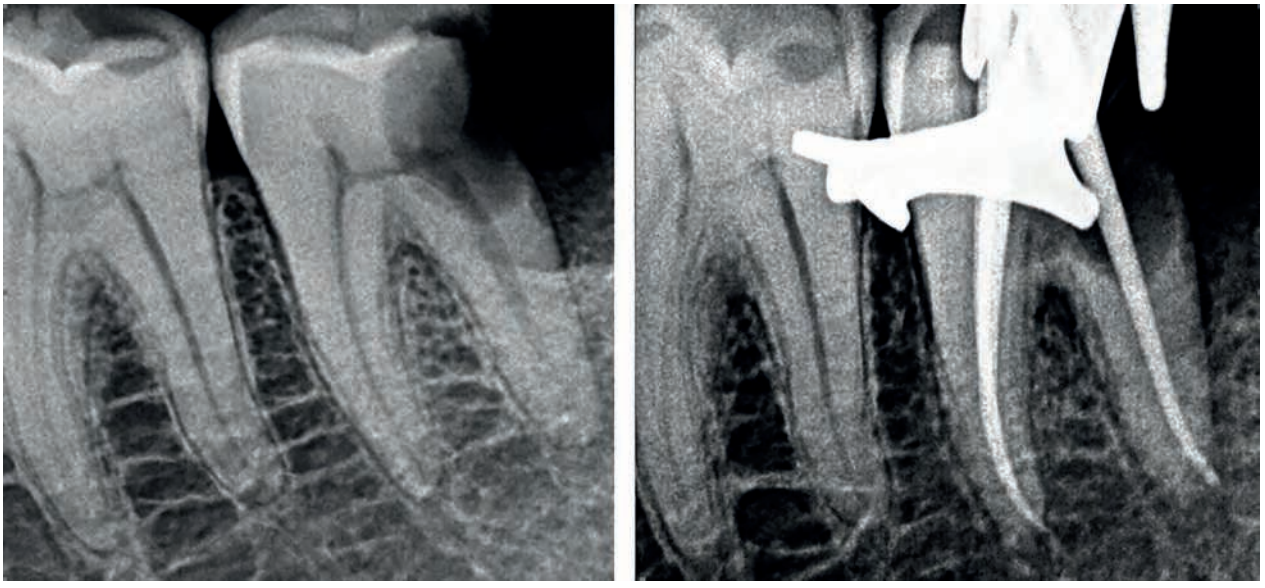
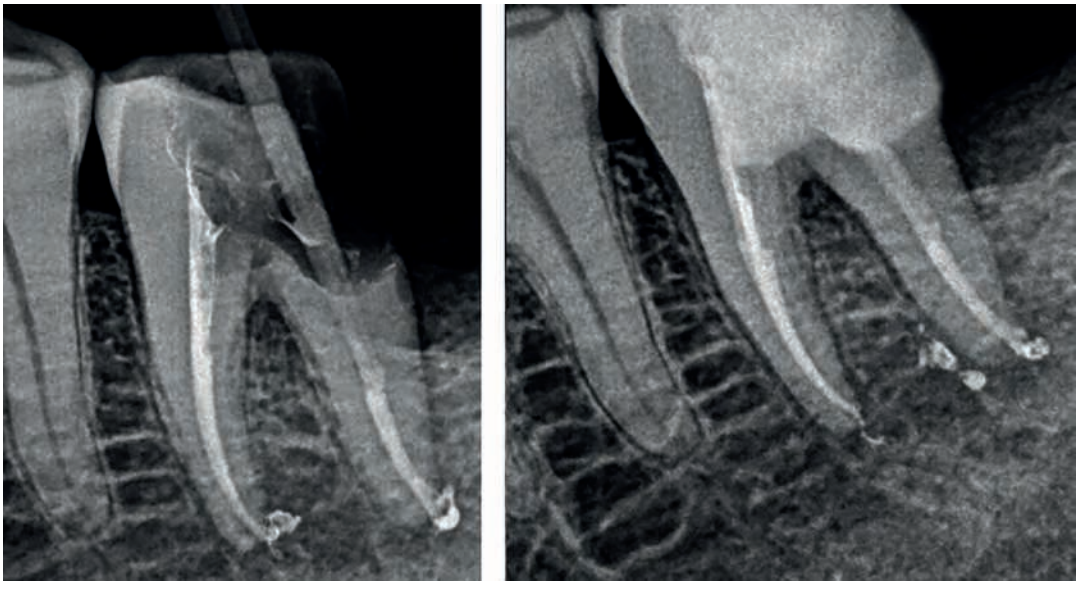


Figure 18.19 FEM analysis showing favorable stress distribution of glass fiber posts when compared to that of titanium posts. (a) (i) Contours generated, (ii) areas plotted for each structure and material, (iii) mesh of each structure, (iv) model displacement and load application, (v) stress distribution by von Mises criteria, (vi) stress distribution by shear stress criteria. (b) (i–iii) Stress distribution by von Mises criteria on maxillary central incisor models, (iv) titanium post designs, (v) glass fiber post designs, (vi) natural tooth. (c) (i–iii) Stress distribution by shear stress criteria on maxillary central incisor models, titanium post designs, (iv and v) glass fiber post designs, (vi) natural tooth. (*Courtesy: Carlos Jose Soares et al., Federal University of Uberlândia, Brazil.*)



(a) (b)



(c) (d)

Figure 18.20 (a) Mandibular second molar with extensive tooth loss due to dental caries. (b) Root canal therapy and master cone X-ray. (c) Fiber post being placed in the distal canal of the molar. (d) Dual-cure composite core buildup completed with the help of a sectional matrix system. Tooth would require a full-coverage crown.

Clinical Note

Clinical recommendation of choosing the type of prefabricated post system is based on the extent of the coronal tooth structure loss:

- Glass fiber–reinforced epoxy resin post system → More than one-half coronal tooth structure loss
- Metal post system → More than two-third coronal tooth structure loss

VI. LUTING CEMENT

Cementation plays a significant role in enhancing retention, stress distribution, and sealing irregularities between the tooth and the post. The most common luting agents are as follows:

- Resin luting cement
- Glass ionomer cement (Type I)
- Resin-modified glass ionomer cement
- Zinc phosphate cement

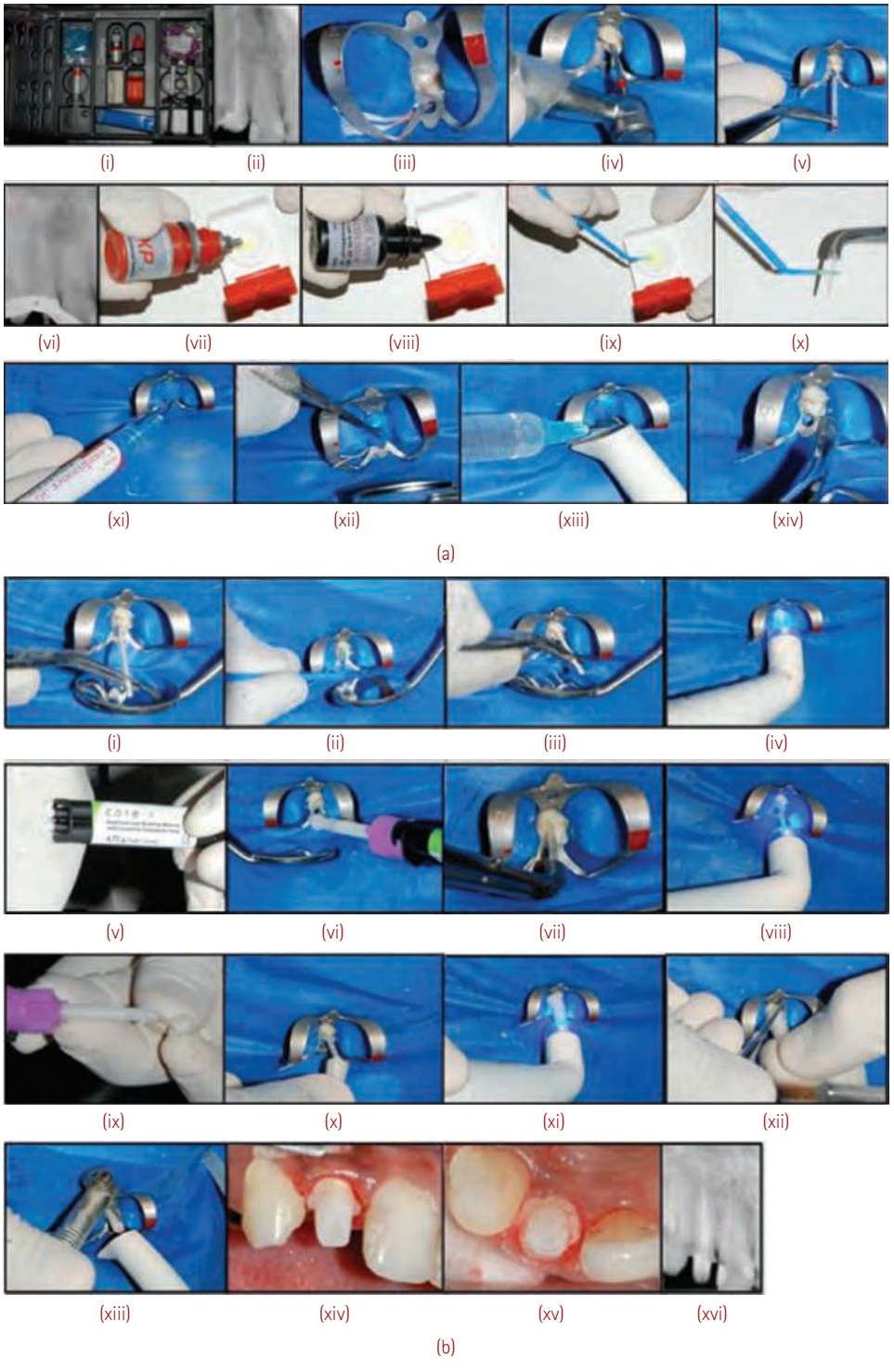


Figure 18.21 Technique for the composite post and core buildup: (a) (i) Post and core buildup kit (*courtesy: Dentsply*); (ii) preoperative radiograph of tooth 12; (iii) tooth isolated with rubber dam; (iv) post space drill no. 25 with reduction-gear handpiece; (v) post trial placement; (vi) radiograph showing post position; (vii) etch and rinse light cure resin bonding agent (XP-Bond, Dentsply); (viii) self-cure activator placed with XP bond; (ix) two components mixed using microbrush; (x) post silanization with a bonding agent; (xi) application of 36% phosphoric acid etchant to the tooth structure; (xii) activation of etchant using a probe; (xiii) washing the etchant with saline and evacuation with high-volume suction device; (xiv) air-drying with three-way syringe. (b) (i) Removal of excess moisture with paper point; (ii) application of bonding agent; (iii) removal of the excess bonding agent from the canal using paper point; (iv) curing the bonding agent for 10 seconds; (v) initial removal of the core material to allow equal flow in both tubes; (vi) introduction of dual-cure resin cement core X flow through automix syringe; (vii) post placement; (viii) curing the post on the labiolingual and occlusal surfaces; (ix) placement of the core buildup material into the core former; (x) placement of the core former on the tooth structure; (xi) curing the post and core buildup unit; (xii) removal of the plastic core former; (xiii) preparing and recontouring the excess post and core; (xiv) final crown preparation—labial view; (xv) final crown preparation—occlusal view; (xvi) radiographic appearance of the post and core buildup. (*Courtesy: Vivek Hegde, India.*)

Zinc phosphate cement and Type I GIC cement have been successfully used for the cementation of posts for many years. The current trend is to employ *resin luting cement*.

Advantages of resin luting agents are as follows:

- Increased retention
- Strengthening of the root (short term at least)
- Reduced leakage
- More resistant to cyclic loading
- Ability to bond with resin-based posts to form one unit (monoblock)

Disadvantages of resin luting agents are as follows:

- More technique sensitivity
- Proper cleaning and etching of the canals which were obturated with eugenol-containing sealers is important to ensure proper polymerization
- The steps of bonding the post with such auto cure or dual-cure resin cements should be performed carefully and quickly

CLINICAL RECOMMENDATIONS

- Avoid contamination of the root canal system.
- Restore the tooth immediately after root canal treatment, if possible.
- Posterior teeth with root canal treatment should receive cuspal coverage restorations. Bonded restorations, once thought to obviate the need for cuspal coverage, provide only short-term strengthening of the teeth, according to recent studies.
- Anterior teeth with minimal loss of the tooth structure can be restored conservatively with acid-etched composite-bonded restorations.
- Preservation of coronal and radicular tooth structure is desirable.
- The principal purpose of a post is to retain the core buildup.
- A ferrule is highly desirable when a post is used. An adequate ferrule is considered a minimum of *2 mm of the vertical height* and *1 mm of the dentin thickness*.
- When a post is needed, conserve as much radicular dentin as possible.
- Retain a *minimum of 4–5 mm of gutta-percha apically*.
- Use a post designed to incorporate mechanical features that resist rotational forces.
- Since forces concentrate at the crest of the bone during function, place the post to extend apical to the crest of the bone. The post should extend "into bone" at least as far as it protrudes "out of bone."
- Restore teeth in a way that allows future retreatment of the root canal system.
- In most cases, the particular post system used is not as important as following the principles of adequate length, adequate resistance form, adequate strength to allow preservation of dentin, and an adequate ferrule.

If these principles are followed, most post systems will perform well. The clinician should be knowledgeable in selecting the right type of post and core systems to meet the biological, mechanical, and esthetic needs for each individual tooth.

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19 Treatment of Traumatized Teeth

Healing is a matter of time, but it is sometimes also a matter of opportunity.
—Hippocrates

Trauma of the oral and maxillofacial region occurs frequently and comprises 5% of all injuries for which people seek dental treatment. Among all facial injuries, dental injuries are the most common, of which crown fractures and luxations occur most frequently. Trauma to the teeth may result either in injury of the pulp, with or without damage to the crown or root, or in displacement of the tooth from its socket. When the crown or root is fractured, the pulp may recover and survive the injury, it may succumb immediately, or it may undergo progressive degeneration and ultimately die.

CAUSES AND INCIDENCE OF DENTAL INJURIES

Traumatic injuries to the teeth can occur at any age. Young children learning to walk or falling from a chair are subject to anterior tooth injuries. Frequently, child abuse results in facial and dental trauma. Sports accidents and fights affect teenagers and young adults, whereas automobile accidents affect all age groups. As many dental accidents are sports related, every precaution should be taken to protect the teeth of children and teenagers from such accidents by conducting educational programs in addition to mouth guards.

The common causes of traumatic injuries to the teeth include the following:

- Sports accidents
- Automobile accidents
- Fights and assaults
- Domestic violence
- Inappropriate use of teeth
- Biting hard items

Clinical Note

- The incidence of tooth fractures is about 5%.
- The following age groups are most prone to dental accidents:
  - Children 8–12 years of age
  - Children 2–4 years of age
  - Boys have about two to three times as many fractured teeth as girls

The three key predisposing factors for these kinds of injuries are as follows:

1. Increased overjet of the teeth
2. Protrusion of the maxillary anterior teeth
3. Insufficient lip closure

FRACTURES OF TEETH

Box 19.1 represents the various classifications for fractured teeth.

TERMINOLOGY OF TOOTH FRACTURES

- *Craze lines:* Microfractures confined to the enamel
- *Cuspal fracture:* Diagonal fractures that usually do not involve the pulp directly
- *Cracked teeth:* Incomplete vertical fractures often involving the pulp
- *Split tooth:* Complete vertical fractures
- *Vertical root fractures:* Longitudinal complete fractures usually of endodontically treated teeth

DIAGNOSIS

A. Clinical Examination

Diagnosis is made from the patient's history, visual and clinical examination, intraoral and extraoral radiographs, electric pulp test, and thermal tests.

- Following traumatic dental injuries, the reaction to tests of pulp vitality may be negative for as long as 3 months in case of root fractures or trauma to supporting structures, i.e., the pulp is *"stunned."* At first, the injured nerve bundles are paralyzed and do not respond, the blood vessels are torn, and hemorrhage may even be evident by a slight discoloration of the tooth (pinkish hue, "blushing" appearance) that gradually disappears as the tooth returns to its normal color. In time, the pulp responds to the electric pulp test, sparingly at first, but with an increasing response with the passage of time. Hence, *sensitivity tests may be negative initially and have to be monitored over a period of time.*
- Horizontal and diagonal root fractures are best determined by *multiple angulated radiographs*, elongating the tooth image to accentuate the line of fracture.
- Cone-beam computed tomography (CBCT) is recommended for root fractures and trauma to supporting structures according to the American Association of Endodontists (AAE) 2013 guidelines.

Box 19.1

Classifications of Traumatic Injuries

The following are the most common classifications that have been suggested for fractured teeth.

I. ***Andreasen's modified classification of traumatic injuries to teeth***
1. *Enamel infraction:* An incomplete fracture (crack) of the enamel without loss of tooth substance
2. *Enamel fracture (uncomplicated crown fracture):* A fracture with loss of enamel only
3. *Enamel–dentin fracture (uncomplicated crown fracture):* A fracture with loss of enamel and dentin, but not involving the pulp
4. *Complicated crown fracture:* A fracture involving enamel and dentin, and exposing the pulp
5. *Uncomplicated crown–root fracture:* A fracture involving enamel, coronal and radicular dentin, and cementum, but not exposing pulp
6. *Complicated crown–root fracture:* A fracture involving enamel, coronal and radicular dentin, and cementum with exposure of the pulp
7. *Root fracture:* A fracture involving radicular dentin, cementum, and pulp
8. *Luxation injuries*
   (a) *Concussion:* An injury to the tooth-supporting structures without abnormal loosening or displacement of the tooth, but with increased reaction to percussion
   (b) *Subluxation (loosening):* An injury to the tooth-supporting structures with abnormal loosening, but without displacement of the tooth
   (c) *Extrusive luxation (peripheral dislocation, partial avulsion):* Partial displacement of the tooth out of its socket
   (d) *Lateral luxation:* Displacement of the tooth in a direction other than axially. This is accompanied by comminution or fracture of the alveolar socket
   (e) *Intrusive luxation (central dislocation):* Displacement of the tooth into the alveolar bone. This injury is accompanied by comminution or fracture of the alveolar socket
   (f) *Avulsion (exarticulation):* Complete displacement of the tooth out of its socket

II. ***Ellis and Davey classification (1960)***
1. Class I Enamel fracture
2. Class II Enamel and dentin fracture without pulp exposure
3. Class III Fracture involving enamel, dentin, and pulp
4. Class IV Nonvital
5. Class V Avulsion
6. Class VI Root fracture without involvement of crown structure
7. Class VII Displacement of the tooth without fracture of the crown
8. Class VIII Loss of crown en masse
9. Class IX Trauma to the deciduous teeth

III. ***Heithersay and Morile classification of subgingival fractures***
1. Class I Fracture line does not extend below the level of the attached gingiva
2. Class II Fracture line extends below the level of the attached gingiva, but not below the level of the alveolar crest
3. Class III Fracture line extends below the level of the alveolar crest
4. Class IV Fracture line is within the coronal third of the root, but below the level of the alveolar crest.

IV. ***Andreasen's modified classification of soft-tissue and bony injuries***
1. *Laceration of gingiva or oral mucosa:* A shallow or deep wound in the mucosa resulting from a tear; usually produced by a sharp object
2. *Contusion of gingiva or oral mucosa:* A bruise usually produced by impact with a blunt object and not accompanied by a break in the mucosa, usually causing submucosal hemorrhage
3. *Abrasion of gingiva or oral mucosa:* A superficial wound produced by rubbing or scraping of the mucosa, leaving a raw, bleeding surface
4. *Fracture of the mandibular or maxillary alveolar socket wall:* A fracture of the alveolar process which involves the alveolar socket
5. *Fracture of the mandibular or maxillary alveolar process:* A fracture of the alveolar process that may or may not involve the alveolar socket
6. *Fracture of the mandible or maxilla:* A fracture involving the base of the maxilla or mandible and often the alveolar process. These kinds of fractures may or may not involve the alveolar socket

B. Radiographic Examination

It is important to take radiographs from more than one angle to ascertain the extent of the injury. Radiographs of the cheek and lip lacerations are also indicated to search for embedded tooth fragments. The three radiographic angulations recommended by the International Association of Dental Traumatology (IADT) are as follows:

(i) Ninety-degree horizontal angle, with central beam through the tooth

(ii) Occlusal view

(iii) Lateral view from the mesial or distal aspect of the tooth

MANAGEMENT

The management of these traumatic injuries is based on the guidelines given by the IADT in 2012.

I. ENAMEL INFRACTION (Fig. 19.1)

Definition: *An incomplete fracture (crack) of the enamel without loss of tooth structure.*

Clinical Features

- Visual examination using dyes (methylene blue) along with magnification can help in visualizing an infraction.

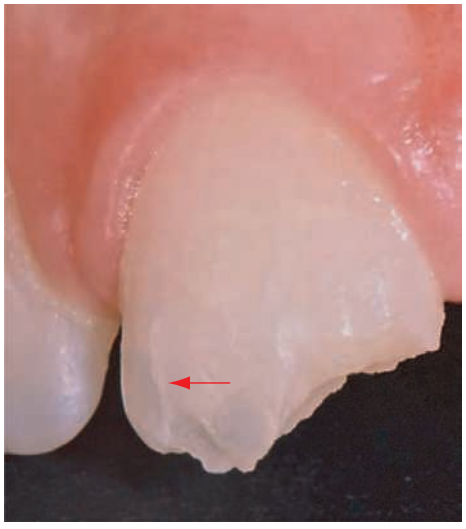


Figure 19.1 Enamel infraction lines seen in a tooth with crown fracture without pulp exposure.

- Transillumination can be done using a focused light source. When light passes through the tooth and encounters a fracture line, it will bend and not pass through the fracture line and the opposite tooth structure will be dark.
- The tooth is not tender on percussion. If tenderness is observed, evaluate the tooth for a possible luxation injury or a root fracture.

Radiographic Features

No radiographic abnormalities. Radiographs recommended: a periapical view. Additional radiographs are indicated if other signs or symptoms are present.

Treatment

In case of marked infractions, etching and sealing with resin to prevent discoloration of the infraction lines. Otherwise, no treatment is necessary.

Follow-Up

No follow-up is generally needed for infraction injuries unless they are associated with a luxation injury or other fracture types.

Clinical Note

A crack line or chip of the enamel is the key clinical feature of fractures. These kinds of injuries do not pose a threat to the vitality of the pulp and have a good prognosis.

II. ENAMEL FRACTURES

Definition: *A complete fracture of the enamel.*

Clinical Features

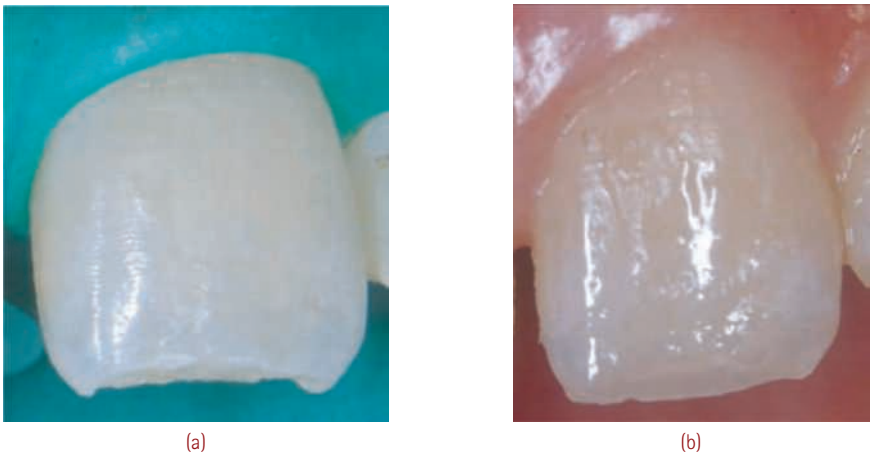
Visual signs: the loss of enamel is visible, with no exposed dentin. And there is no tenderness on percussion. Normal mobility and pulp sensibility test is recommended.

Radiographic Findings

Visible enamel loss. For radiographic evaluation, three angulations are required (periapical, occlusal, and eccentric exposures) to rule out luxation injuries or root fractures. Radiograph of lip or cheek is required to search for tooth fragments or foreign materials.

Treatment

The chipped enamel might make the tooth rough and may be an esthetic problem to the patient. Treatment involves smoothening of the roughened margins to prevent laceration of the soft tissues. In more extensive enamel fractures, recontouring the roughened margins followed by esthetic composite restorations would be necessary (**Figs 19.1** and **19.2**). If the fractured fragment is available, it can be repositioned and bonded to the tooth.



(a) (b)

Figure 19.2 (a) Enamel fracture. (b) Restoration with direct composite restoration.

Follow-Up

Periodic assessment of the vitality status of such teeth is recommended. Clinical and radiographic evaluation is suggested at 6–8 weeks and 1 year.

III. ENAMEL–DENTIN FRACTURE WITHOUT PULPAL EXPOSURE

Definition: *A fracture confined to enamel and dentin with loss of tooth structure, but not exposing the pulp.*

The objective in treating a tooth with a fractured crown without pulp exposure is threefold:

1. Elimination of discomfort
2. Preservation of the vital pulp
3. Restoration of the fractured crown

Clinical Features

The tooth is not tender on percussion. If tenderness is observed, evaluate the tooth for possible luxation or root fracture injury. Normal mobility is observed and pulp sensibility test is usually positive.

Radiographic Findings

The enamel–dentin loss is visible. Radiographs recommended: periapical, occlusal, and eccentric exposure to rule out tooth displacement or possible presence of root fracture. Radiograph of lip or cheek lacerations suggested to search for tooth fragments or foreign materials.

Treatment

In an uncomplicated fracture of the crown without pulpal exposure, a *remaining dentinal thickness of 2 mm is sufficient to shield the pulp and ensure a good prognosis*. Inflammatory response in the form of pain on percussion is usually transient as long as the vascular supply to the pulp remains intact. Composite resin restoration is the preferred restorative procedure in such cases. In certain cases, the fractured segments can be approximated and bonded back with the help of dentin bonding agents and composite resins (**Fig. 19.3**). The use of indirect veneering procedures at a later date is another approach to improve the esthetics.

Follow-Up

Clinical and radiographic control at 6–8 weeks and 1 year. The tooth should be periodically tested with the electric pulp tester or Endo-Ice. If the pulp continues to respond normally during this time, the pulp can be assumed to have recovered. If progressively more current is necessary to elicit a vitality response, the pulpal prognosis is unfavorable, and the pulp will probably become necrotic necessitating endodontic treatment.

IV. ENAMEL–DENTIN FRACTURE WITH PULPAL EXPOSURE

Definition: *A fracture involving the enamel and dentin with loss of tooth structure and exposure of pulp.*

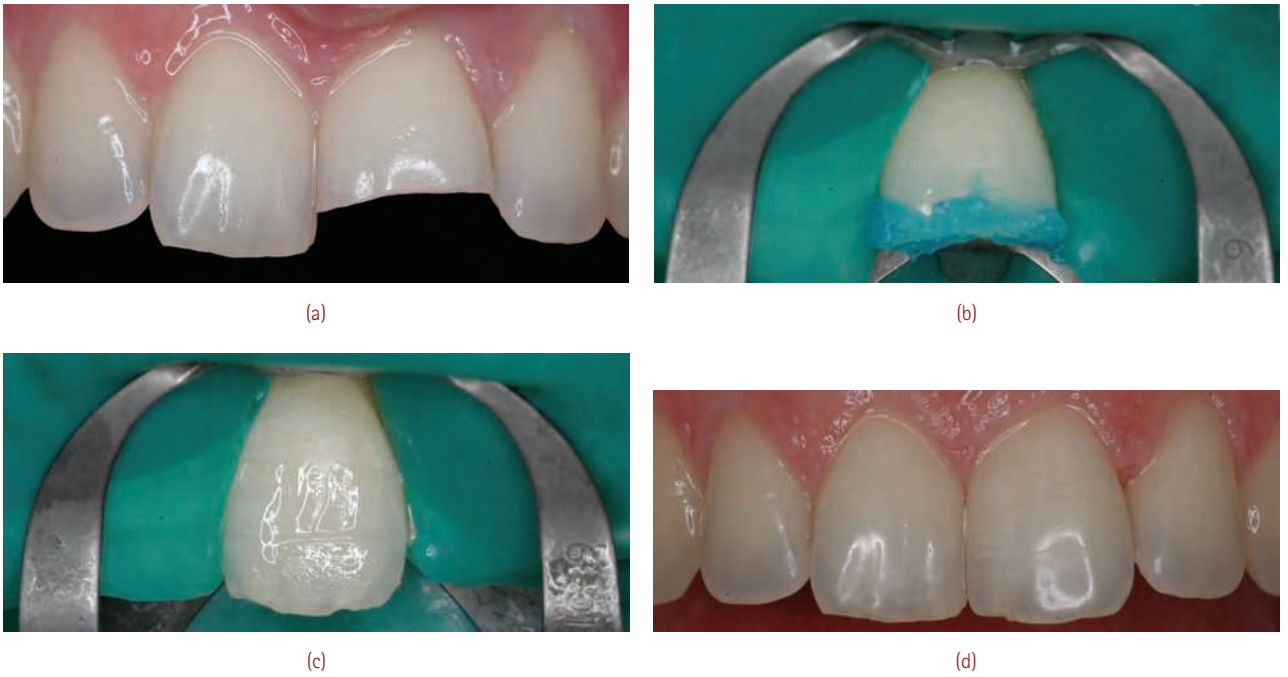


Figure 19.3 (a) Preoperative image showing the mesiodistal crown fracture of vital 21. (b) Rubber dam isolation, beveling, and acid etching performed. (c) Composite contouring. (d) Postoperative view. (*Courtesy: Gianluca Plotino, Italy.*)

Clinical Features

Normal mobility. The tooth is not tender on percussion; however, if tenderness is observed, evaluate for possible luxation or root fracture injury. Exposed pulp is sensitive to stimuli (**Fig. 19.4a** and **19.4b**).

Radiographic Findings

The loss of tooth structure is visible (**Fig. 19.4c**).

Treatment

The primary aim for a fractured crown presenting with a pulpal exposure is to ideally maintain the pulpal vitality. The management would be based on the status of the pulp tissue and the degree of root closure:

- Direct pulp capping
- Pulpotomy (if radicular pulp is vital)

Vital pulp therapy would be the treatment of choice if pulpal inflammation is minimal and confined to the coronal part of the pulp tissue.

In cases of necrosis of the pulp, the following endodontic procedures would be recommended:

- Pulpectomy (endodontic treatment) in cases where physiologic root formation is complete
- Regenerative endodontics/apexification in cases of permanent teeth with open apex

Clinical Note

- Mechanical exposure of the pulp due to trauma has a better prognosis than carious exposures. Every attempt must be made to minimize bacterial contamination of the exposure.
- The extent of fracture and the stage of root development are the two critical factors that would determine the treatment plan.

For more details on direct pulp capping, pulpotomy, and apexification, the student is referred to Chapters 11 and 12 for details on vital pulp therapy and regenerative endodontics.

Follow-Up

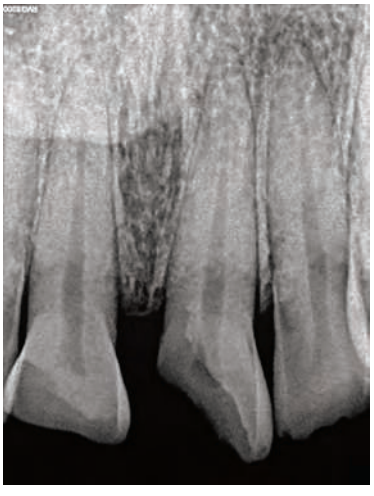
Clinical and radiographic control at 6–8 weeks and 1 year.



(a)



(b)



(c)

Figure 19.4 (a) Traumatic injury causing enamel–dentin fracture with pulpal exposure in right maxillary central incisor and enamel–dentin fracture without pulpal exposure in the left maxillary central incisor. (b) Occlusal view. (c) Radiographic view.

V. CROWN–ROOT FRACTURES

1. CROWN–ROOT FRACTURES WITHOUT PULPAL INVOLVEMENT

Definition: *A fracture involving enamel, dentin, and cementum with loss of tooth structure, but not exposing the pulp.*

Clinical Features

This kind of traumatic dental injury is characterized by an oblique fracture line that usually begins few millimeters incisal to the marginal gingiva and extends beyond the gingival crevice. These resemble a crown fracture but are more complex to treat as the fracture involves the root also. Clinically, the displacement of the coronal fracture segment is minimal as fractured segments are held together by the underlying periodontal ligament (PDL).

The tooth is tender on percussion. Coronal fragment is usually mobile. Sensibility pulp test is usually positive for the apical fragment.

Radiographic Findings

Apical extension of fracture is usually not visible. Radiographs recommended are periapical, occlusal, and eccentric exposures in order to detect fracture lines in the root.

Treatment

- *Localization of fracture line:* The fracture involves the crown and root of the tooth and is in a horizontal or diagonal plane, CBCT exposure reveals the whole fracture extension.
- *Emergency treatment:* Temporary stabilization of a loose segment to adjacent teeth is done.
- *Definitive treatment:* The treatment modalities available for the management of crown–root fractures include removal or reattachment of the fractured fragment. Removal of the fractured fragment is indicated in superficial or chisel fractures of the crown wherein reapproximation of the segment is difficult. In subgingival extensions, the treatment principle is to convert a subgingival fracture into a supragingival fracture with the help of gingivectomy and sometimes ostectomy. It is a simple procedure involving the removal of the mobile segment under anesthesia and treating with a definitive restoration finally.

2. CROWN–ROOT FRACTURES WITH PULPAL INVOLVEMENT

Definition: *A fracture involving enamel, dentin, cementum, and exposing the pulp.*

Clinical Features

The fracture line is usually single but multiple fractures can occasionally be seen. In spite of the pulpal exposure, symptoms are mild and pain is due to mobility of the fractured segment during function (**Fig. 19.5**). The tooth is tender on percussion. Coronal fragment is mobile.



Figure 19.5 Crown–root fracture with pulpal exposure in a maxillary canine. (*Courtesy: Nandini S., India.*)

Radiographic Findings

Apical extension of the fracture is usually not visible. Radiographs recommended are periapical and occlusal.

Treatment

In crown–root fractures with irreversible pulpal changes, endodontic therapy would be warranted.

- *With pulpal exposure and immature roots:* Perform a partial pulpotomy to preserve pulp vitality.
- *Pulp exposure with mature roots*
  - Perform endodontic treatment.
  - The use of a fiber-reinforced composite post as an aid in enhancing the retention of the fractured segment can also be attempted if proper reapproximation of the segments is possible (**Fig. 19.6**).

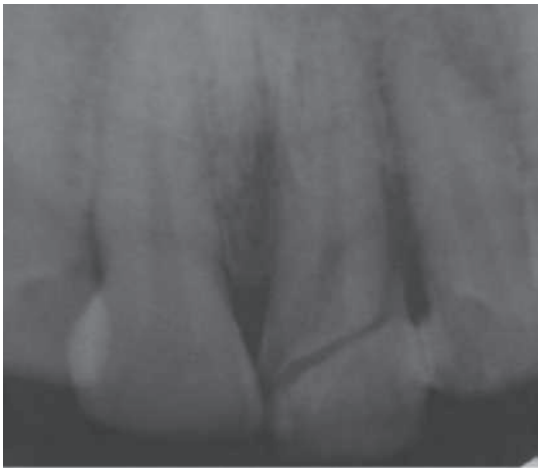
Orthodontic Extrusion of the Apical Fragment

In certain cases, the complete coronal fragment might be unrestorable and the remaining radicular segment of the tooth might be partly below the level of the gingiva. Orthodontic extrusion of the subgingival fragment to a supragingival position was first advocated by Heithersay in 1973.

The procedure is slow and cumbersome and is indicated in cases where the crown–root ratio would not be compromised after the extrusion (**Fig. 19.7**). This procedure can provide excellent results.

Surgical Extrusion of the Apical Fragment

This procedure advocates the surgical movement of the apical fragment to a supragingival position. It is indicated in cases wherein the root is long enough to accommodate a postretained crown after the surgical extrusion. Surgical extrusion is faster than orthodontic extrusion and is a safe and rapid method for the management of such cases. However, care should be taken to ensure that the PDL is not harmed during the procedure.



(a)



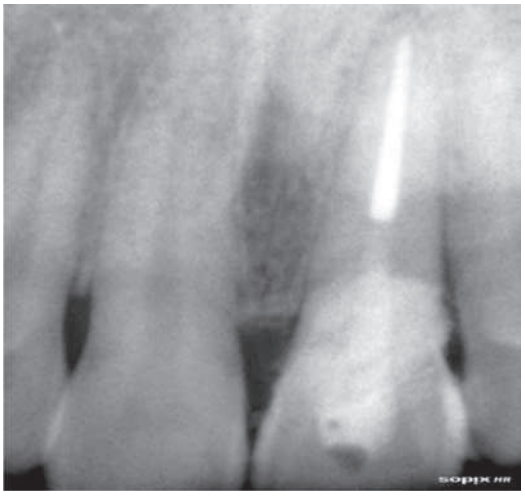
(b)



(c)



(d)

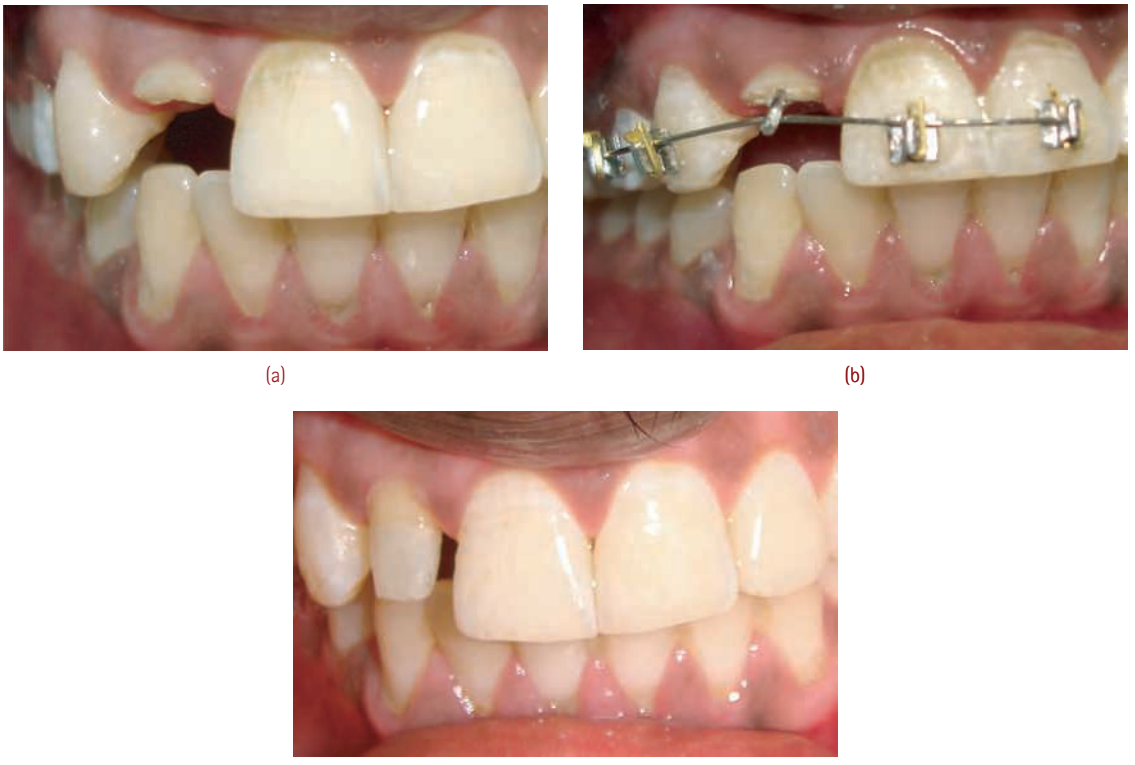


(e)



(f)

Figure 19.6 (a) Crown–root fracture in relation to a maxillary central incisor. (b) Fractured crown segment removed under local anesthesia. (c) Removed crown fragment. (d) Fiber-reinforced composite post placed after completion of root canal treatment and subsequent post space preparation. (e) Radiographic view after the reattachment process. (f) Two-year clinical follow-up shows the tooth to be functional and asymptomatic. (*Courtesy: Abarajithan, India.*)



(a) (b)

(c)

Figure 19.7 (a) Crown–root fracture of a maxillary lateral incisor. (b) Orthodontic extrusion being done to bring the subgingival margins of the fractured segment to a more favorable supragingival position. (c) Post and core buildup after orthodontic extrusion of the apical fragment is completed. (*Courtesy: Abarajithan, India.*)

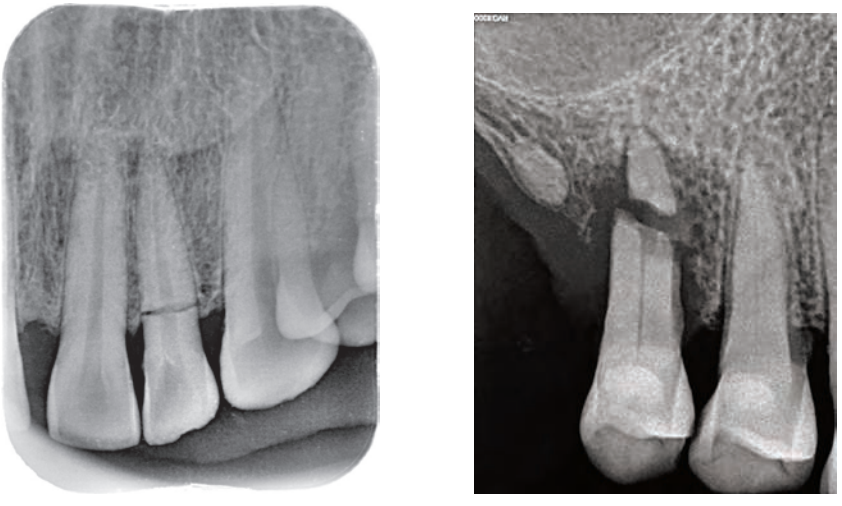
VI. ROOT FRACTURES

Root fractures constitute less than 0.5–7% of all dental injuries and are characterized by fracture line involving the root in a horizontal or diagonal plane.

Classification

Based on the level of the fracture, root fractures are classified as follows:

- Coronal third root fracture (**Fig. 19.8a**)
- Middle third root fracture (**Fig. 19.9**)
- Apical third root fracture (**Fig. 19.8b**)



(a) (b)

Figure 19.8 (a) Coronal third fracture of maxillary lateral incisor having a poor prognosis. (b) Apical third root fracture.



(a)



(b)



(c)



(d)



(e)

Figure 19.9 (a) Incisal third fracture of upper central incisors. (b) Radiograph revealing no pulpal involvement in left upper central incisor. But note the midroot fracture in the same tooth. (c) The coronal segment was endodontically treated and obturated with an apical matrix of mineral trioxide aggregate (MTA) and thermoplasticized gutta-percha. (d) Esthetic rehabilitation of the fractured tooth structure with direct composite resin. (e) Two-year follow-up radiograph showing healing of the interfragment tissues. Note the normal radiographic picture around the apical segment.

1. Coronal Third Root Fracture

When a fracture occurs in the coronal third of the root, the prognosis is less favorable because of the difficulty in immobilizing the tooth. Repair does not occur due to constant movement of the tooth and exposure of the pulp to the oral environment. In time, the tooth becomes loose and must be removed, or it may be completely exfoliated as resorption occurs. Occasionally, the apical fragment may be sufficiently long and may be supported by the surrounding periodontium to be satisfactorily retained.

Clinical Note

In cases of coronal third root fractures, it is beneficial to have the splints for stabilization up to **4 months** of time.

2. Middle Third Root Fracture

The prognosis and treatment plan of a midroot fracture depends on the following factors:

- Position of the tooth after root fracture
- Mobility of the coronal segment
- Status of the pulp
- Position of the fracture line

Depending on these factors, a number of treatment options are available:

- *Root canal therapy of the coronal segment and removal of the apical segment:* This treatment plan has to be chosen if the apical segment has been separated considerably from the coronal one, and, in addition, appears to be involved with a lesion.
- *Root canal treatment of the coronal segment and no treatment of the apical one:* This probably is the *treatment of choice* when the apical segment contains vital healthy pulp tissue (**Fig. 19.9**). Cvek recommended the use of apexification procedure in the coronal segment, so that a hard-tissue barrier at the exit of the coronal root canal is formed. An alternate more effective method is to employ mineral trioxide aggregate (MTA) to form the apical barrier in the coronal segment of the fractured root and backfill the canal with thermoplasticized gutta-percha.

3. Apical Third Root Fracture

If the fracture is in the apical third of the root, the prognosis is favorable, provided the tooth is immobilized and not placed under undue pressure of mastication. The opposing tooth or teeth should be ground to minimize incisal-occlusal stress.

A tooth with its root fractured in its apical third has an excellent prognosis because the pulp in the apical fragment usually remains vital, and the tooth may remain firm in its socket. A mobile tooth should be splinted. If the pulp in the coronal fragment remains vital and the tooth is stable, with or without ligation, then no additional treatment is indicated.

In the event of pulpal death in the coronal fragment, endodontic treatment can be done, which is preferably limited to the coronal fragment. If the tooth fails to recover, the apical root fragment can be removed surgically.

Clinical Note

- As a thumb rule, the prognosis of root fractures depends on the location of the fracture.
- The more apical the fracture, the better the prognosis.

Clinical Findings

The coronal segment may be mobile and may be displaced. The tooth may be tender on percussion. Bleeding from the gingival sulcus may be noted. Sensibility testing may give negative results initially, indicating transient or permanent neural damage. Monitoring the status of the pulp is recommended. Transient crown discoloration (red or gray) may occur.

Radiographic Findings

It is important to note that horizontal root fractures can be detected by regular 90° angle film with the central beam through the tooth. Diagonal fractures can be visualized by an occlusal view radiograph. Hence, it is prudent to take both the views when one suspects a root fracture.

Clinical Note

- The coronal segment may be displaced while the apical segment is usually not displaced.
- As apical pulpal circulation is not disrupted, pulp necrosis in the apical segment is extremely rare.
- Permanent pulpal necrosis of the coronal segment requiring endodontic treatment occurs in about 25% of cases.

Treatment

If the coronal segment is displaced, then reposition the segment as soon as possible. Check the position radiographically and stabilize the tooth with a flexible splint for 4 weeks. When a horizontal or diagonal fracture of the root occurs, one should immobilize the tooth by splinting it to adjacent teeth to keep it at rest. The splint should be removed in 4–6 weeks, depending on the status of the alveolar bone surrounding the tooth, mobility of the tooth, and overall root length of the tooth.

If the root fracture is near the cervical area of the tooth, stabilization is beneficial for a longer period of time (up to 4 months). It is advisable to monitor healing for at least 1 year to determine the pulpal status. If pulp necrosis develops, root canal treatment of the coronal tooth segment to the fracture line is indicated to preserve the tooth.

Healing of Root Fractures

Essentially, repair of the fractured root segments depends on three critical factors:

(i) Distance between the fragments
(ii) Degree and duration of immobilization
(iii) Presence or absence of infection

Andreasen and Hjorting-Hansen described four types of root repair following treatment of root fracture:

(i) Calcified tissue
(ii) Connective tissue
(iii) Connective tissue and bone
(iv) Granulomatous tissue

Following fracture, complete union of the parts does not usually occur. Healing of the fractured parts depends on the PDL. When the pulp remains vital, blood clot is formed and macrophages dispose of the damaged tissue. A meshwork of granulation tissue develops; then fibroblasts appear to lay down the fibrous tissue. This tissue is replaced with cementum by cementoblasts that cover the fractured root surfaces.

If the pulp is vital, odontoblasts cover the medial fractured root surfaces with a dentin-like tissue. At times, the cementum extends into the canal and covers the irregular dentinal surface for a short distance. Connective tissue fills the space between the cementum-covered fragments. If, however, a wide gap exists between the fragments, the fibrous tissue will either remain or be replaced by bone or bone-like substance. When the treatment fails, granulomatous (inflamed granulation) tissue forms between the fractured segments of the root.

At times, a layer of calcified repair tissue deposited across the pulp tissue at the line of fracture seals the upper and lower portions of the pulp. This repair tissue consists of both tubular dentin and uncalcified organic matrix.

The recommended clinical guidelines for the management of fractures of tooth and root by the International Association of Dental Traumatology (IADT) are given in **Table 19.1**.

Table 19.1 Treatment Guidelines for Fractures of Teeth and Alveolar Bone [Adapted from International Association of Dental Traumatology updated guidelines (2020) for the management of traumatic dental injuries]

Type	Clinical Finding	Radiographic Finding	Treatment
Enamel infraction	• An incomplete fracture (crack) of the enamel without loss of tooth structure	• No radiographic changes	• Etching and sealing with resin to prevent discoloration of the infraction lines/no treatment necessary
Enamel fracture	• Complete fracture of enamel	• Enamel loss is visible	• If fragment available, can be bonded back on to the tooth • Fractured margins to be smoothened and composite restoration to be given if required
Enamel-dentin fracture without pulpal exposure	• Fracture confined to enamel and dentin with loss of tooth structure, but not exposing the pulp	• Enamel dentin loss is visible	• If fragment available, can be bonded to the tooth • Provisional treatment: with GIC or composite resin • If exposed dentin is within 0.5 mm of the pulp, place calcium hydroxide (CaOH) lining base and cover with GIC and composite restoration
Enamel-dentin fracture with pulpal exposure	• Fracture of enamel and dentin with loss of tooth structure and exposure of the pulp	• Enamel dentin loss is visible	• Immature teeth and completely formed teeth of young patients it is advantageous to preserve pulp vitality by partial pulpotomy or pulp capping • Calcium silicate based cement (CSBC) or non-setting calcium hydroxide can be placed on the exposed pulp • Patients with mature apical development, RCT is usually the treatment of choice although pulp capping or partial pulpotomy may also be done • Fragment available: Exposed pulp treated > rehydration > Bond back the tooth structure • Fragment not available: Exposed dentin coverd with glass inomer cement or using bonding agent and composite resin

(*continued*)

Table 19.1 Treatment Guidelines for Fractures of Teeth and Alveolar Bone [Adapted from International Association of Dental Traumatology updated guidelines (2020) for the management of traumatic dental injuries] (*continued*)

Type	Clinical Finding	Radiographic Finding	Treatment
Crown- root fracture with out pulp exposure	• A fracture involving enamel, dentin and cementum with loss of tooth structure, but not exposing the pulp	• Apical extension of fracture usually not visible • Recommended to take one parallel IOPA and two additional radiograph with different horizontal angulations	• **Emergency treatment**, a temporary stabilization of loose segment to adjacent teeth. • **Non-Emergency treatment**: fragment removal only • Removal of coronal or mobile fragment and restore with GIC or composite
Crown root fracture with pulp exposure	• Fracture involving enamel, dentin and cementum and exposing the pulp • Percussion test : tender • Cronal fragment mobile	• Apical extension of fracture usually not visible • Recommended to take one parallel IOPA and two additional radiograph with different horizontal angulations	• Emergency treatment: temporary stabilization of the loose segment to adjacent teeth • **Immature teeth with incomplete root formation:** partial pulpotomy with CSBC or Non-setting Caoh • **Mature teeth with complete root formation:** Pulpectomy
Root fracture	• Coronal segment may be mobile and may be displaced • Tender to percussion • Bleeding from gingival sulcus • Monitoring the status of pulp is recommended • Transient crown discoloration (red or gray) may occur	• Fracture involves root of teeth and is in horizontal or oblique plane • If fracture in horizontal plane periapical 90 degree angle film with the central beam through the tooth • If fracture in oblique plane which is common with apical third fractures, an occlusal view is helpful • CBCT to be considered	• Reposition if displaced, the coronal segment of tooth as soon as possible • Check position radiographically • Stabilize the tooth with flexible splint for 4 weeks. if root fracture near cervical area of tooth, stabilization required up to 4 months • To monitor healing for 1 year • Pulp necrosis may occur in coronal fragment only. Hence, pulpectomy treatment for coronal segment is indicated (**Fig. 19.9**)
Alveolar fracture	• The alveolar fracture is complete and extends all the way from the buccal to the palatal bone in the maxilla and from the buccal to the lingual bony surface in the mandible • Segment mobility and dislocation with several teeth moving together are common finding • Occlusal disturbances due to displacement and misalignment is often noted	• Fracture line may be located at any level, from the marginal bone to the root apex • Recommended to take one parallel IOPA and two additional radiograph with different horizontal angulations • Occlusal radiograph • CBCT to be considered	• Reposition any displaced segment and then splint for 4 weeks • Suture gingival laceration if present
Concussion	• The tooth is tender to touch or percussion • Tooth is usually neither displaced nor has any mobility	• No radiographic abnormalities • Recommended to take one parallel IOPA and additional radiographs are indicated if signs and symptoms of other potential injuries are present	• No treatment is needed • Monitor pulpal condition for atleast 1 year
Subluxation	• Tooth is tender to touch or percussion • Tooth has increased mobility but not dispalaced • Bleeding from gingival cervice may be noted • Sensibility test negative	• Radiographic abnormalities are usually not found • Recommended to take one parallel IOPA and two additional radiograph with different horizontal angulations • Occlusal radiograph	• Normally no treatment is needed; however, a passive and flexible splint to stabilize the tooth for patient comfort can be used for up to 2 weeks

(*continued*)

Table 19.1 Treatment Guidelines for Fractures of Teeth and Alveolar Bone [Adapted from International Association of Dental Traumatology updated guidelines (2020) for the management of traumatic dental injuries] (*continued*)

Type	Clinical Finding	Radiographic Finding	Treatment
Extrusive luxation	• The tooth appears elongated and is excessively mobile • Sensibility test negative	• Increased periodontal ligament space apically • Recommended to take one parallel IOPA and two additional radiograph with different horizontal angulations • Occlusal radiograph	• Reposition the tooth by gently re-inserting It into the tooth socket • Stabilize the tooth for 2 weeks using a passive and flexible splint • If pulp becomes necrotic, endodontic treatment is indicated
Lateral luxation	• The tooth is displaced usually in a palatal/lingual or labial direction • Usually associated with fracture of alveolar bone • Percussion will give a high, metallic (ankylotic) sound • Sensibility test negative	• The widened periodontal ligament space is best seen on eccentric or occlusal exposures • Recommended to take one parallel IOPA and two additional radiograph with different horizontal angulations • Occlusal radiograph	• Reposition the tooth digitally by disengaging it from its locked position and gently reposition it into its original location under local anesthesia. • Stabilize the tooth for 4 weeks using a passive and flexible splint • Monitor the pulpal condition with pulp sensibility test • If the pulp becomes necrotic, root canal treatment is indicated to prevent root resorption • **Teeth with incomplete root formation:** – Spontaneous revascularization may occur. – If the pulp becomes necrotic and there are signs of inflammatory (infection-related) external resorption, root canal treatment should be started as soon as possible. – Endodontic procedures suitable for immature teeth should be used • **Teeth with complete root formation**: – The pulp will likely become necrotic. – Root canal treatment should be started, using a corticosteroid-antibiotic or calcium hydroxide as an intracanal medicament to prevent the development of inflammatory (infection-related) external resorption
Intrusive luxation	• The tooth is displaced axially into the alveolar bone • Tooth is immobile • percussion may give a high, metallic (ankylotic) sound • Sensibility test negative	• The periodontal ligament space may be absent from all or part of the root • The cementoenamel junction is located more apically in the intruded tooth than in adjacent non-injured teeth • Recommended to take one parallel IOPA and two additional radiograph with different horizontal angulations • Occlusal radiograph	**Teeth with incomplete root formation (immature teeth)** • Allow re-eruption without intervention (spontaneous repositioning) for all intruded teeth independent of the degree of intrusion • If no re-eruption within 8 weeks, initiate orthodontic repositioning • Monitor the pulp condition • In teeth with incomplete root formation spontaneous pulp revascularization may occur. However, if it is noted that the pulp becomes necrotic and infected or that there are signs of inflammatory (infection-related) external resorption at follow-up appointments, root canal treatment is indicated and should be started as soon as possible when the position of the tooth allows. Endodontic procedures suitable for immature teeth should be used.

(*continued*)

Table 19.1 Treatment Guidelines for Fractures of Teeth and Alveolar Bone [Adapted from International Association of Dental Traumatology updated guidelines (2020) for the management of traumatic dental injuries] *(continued)*

Type	Clinical Finding	Radiographic Finding	Treatment
			Teeth with complete root formation (mature teeth) • Allow re-eruption without intervention if the tooth is intruded less than 3 mm. If no re-eruption within 8 weeks, reposition surgically and splint for 2 weeks. Alternatively, reposition orthodontically before ankylosis develops • If the tooth is intruded 3–7 mm, reposition surgically (preferably) or orthodontically • If the tooth is intruded beyond 7 mm, reposition surgically • In teeth with complete root formation, the pulp almost always becomes necrotic. Root canal treatment should be started at 2 weeks or as soon as the position of the tooth allows, using a corticosteroid-antibiotic or calcium hydroxide as an intra canal medication. The purpose of this treatment is to prevent the development of inflammatory (infection-related) external resorption

VII. LUXATED TEETH

Definition: *Luxation is the displacement or partial dislocation of a tooth from its socket.*

These injuries vary from 16 to 60% of all traumatic dental injuries. When a tooth is partially luxated from a blow, the soft tissues become swollen and covered with blood, and the tooth may appear loose, especially if it is extruded. The PDL in such cases is usually torn in several places, if not entirely, depending on the amount of displacement. Grossman reported that luxated teeth are seldom fractured simultaneously. He suggested that a blow that luxates teeth is usually received almost parallel with the long axis of the tooth, rather than at right angles, and that a fracture is less likely to occur.

Injuries resulting in mobility of individual teeth due to luxation injuries must be determined. One should be careful while testing the degree of mobility of the tooth not to displace it further.

Luxation injuries can be further classified into the following:

1. Concussion
2. Subluxation (loosening)
3. Extrusive luxation (peripheral displacement, partial avulsion)
4. Lateral luxation
5. Intrusive luxation (central dislocation)

1. CONCUSSION

Definition: *It is defined as an injury to the supporting structures of the tooth without abnormal loosening or displacement of the tooth, but with significant reaction to percussion.*

Clinical Features

With the exception of a diffuse ache in the area, affected by the blow, the patient may have little discomfort in the affected tooth. The tooth may feel numb shortly after the blow. There is usually no bleeding. The tooth responds normally to sensitivity tests.

Radiographic Features

Usually no radiographic changes are seen.

Treatment

The treatment may be confined to occlusal readjustment of the opposing teeth and repeated periodic vitality testing during the follow-up period.

2. SUBLUXATION

Definition: *It is defined as injury to the supporting structure of a tooth resulting in abnormal loosening of the tooth without any displacement.*

Clinical Features

The affected teeth are present in their normal positions in the arch but exhibit horizontal mobility and have pain on percussion. Bleeding from the gingival crevice is present indicating damage to the supporting periodontal tissues. These teeth respond normally to sensitivity tests.

Radiographic Features

Radiographic abnormalities are usually not found.

Treatment

The treatment is similar to that of concussion injuries. However, splinting might be required in cases of multiple tooth injuries.

3. EXTRUSIVE LUXATION

Definition: *It is defined as the partial displacement of the tooth from its alveolar socket.*

Clinical Features

Such teeth appear elongated with lingual deviation of the crown as the tooth usually exhibits increased mobility. These injuries are always accompanied by bleeding from the PDL.

Radiographic Features

Increased PDL space apically

Treatment

Extruded teeth should be forced back into the socket as soon as possible after the accident. This procedure is preferably done after anesthetizing the region and by means of gentle finger pressure, or pressure may be exerted on a wooden tongue blade placed against the incisal surfaces of the adjacent teeth to force them back into their sockets. The affected tooth should be splinted with a passive and flexible splint for a period of 2 weeks. The tooth should be ground out of occlusion to prevent additional trauma.

Depending on the degree of displacement, the pulp may survive and remain vital because the vascular supply to the pulp is not always severed or even impaired. The tooth should be tested for vitality once a month. Grossman reported a case of luxation of five teeth, with gradual recovery of vitality of the pulps in three teeth. If the pulp is found to be nonvital, endodontic treatment should be instituted at once to prevent periradicular involvement.



Clinical Note

- Return to a normal vitality index may be slow, but it should be complete or nearly complete within **6 months**.
- When progressively more current is required to elicit a response to the electric pulp test, and when response to the cold test becomes weaker with time, a dying pulp should be suspected.

4. LATERAL LUXATION

Definition: *It is defined as an eccentric displacement of tooth other than in an axial direction.*

Clinical Features

These injuries are associated with comminution or fracture of the alveolar socket. The crowns are usually displaced in a lingual direction along with the fracture of the alveolar socket wall. Fracture of the alveolar process may be present.

Radiographic Features

The widened PDL space is best seen on eccentric or occlusal exposures.

Treatment

Treatment comprises repositioning of the tooth back to its normal position. This is difficult and painful and has to be done with the help of a forceps under infraorbital regional block anesthesia. These teeth have to be stabilized with a flexible splint for a period of 3 weeks. Longer fixation periods are recommended in cases of marginal bone breakdown.

5. INTRUSIVE LUXATION

Definition: *It is defined as the intrusion or displacement of the tooth into the alveolar bone along the long axis of the tooth and is accompanied by fracture of the alveolar socket.*

Clinical Features

The tooth is tender on percussion. The extent of intrusion varies from few millimeters to complete burial of the tooth into the socket. When the tooth is intruded, only a small portion of the crown may be visible because of swelling of the tissues and the amount of tooth intrusion. An intruded tooth is usually stable in contrast to the mobility of extruded teeth. Such teeth are not sensitive to percussion.

Radiographic Features

The cementoenamel junction is located more apically than the adjacent, noninjured teeth. If the tooth is totally intruded, a lateral cephalogram should be considered to evaluate the penetration into the nasal cavity. The PDL space may be absent.

Treatment

An intruded tooth usually requires no immediate treatment, unless it is a primary tooth that can adversely affect the permanent tooth bud, because the tooth will slowly re-erupt. Emergency treatment is usually accomplished by applying cold compression to alleviate the swelling and pain and by stopping of bleeding.

- *Teeth with incomplete root formation*
  - Spontaneous re-eruption is the treatment of choice in teeth with incomplete root formation. This re-eruption process is slow and varies between 2 and 14 months'



Figure 19.10 (a) Radiograph: intrusion luxation of maxillary central incisors at day 1. (b) Photograph: intrusion luxation of maxillary central incisors at day 1. (c) Photograph: intrusion luxation of maxillary central incisors at 2 months. (d) Radiograph: intrusion luxation of maxillary central incisors at 2 months. (e) Radiograph: intrusion luxation of maxillary central incisors at 6 months. (f) Photograph: intrusion luxation of maxillary central incisors at 6 months. (g) Radiograph: intrusion luxation of maxillary central incisors at 2 years showing normal radiographic features. (*Courtesy: Louis H. Berman, USA.*)

time (**Fig. 19.10**). If there is no re-eruption for 8 weeks, initiate orthodontic repositioning.
  - Monitor closely for pulp vitality.
  - If the pulp becomes necrotic, pulp revascularization therapy or apexification should be considered.
- *Teeth with complete root formation*
  - The pulp will likely become necrotic and root canal therapy should be initiated 2 weeks after the injury.
  - After cleaning and disinfection, a temporary dressing with calcium hydroxide or corticosteroid—antibiotic medicament is recommended for up to 4 weeks.

Clinical Note

- It is one of the most severe forms of dental traumatic injuries.
- Intrusion occurs with greater frequency in primary teeth than in the permanent dentition.
- Diagnosis is readily established from the patient's history and by means of radiographic examination.
- Surgical extrusion is recommended in cases of multiple teeth intrusions.
- When return of the tooth to its original position in the socket is slow, the tooth may be actively erupted and properly positioned using an orthodontic appliance (**Fig. 19.11**).



Figure 19.11 (a) Day 1 view: intrusive luxation of the maxillary central incisors in an 8-year-old boy due to trauma. (b) Day 1: orthopantomogram (OPG) view of the intrusion injury. (c) Two-month view: intraoral radiographic view of the intrusion. Nonvital response in both teeth. (d) Three-month view: orthodontic extrusion initiated. (e) Three-month view: endodontic treatment commenced with the placement of intracanal calcium hydroxide. (f) Ten-month view: intracanal calcium hydroxide dressing changed. (g) One-year-and-1-month view: orthodontic treatment discontinued. (h) One-year-and-1-month view: intracanal calcium hydroxide dressing changed. (i) One-year-and-7-month view: intracanal calcium hydroxide dressing changed. (j) One-year-and-10-month view: obturation completed. (*Courtesy: Sashi Nallapati, Jamaica.*)

VIII. AVULSION (EXARTICULATION, TOTAL LUXATION)

Definition: *It is defined as the complete and total displacement of the tooth from its socket.*

The incidence of avulsion varies from 0.5 to 3% of traumatic injuries in permanent dentition and 7 to 13% in primary dentition. The main etiologic factors for avulsion are sports and fight injuries. The maxillary central incisors are the most frequently avulsed teeth.

The avulsed or luxated tooth is both a dental and an emotional problem. It is usually the result of trauma to an anterior tooth of a child or young adult. The shock and pain of the injury and the loss of a tooth needed for eating, speaking, and smiling often lead to emotional upheaval in the patient and parent. The situation is compounded by the need for emergency treatment, to enhance the prognosis. The longer the luxated tooth is out of its socket, the less likely it will remain in a healthy, functional state after replantation.

Classification of Avulsed Teeth

The avulsed teeth can be classified into the following and treatment done accordingly. The following are the recommendations and guidelines given by the AAE in 2013.

1. The Tooth Has Already Been Replanted at the Site of Avulsion (Fig. 19.12)

The following instructions should be given to the parent or patient as soon as the dentist has been informed of the accident and in preparation for an imminent visit:

- Carefully hold the tooth by the crown and gently wash the tooth in running water without brushing or cleaning it, and examine it to be certain that the tooth is intact.
- Avoid touching or scraping the root surface of the tooth.
- Have the patient to rinse his/her mouth.
- Replace tooth in its socket using gentle, steady finger pressure. If the patient is cooperative and able, have the patient gently close the teeth together to force the tooth back into its original position.
- Take the patient to the dentist immediately

(a) Closed Apex

Immediate Treatment

- Leave the tooth in its place.
- Clean the affected area with water or saline.
- Suture gingival laceration, especially in the cervical area.
- Verify normal position of the replanted tooth radiographically.
- Apply a passive and flexible splint for 2 weeks (0.016 inch or 0.4 mm).
- Initiate root canal treatment within 2 weeks of replantation. Calcium hydroxide intracanal medicament for 4 weeks followed by obturation.

(b) Open Apex

Immediate Treatment

- Leave the tooth in its place.
- Clean the affected area with water or saline.
- Suture gingival laceration, especially in the cervical area.
- Verify the normal position of the replanted tooth radiographically.
- Apply a flexible splint for 2 weeks (up to 0.016 inch or 0.4 mm).

The radiographic imaging and endodontic management of teeth with closed and open apex are as follows:

- **Radiographic imaging**
  - Two periapical radiographs from mesial and distal angulations
  - CBCT should be considered to confirm the reposition of the tooth and rule out alveolar bone fracture(s)
- **Endodontic treatment**
  - The goal for replanting developing and immature teeth in children is to allow for possible revascularization of the pulp space.
  - For very immature teeth, root canal treatment should be avoided unless there is clinical or radiographic evidence of pulp necrosis.
  - If pulp necrosis is diagnosed, pulp revascularization or root canal treatment (apexification) is recommended.

2. The Tooth Has Been Kept in Special Storage Media with the Extraoral Dry Time Less Than 60 minutes (Fig. 19.13)

If the patient or parent cannot replace the tooth in its socket, then care in transporting that tooth to the dentist becomes essential. The tooth must be carried in a moist vehicle to maintain the viability of the torn PDL. The most readily available vehicle is the patient's mouth, in which the tooth is bathed in saliva at body temperature. If this cannot be safely done (if the patient is too young), then the tooth has to be placed in a suitable storage media (**Box 19.2**) while transporting it to the dental office for further management.

Box 19.2

Transport Medium for an Avulsed Tooth

The choice of storage media for preserving the avulsed tooth is extremely important for the success of future replantation. Suggested storage media are as follows:

- Hank's balanced salt solution (HBSS)
- Patient's own saliva
  - Vestibule of the mouth
  - Container into which the patient spits
- Milk
- Coconut water
- Propolis
- Viaspan

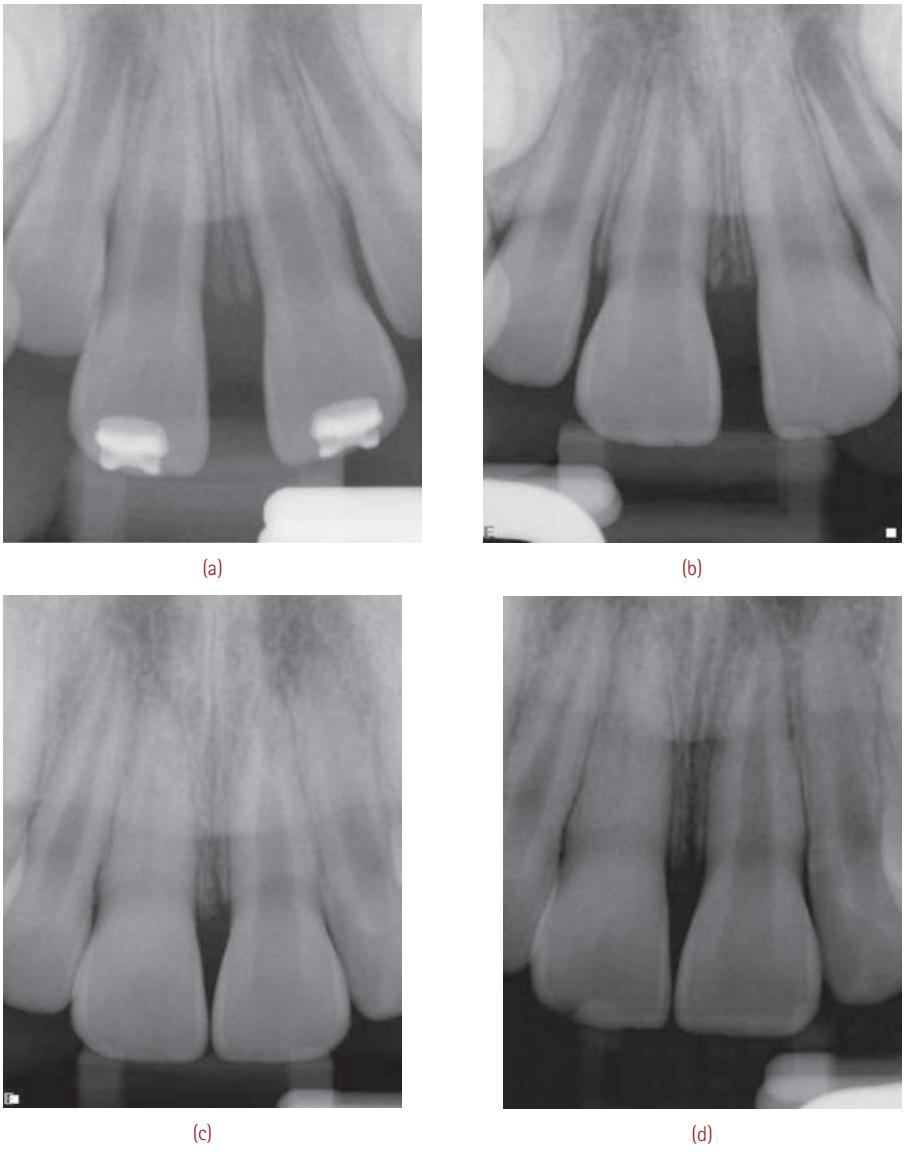


Figure 19.12 (a) Avulsion of maxillary central incisor of an 8-year-old boy. Tooth was avulsed and replanted in 10 minutes by the parent. Roots were not cleaned. No storage medium was used between avulsion and replantation. One day postavulsion: note the radiographic evidence of underdeveloped root and apex. (b) Four months postreplantation: questionable vitality from pulp tests. (c) Two years postreplantation: extensive canal calcification, normal periapical bone. (d) Five years postreplantation: extensive canal calcification, normal periapical bone. (*Courtesy: Louis H. Berman, USA.*)

Clinical Note

- The tooth should not be wrapped in a dry handkerchief or paper tissue because the periodontal ligament will become dehydrated.
- Several studies have shown that *extraoral time* for an avulsed tooth optimally ***should not exceed 20 minutes***; the patient must be taken to the dentist immediately. The sooner the replantation, the better the prognosis.

Box 19.3 lists the management of avulsed teeth with an extraoral dry time of less than 60 minutes.

3. The Avulsed Tooth Has Been Stored for an Extraoral Dry Time of More Than 60 minutes

Box 19.4 presents the management of avulsed teeth with an extraoral dry time of more than 60 minutes.

Follow-Up Procedures for Avulsed Permanent Teeth

Root Canal Treatment

- In teeth with closed apex, the ideal time to begin root canal treatment is within 2 weeks after the replantation

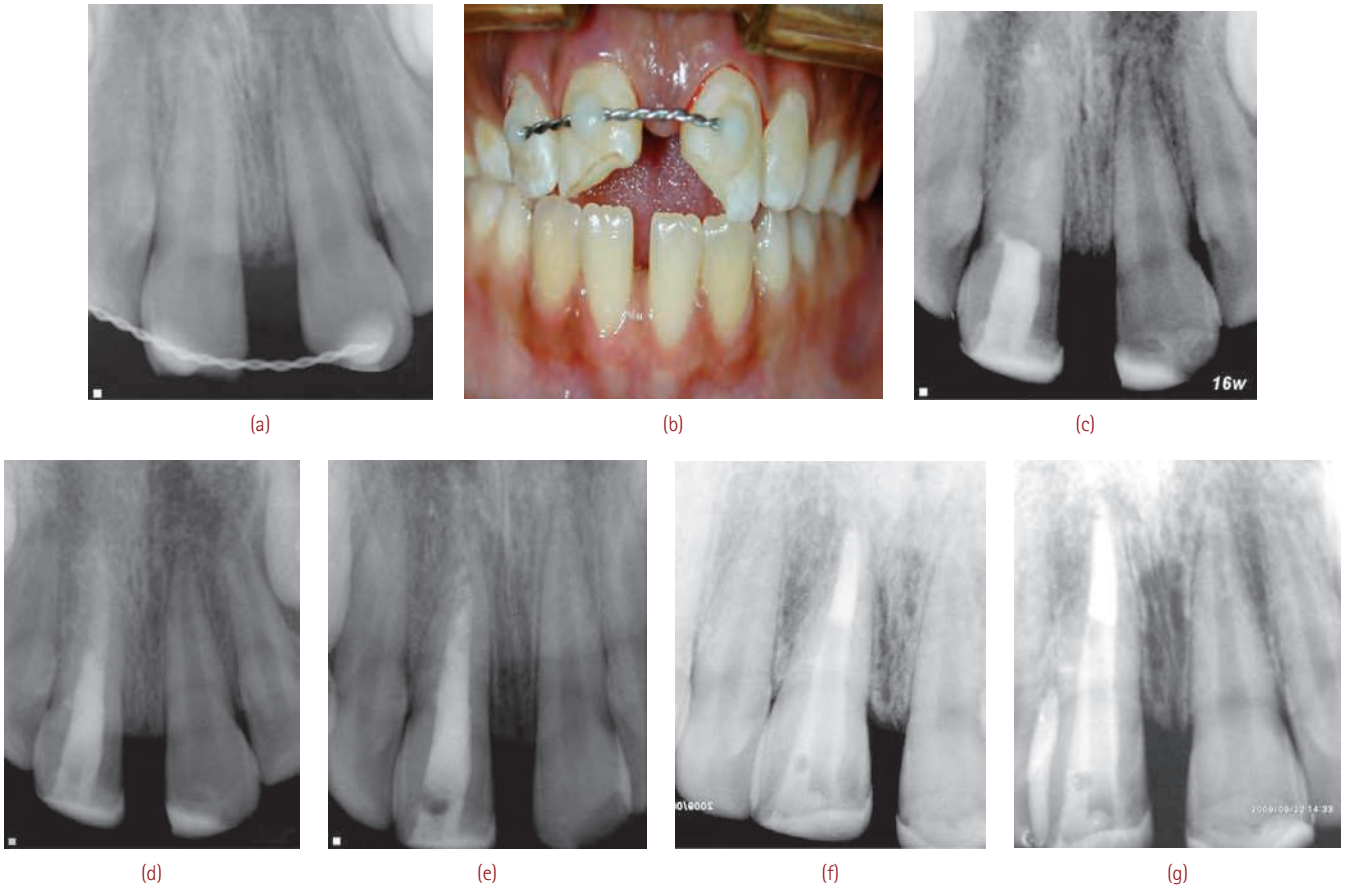


Figure 19.13 (a) Avulsion of maxillary central incisor of an 8-year-old boy. Avulsed tooth was kept in dry gauze for 45 minutes before replantation. (b) Nonrigid splint was placed for 10 days. (c) Pulp was extirpated and $Ca(OH)_2$ was placed as intracanal medicament. (d and e) Calcium hydroxide intracanal medicament refreshed every 3 months till periodontal ligament could be traced around most of the root surface. (f) Obturation was done with MTA in the apical third. Glass fiber post was cemented with resin ionomer. (g) At 15-month recall, the tooth was asymptomatic and functional with no sign of further replacement resorption. (*Courtesy: Sashi Nallapati, Jamaica.*)

procedure. Calcium hydroxide is recommended as an intracanal medication for up to 1 month followed by root canal filling with an appropriate technique.

- In teeth with open apices, which have been replanted immediately or kept in appropriate storage media, pulp revascularization is possible. Root canal treatment should be avoided unless there is clinical and radiographic evidence of pulp necrosis.
- Root canal treatment may be done prior to replantation in a tooth that has been dry for more than 60 minutes before replantation.

Follow-Up

Replanted teeth should be monitored by frequent controls during the first year (once a week during the months 1, 3, 6, and 12) and then yearly thereafter. Clinical and radiographic examinations will provide information to determine the eventual clinical outcome.

Favorable Outcome

- *Closed apex:* The tooth is asymptomatic with normal mobility and normal percussion sound. No radiographic evidence of resorption or periradicular osteitis; the lamina dura appears normal.
- *Open apex:* The tooth is asymptomatic with normal mobility and normal percussion sound. Radiographic evidence of arrested or continued root formation and eruption is found.

Unfavorable Outcome

- *Closed apex:* The tooth is symptomatic with excessive mobility or no mobility (ankylosis) and high-pitched percussion sound. Radiographic evidence of resorption (inflammatory, infection-related resorption, or ankylosis-related replacement resorption).
- *Open apex:* The tooth is symptomatic with excessive mobility or no mobility (ankylosis) and high-pitched percussion sound. In the case of ankylosis, the crown of the tooth will appear to be in an infraocclusal position. Radiographic evidence of resorption (inflammatory, infection-related resorption, or ankylosis-related replacement resorption).

Box 19.3

Management of Avulsed Teeth with an Extraoral Dry Time of Less Than 60 Minutes

Extraoral dry time
LESS THAN 60 minutes

↓

Administer local anesthesia (preferably without a vasoconstrictor) and irrigate the socket with saline. Examine the socket for possible fracture and reposition. Two periapical radiographs from mesial and distal angulation are recommended while CBCT should be considered to confirm the reposition of the tooth and rule out of alveolar bone fracture(s).

CLOSED APEX

↓

Remove necrotic tissue from the root surface with gauze soaked in saline. Irrigate the socket with saline and replant the tooth gently with digital pressure.

↓

Apply a passive and flexible splint for 2 weeks

↓

Initiate RCT within two weeks of replantation

↓

Calcium hydroxide intracanal medicament for 4 weeks followed by obturation

↓

Follow up at 2 weeks, 4 weeks, 3 months, 6 months, 1 year and then yearly for at least 5 years.

OPEN APEX

↓

Remove necrotic tissue from the root surface with gauze soaked in saline. Irrigate the socket with saline and replant the tooth gently with digital pressure.

↓

Apply a passive and flexible splint for 2 weeks. Systemic antibiotics recommended (Amoxicillin is the drug of choice)

↓

Spontaneous revascularization is primary goal. If this does not occur, apexification or root canal treatment is the treatment of choice.

↓

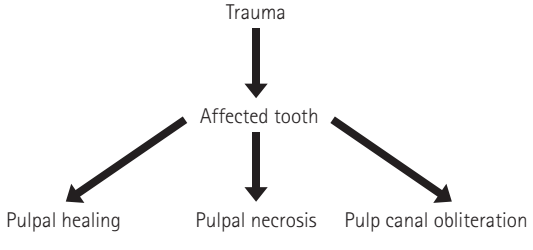
Follow-up at 2 weeks, 4 weeks, 3 months, 6 months, 1 year and then yearly for at least 5 years

RESPONSE OF PULP TO TRAUMA

The pulpal response to dental trauma is dependent on three critical factors:

1. Intensity of the trauma
2. Stage of root development
3. Presence or absence of bacteria

Depending on these factors, the following clinical outcomes are possible:



PULPAL HEALING

The prognosis depends on whether the pulp is exposed, the degree of damage to the pulp, the age of the patient, and other factors. When the pulp has become exposed, pain may be continuous or intermittent in nature. In some cases, surprisingly, the patient is free of pain. In an older person, sufficient pulp recession may already have occurred to protect the pulp against irritation from external stimuli, and the tooth may be practically symptomless.

In young patients, although the pulp is not exposed, if the break has bared the dentin, the tooth will become sensitive to temperature changes and to sweet and sour, because the pulp chamber is large, the pulp horns are still extensive, and the dentinal tubules are relatively large containing tissue and fluids that are susceptible to noxious stimuli. If the tooth is still developing or immature (apical foramen diameter

Box 19.4

Management of Avulsed Teeth with an Extraoral Dry Time of More Than 60 Minutes

Extraoral dry time
MORE THAN 60 minutes

↓

Administer local anesthesia (preferably without a vasoconstrictor) and irrigate the socket with saline. Examine the socket for possible fracture and reposition. Two periapical radiographs from mesial and distal angulation are recommended while CBCT should be considered to confirm the reposition of the tooth and rule out of alveolar bone fracture(s).

CLOSED APEX

↓

Remove necrotic tissue from the root surface with gauze soaked in saline. Irrigate the socket with saline and replant the tooth gently with digital pressure.

↓

Apply a passive and flexible splint for 2 weeks. Systemic antibiotics recommended (Amoxicillin is the drug of choice).

↓

Initiate RCT within two weeks of replantation

↓

Calcium hydroxide intracanal medicament for 4 weeks followed by obturation (Alternate option is to use intracanal corticosteroid medicament for 6 weeks)

↓

Follow-up at 2 weeks, 4 weeks, 3 months, 6 months, 1 year and then yearly for at least 5 years. Poor long-term prognosis (ankylosis and root resorption)

OPEN APEX

↓

Remove necrotic tissue from the root surface with gauze soaked in saline. Irrigate the socket with saline and replant the tooth gently with digital pressure.

↓

Apply a passive and flexible splint for 2 weeks. Systemic antibiotics recommended (Amoxicillin is the drug of choice)

↓

Spontaneous revascularization is primary goal. If this does not occur, apexification or root canal treatment is the treatment of choice.

↓

Follow-up at 2 weeks, 4 weeks, 3 months, 6 months, 1 year and then yearly for at least 5 years

>0.5 mm), the possibility of pulpal healing through revascularization exists. If a displaced or luxated tooth is repositioned in its normal location, revascularization of the pulp may proceed from the apical opening in a coronal direction. Thus, teeth with short roots and large-diameter apical openings are more likely to have successful outcomes.

PULPAL NECROSIS

Pulpal necrosis following severance of the blood supply may proceed through coagulation necrosis to liquefaction necrosis to gangrenous necrosis depending on the presence or absence of bacteria. Pulpal necrosis in fully formed mature teeth can be easily treated with proper endodontic therapy. Loss of vitality in developing teeth would lead to weak, fracture-prone roots. Hence, every effort should be made to employ vital pulp therapy to achieve pulpal survival and healing in such teeth. At times, pulp necrosis is accompanied by external resorption or internal resorption (**Fig. 19.14**).

PULP CANAL OBLITERATION (CALCIFIC METAMORPHOSIS)

Calcification of the root canal from trauma has a small but ponderable incidence, considering the number of teeth traumatized in children and young people. This is frequently

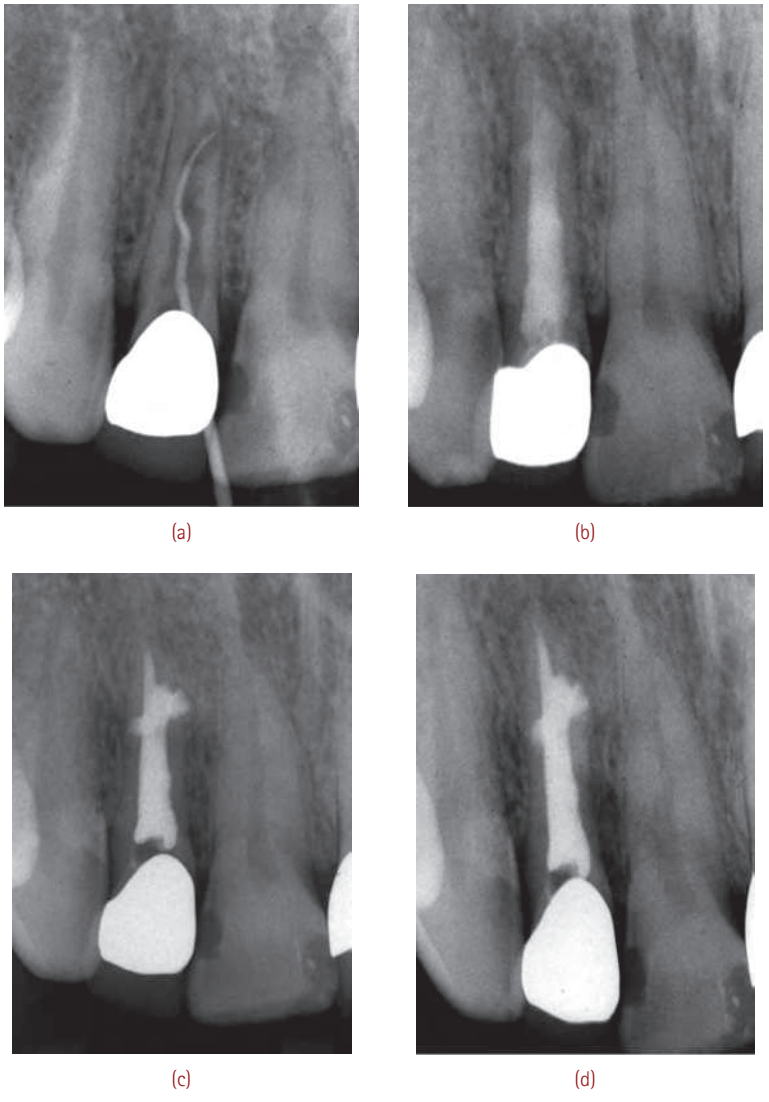


Figure 19.14 (a) Maxillary lateral incisor with a history of trauma—apex closed, coronal portion open. The tooth was crowned, but the pulp began an internal resorptive process that perforated before the pulp became necrotic. Note the sinus tract tracing. (b) Calcium hydroxide was placed. (c) The root canal was obturated 10 months later. (d) Re-examination at 1 year.

observed in luxation-type injuries associated with displacement (**Fig. 19.15**). Teeth with calcified root canals usually remain symptomless for many years, except for their radiographic appearance and some discoloration of their crown. If two adjacent teeth are traumatized at the same time, it is possible for the pulp of one tooth to be stimulated to lay down dentin, ultimately resulting in calcification and partial or complete obliteration of the root canal. In the adjacent tooth, the pulp succumbs and becomes necrotic, resulting in a wide, open apical foramen.

EFFECT OF TRAUMA ON SUPPORTING TISSUES

Root resorption around the fracture site can be observed sometimes. Usually resorption occurs within 1 year after the injury, and according to Andreasen, the supporting tissues of the tooth comprising the PDL and bone react to dental traumatic injuries in three possible ways:

1. *Surface resorption (repair-related resorption)*
   a. External surface resorption
   b. Internal surface resorption

   Surface resorption is usually a transient and reversible form of resorption following luxative and avulsion injuries. It is restricted to small areas of the root surface and heals as long as the pulp remains vital and uninfected by bacteria.
2. *Inflammatory resorption (infection-related resorption)*
   a. External inflammatory resorption (**Fig. 19.16a**)
   b. Internal tunneling resorption (**Fig. 19.16b**)

   As the name indicates, inflammatory resorption is an aggressive form of injury-related resorption typically

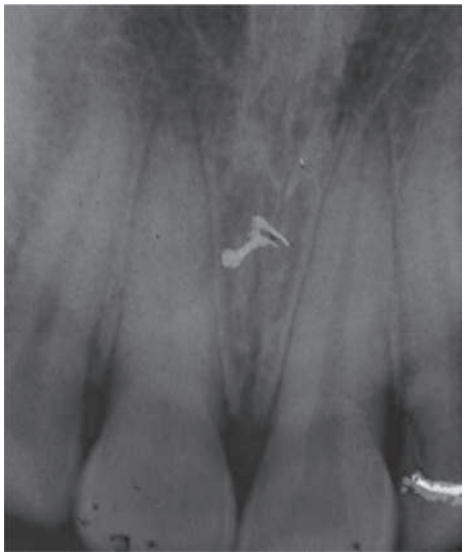
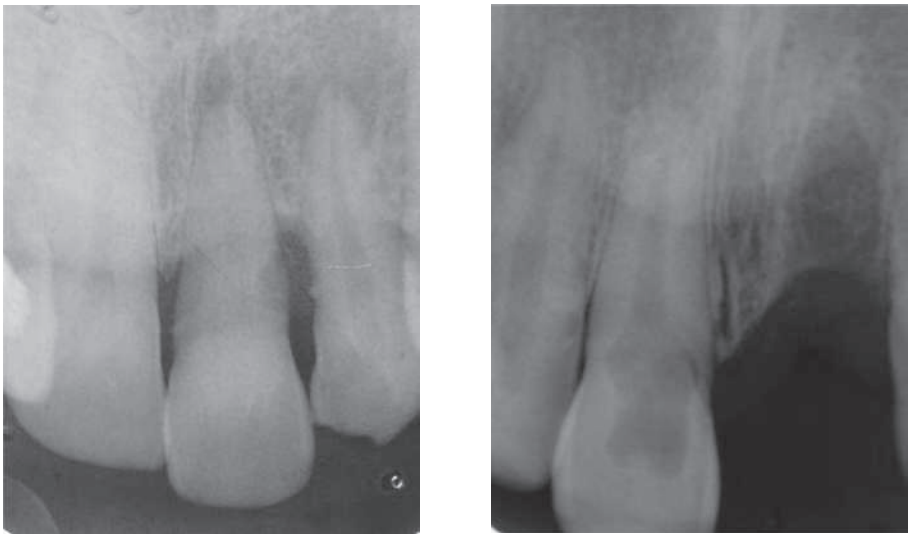


Figure 19.15 Calcific metamorphosis: canal obliteration in a maxillary right central incisor with a history of trauma 10 years back. The patient is clinically asymptomatic.

occurring in traumatized teeth which get infected with bacteria. The lack of pulpal blood supply and infection cause external and at times even internal root resorption. Root canal treatment can prevent resorption and can arrest it even if the resorption has already commenced.

3. *Replacement resorption (ankylosis-related resorption):* This kind of resorptive process is associated with teeth with extensively damaged cementum and PDL. Avulsion injuries are classic examples of teeth showing such resorptive patterns. The loss of the PDL and cementum exposes the root surface to osteoclasts that replace the cementum and dentin with new bone resulting in the fusion of the bone and the tooth. Clinically, such teeth can be diagnosed by percussion test (metallic sound on percussion) and by the loss of PDL space radiographically.

The pathology and management of external and internal root resorption is discussed in Chapter 5. The surgical management of root resorption would be discussed in Chapter 22.



(a) (b)

Figure 19.16 (a) External root resorption with loss of bone support in a tooth with a history of trauma. (b) Internal resorption without root perforation in a tooth with a history of trauma.

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20 Endodontic–Periodontic Interrelationship

Not everything that can be counted counts, and not everything that counts can be counted....
—Albert Einstein

The tooth, its pulp, and its supporting structures must be viewed as a biological unit. Because the vitality of the tooth depends on its ability to function, and not on the viability of the pulp, the health of these structures is of prime importance. The interrelations among these structures influence each other during function and disease.

- The relationship between periodontal and pulpal disease was first described by Simring and Goldberg in 1969.
- The term "pulpodontic-periodontic syndrome" was first described by Bender and Seltzer in 1972.

Until recently, an endodontically involved tooth with an underlying periodontal pathology was considered to have a questionable prognosis. As a result, many teeth were sacrificed unnecessarily. Fortunately, in many instances, the combined endodontic–periodontic lesion that affects a single tooth can now be diagnosed and treated successfully with predictable prognosis.

PULPOPERIODONTAL PATHWAYS (Fig. 20.1)

The pulp and the periodontium have intimate embryological, anatomical, and vascular pathways of communication. Pathology in either of these two structures invariably leads to an adverse effect on the other. This is evident from the fact that pulpoperiodontal pathoses are responsible for more than 50% of tooth mortality.

Pathways of communication between the pulp and periodontal tissues:

- Apical foramen
- Dentinal tubules
- Lateral canals
- Periodontal ligament
- Alveolar bone
- Neural pathways
- Vasculolymphatic drainage pathways
- Atypical anatomic factors like palatogingival groove
- Pathological communications due to fractures and perforations.

ETIOLOGY OF ENDO–PERIO LESIONS

Examination of the etiological factors that cause endo–perio lesions indicates that these factors originate from either endodontic or periodontal or both the disease

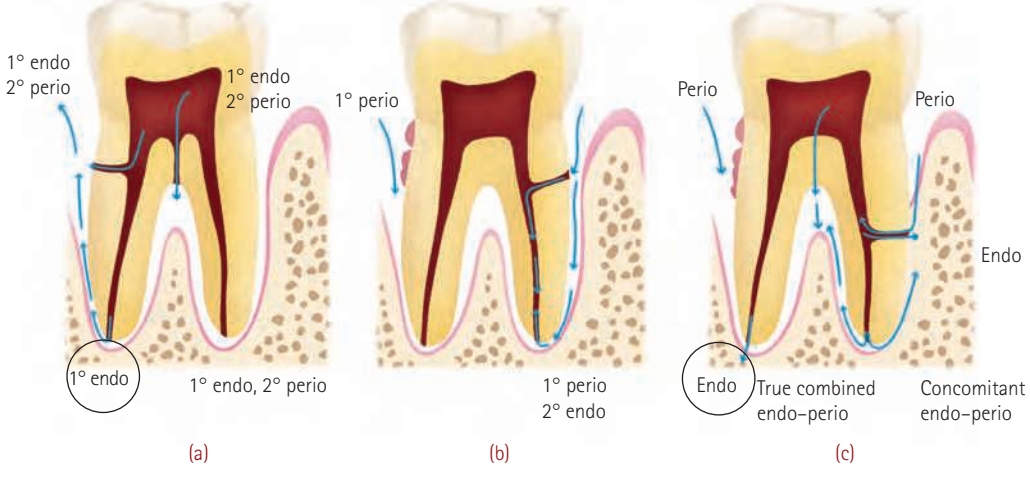


Figure 20.1 Endodontic and periodontal pathways: (a) Endodontic lesions. The pathway of inflammation is through the apical foramen, furcation canals, and lateral accessory canals to the periodontium. This results in a primary endodontic lesion, sometimes progressing toward secondary periodontal involvement. (b) Periodontal lesions. This is the progression of periodontitis by way of lateral canal and through the apical foramen to induce a secondary endodontic lesion. (c) True combined endodontic and periodontal lesion and concomitant endodontic and periodontal lesion.

processes (**Tables 20.1** and **20.2**). For example, a progressing infrabony pocket exposes the pulp tissue to the oral environment by "uncovering" a lateral canal and resulting in irreversible pulpal inflammation. Both endodontic and periodontal therapies are required for healing to occur. Similarly, furcation bone loss can lead to pulp exposure by "uncovering" a subpulpal-floor accessory canal, with concomitant sequelae. Thus, it is possible for periodontal disease to cause secondary pulpal disease.

Conversely, pulpal disease can cause periodontal disease. A pulpal infection can spread through lateral and accessory canals or apical foramina and may cause furcation

Table 20.1 Difference Between Endodontic and Periodontal Lesions

Diagnosis	Endodontic	Periodontal
Etiology	Necrosis of the pulp	Infection and inflammation of the periodontium
Pain	Acute, excruciating, and spontaneous in nature	Dull and chronic in nature
Swelling	Occurs in cases with periapical abscess and is diffuse in nature	Localized
Percussion	Positive and vertical in direction	Mild and lateral in direction
Probing	Probing depth of sulcus <3 mm	Probing depth of sulcus >3 mm
Sinus tracing	Gutta-percha point leads to the apex of the involved tooth	Gutta-percha point would lead to the sulcus of the involved tooth
Mobility	Rare and localized in nature	More common and generalized in nature
Junctional epithelium	Normal	Apical migration
Gingiva	Normal	Gingival inflammation and recession
Therapy	Root canal therapy	Periodontal therapy

Table 20.2 Salient Features of Endodontic–Periodontic Lesions

Condition	Etiology	Clinical Features	Treatment Plan
Primary endodontic lesions	Dental caries, restorative procedures, and traumatic injuries	• Pain, tenderness to palpation, and percussion • Sinus tract, if present, can be traced to the apex of the involved tooth • Abnormal response to vitality testing	Endodontic therapy
Primary endodontic lesions with secondary periodontal involvement	Progression of an untreated or chronic primary endodontic lesion	• Plaque and calculus accumulation in the sulcus leading to pocket formation • Lowering of the epithelial attachment	Endodontic treatment as the primary line of therapy followed by secondary periodontal therapy
Primary periodontal lesions	Plaque and calculus are the primary etiological factors	• Evidence of horizontal and/or angular bone loss associated with tooth mobility • Normal response to pulp vitality testing procedures	Periodontal therapy without any need for endodontic intervention
Primary periodontal lesions with secondary endodontic involvement	When periodontal disease progresses apically, it might involve the pulp through the apical foramen and the lateral canals	• The lesion exhibits signs of periodontal disease such as pocket formation and horizontal/angular bone loss • Signs of pulpal involvement including episodes of acute pulpal pain	Primary endodontic treatment followed by long-term periodontal therapy
True combined lesions	Clinically not possible to differentiate which started first	Chronic lesion with gross pulpal and periodontal destruction	Endodontic therapy followed by radisection/hemisection
Concomitant lesions	Distinct etiological factors of pulpal and periodontal diseases which do not influence one another	Both the diseases are evident independent of each other	Both the diseases are treated independently

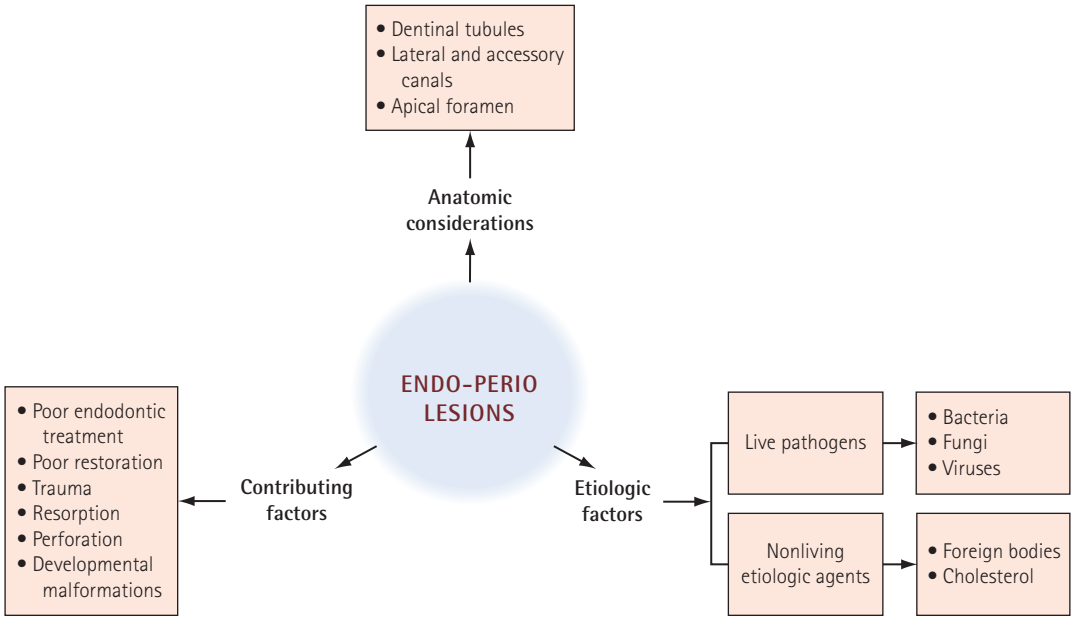


Figure 20.2 The etiopathogenesis of endodontic–periodontic lesions.

breakdown, infrabony pocket formation, and periradicular lesions. Conceivably, a persistent sinus tract draining through the gingival crevice could become an infrabony pocket and could require combined therapy for healing to occur.

Clinical Note

- The time period of persistence of the etiological factors in a susceptible environment is directly related to the probability that combined therapy will be needed. In other words, duration can be a key factor in evaluating etiological effects.
- The etiological factors implicated in the pathogenesis of endodontic–periodontic lesions are given in **Figure 20.2**.

CLASSIFICATION

Understanding the endodontic–periodontic relationship is essential because it frequently dictates the plan of treatment.

I. SIMON'S CLASSIFICATION

Simon et al. proposed a classification based on the etiology and subsequent progression of the disease process.

A. Primary endodontic lesions
B. Primary endodontic lesions with secondary periodontal involvement
C. Primary periodontal lesions
D. Primary periodontal lesions with secondary endodontic involvement
E. True combined lesions
F. Concomitant endodontic and periodontal lesion (added by Belk and Gutmann)

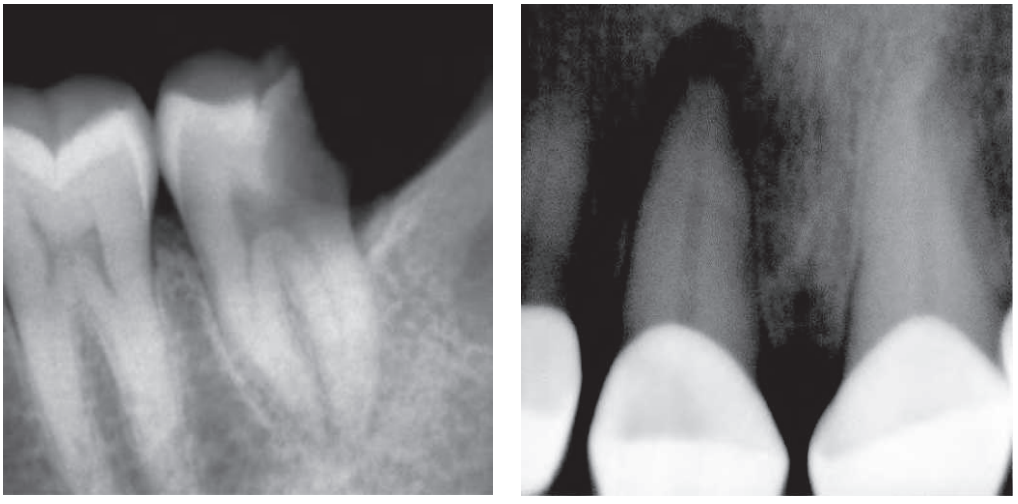
A. Primary Endodontic Lesion

The causes of primary endodontic lesion are dental caries, restorative procedures, and traumatic injuries (**Fig. 20.3**). The disease progresses and causes periradicular changes which are evident radiographically. The patient may also have symptoms such as pain, tenderness to palpation, and percussion. In certain cases, a sinus tract is evident which drains out either through the gingival sulcus or on to the gingiva. A gutta-percha point can be used to trace the sinus which leads to the apical region of the involved tooth.

Clinically, the involved tooth exhibits an abnormal response to vitality testing indicative of degenerative changes of the pulp. The supporting periodontal tissues are normal without any pathosis. The lesion resolves by endodontic therapy alone (**Fig. 20.4**).

B. Primary Endodontic Lesion with Secondary Periodontal Involvement

An untreated or chronic primary endodontic lesion would progress and cause secondary periodontal manifestations. As drainage occurs through the gingival sulcus, plaque and calculus accumulate in the sulcus leading to pocket formation and lowering of the epithelial attachment. Clinically, these lesions have a necrotic pulp with periradicular changes along with plaque and calculus which can be diagnosed with the help of a radiograph and a periodontal probe, respectively. The lesion resolves by treating both conditions, with endodontic treatment to be the primary line of therapy followed by secondary periodontal therapy (**Figs 20.5** and **20.6**).



(a) (b)

Figure 20.3 Primary endodontic lesion: (a) Proximal decay in the mandibular molar causing a lesion of primary endodontic origin. (b) Trauma from occlusion in this maxillary central incisor causing a primary endodontic lesion.

C. PRIMARY PERIODONTAL LESION

Plaque and calculus are the primary etiological factors of inflammation and loss of supporting periodontium. This starts as gingivitis followed by an apical migration of the epithelial attachment causing pocket formation (**Fig. 20.7**), which is demonstrable by periodontal probing. They may be associated with trauma from occlusion. There is evidence of horizontal and/or angular bone loss associated with tooth mobility (**Fig. 20.8**). However, the tooth would respond normally to pulp vitality testing procedures. The prognosis is dependent on the extent of periodontal destruction and on the patient's compliance to long-term therapy. The lesion resolves by periodontal therapy without any need for endodontic intervention.

D. Primary Periodontal Lesion with Secondary Endodontic Involvement

As the periodontal disease progresses apically, it might involve the pulp through the dentinal tubules and the lateral canals. The lesion exhibits signs of periodontal disease such as pocket formation and horizontal/angular bone loss (**Figs 20.9** and **20.10**). Signs of pulpal involvement including episodes of acute pulpal pain would be associated with this condition. Radiographically, the lesion mimics a primary endodontic lesion with secondary periodontal involvement. The lesion resolves by primary endodontic treatment followed by long-term periodontal therapy.

E. True Combined Lesions

In certain cases, the signs and symptoms of pulpal and periodontal involvement are such that it is clinically not possible to differentiate which started first. Such a chronic lesion with gross pulpal and periodontal destruction is referred to as a true combined lesion (**Fig. 20.11**). The prognosis in such cases is typically guarded by the chronic nature of the periodontal disease process. These are typical cases which might need endodontic therapy followed by radisection/hemisection in order to improve the prognosis of the affected tooth.

F. Concomitant Endodontic and Periodontal Lesion

This arises due to the presence of distinct etiological factors of pulpal and periodontal diseases which do not influence one another. The signs and symptoms of both the diseases are evident independent of each other (**Fig. 20.12**). Usually treatment is rendered to only one of the two diseases in a hope that the other would subside. However, resolution of this lesion would occur when both the diseases are treated independently.

II. OLIET AND POLLOCK'S CLASSIFICATION

This classification is based on treatment protocol.

A. Lesions that Require Endodontic Treatment Procedures Only

1. Any tooth with a necrotic pulp and periradicular pathosis, with or without a sinus tract
2. Asymptomatic Apical abscess with a sinus tract draining through the gingival crevice, thus passing through a section of the attachment apparatus in its entire length alongside the root
3. Root fractures, longitudinal and horizontal
4. Root perforations, pathologic and iatrogenic
5. Teeth with incomplete apical root development and inflamed or necrotic pulps, with and without periradicular pathoses
6. Replants, intentional or traumatic
7. Transplants, autotransplants or allotransplants
8. Teeth requiring hemisection or radisectomy
9. Intentional endodontic therapy for prosthodontic consideration

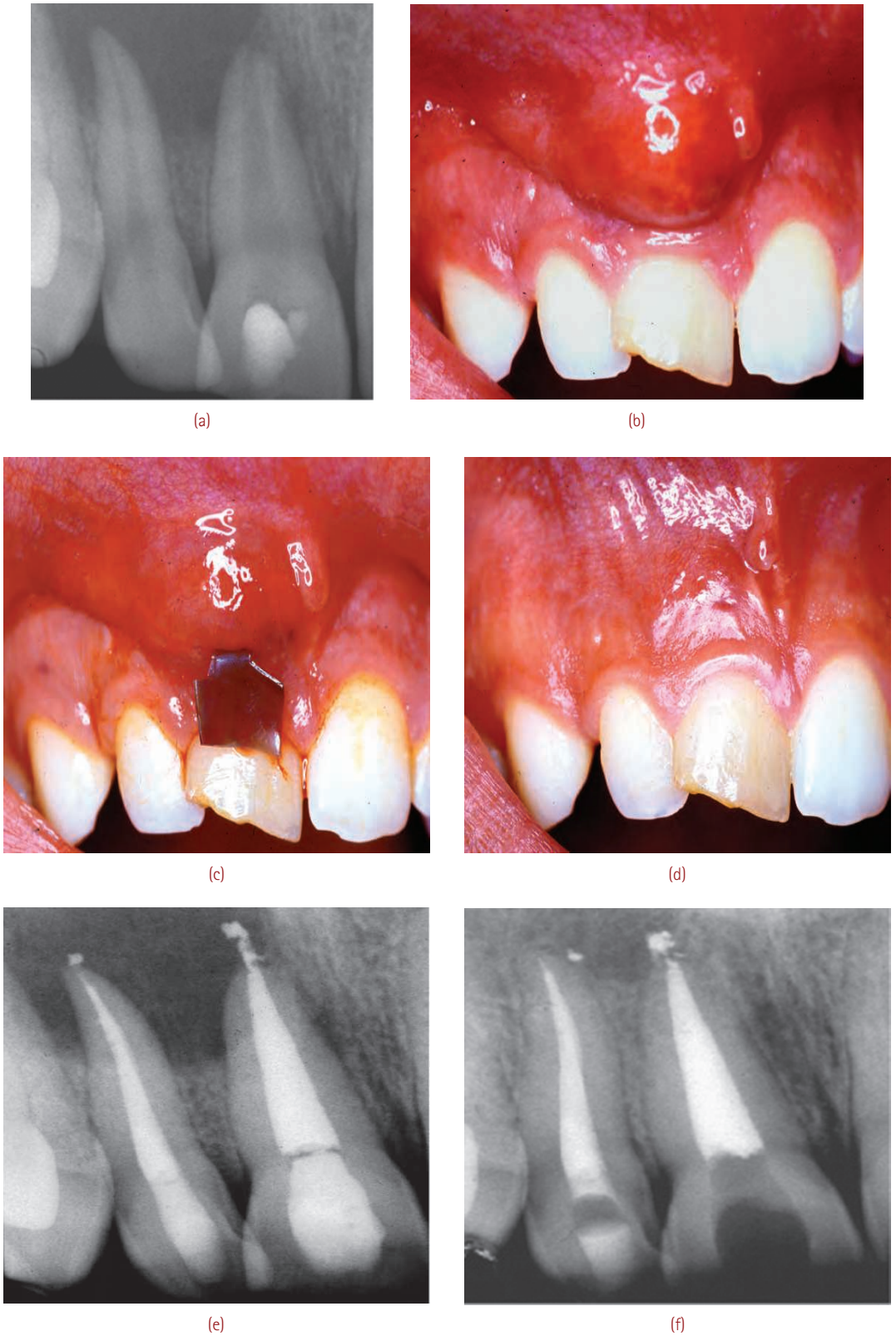
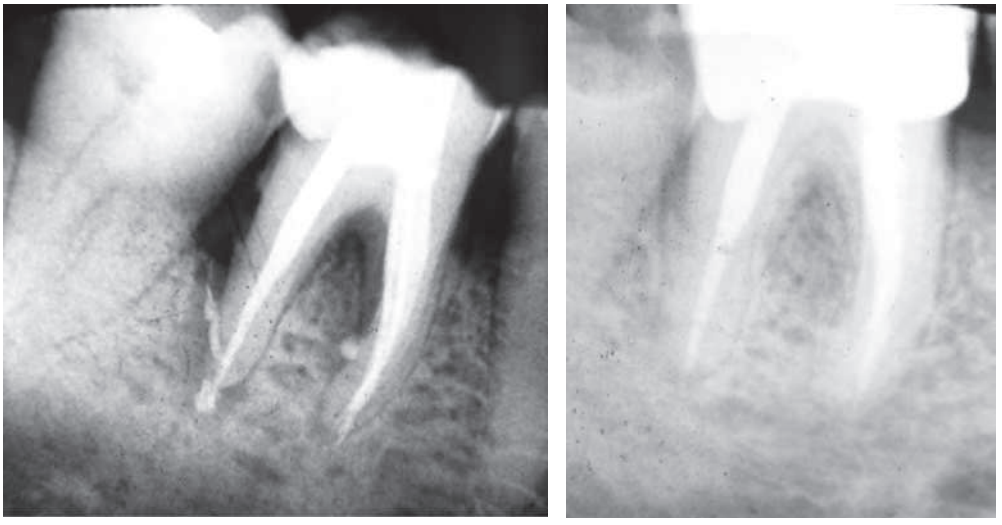


Figure 20.4 (a) Preoperative X-ray of right central and lateral incisors showing a large periradicular lesion. The patient reported a history of trauma several years before. (b) Clinical view showing a soft fluctuant swelling in relation to the affected teeth. (c) The teeth were accessed and cleaned and then filled with calcium hydroxide. Incision and drainage performed, and a drain made of a piece of rubber dam used. (d) Clinical view 1 week later. (e) One week later the teeth were accessed again, and calcium hydroxide was removed. The teeth were then filled using warm vertical compaction of gutta-percha. (f) A 2-year follow-up radiograph showing complete healing of the lesion. (*Courtesy: Wilhem Pertot, France.*)



(a) (b)

Figure 20.5 (a) Primary endodontic lesion with secondary periodontal involvement in relation to the distal root necessitating endodontic therapy of the lower first molar followed by periodontal therapy. (b) Seven-year follow-up showing complete healing of both endodontic and periodontal lesions. (*Courtesy: Arvind Shenoy, India.*)

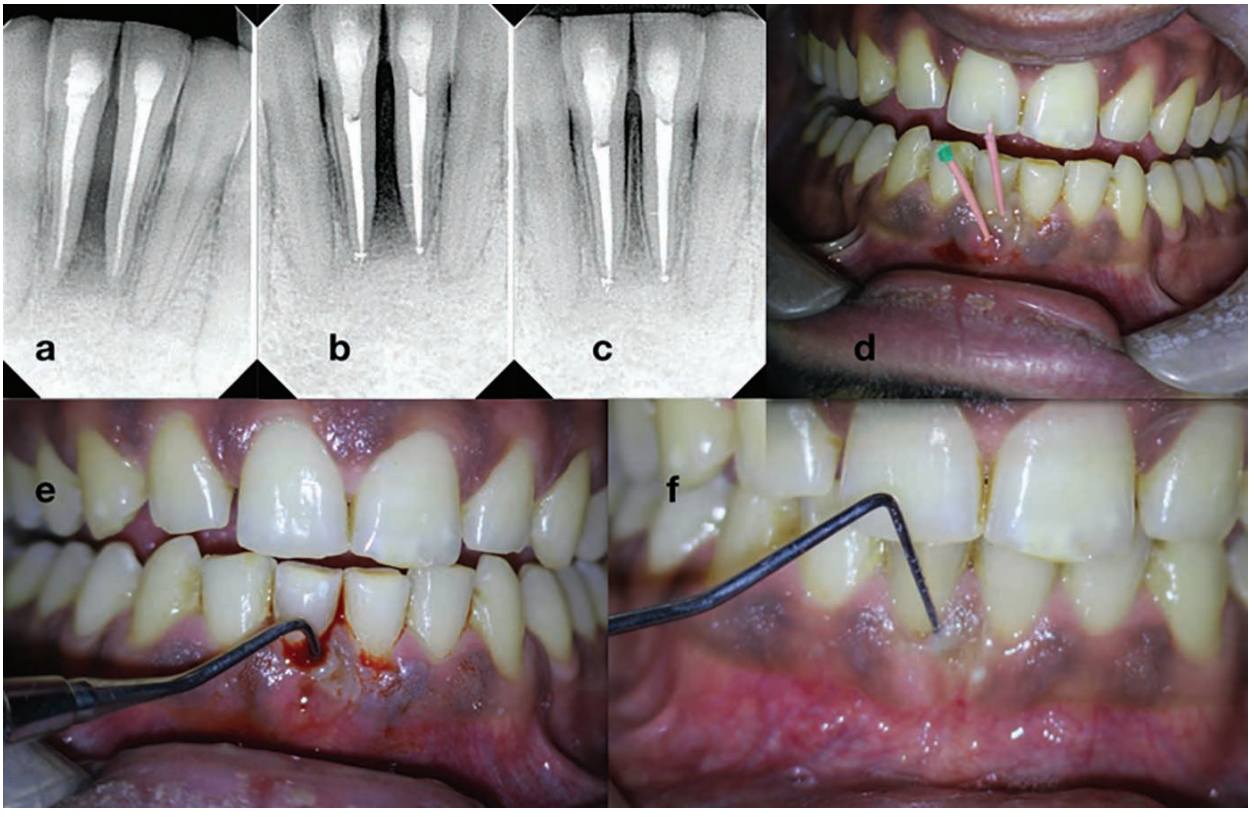


Figure 20.6 (a) Preoperative radiograph revealing combined endodontic periodontal lesion in mandibular central incisors. (b) Postoperative radiograph after the retreatment of both mandibular central incisors (notice the lateral canal visualized). (c) One-year follow-up revealing complete healing of the endodontic periodontal lesion. (d) Preoperative clinical image with 2 sinus tracts present. (e) Preoperative labial view of deep probing depths in the interdental space between the two central mandibular incisors. (f) One-year follow-up clinical labial view revealing healthy tissues and no probing depths. *(Courtesy: Antonis Chaniotis, Greece.)*

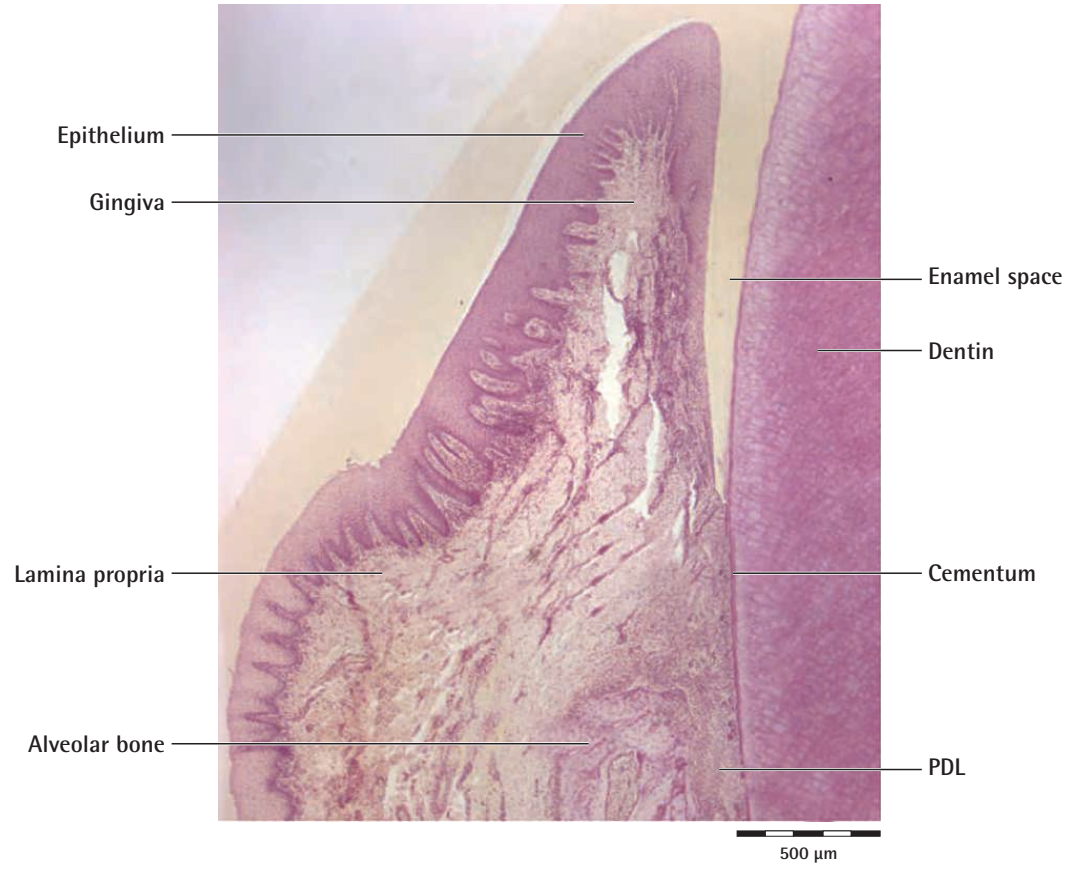
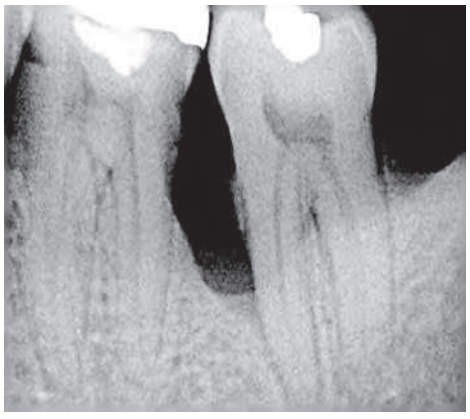
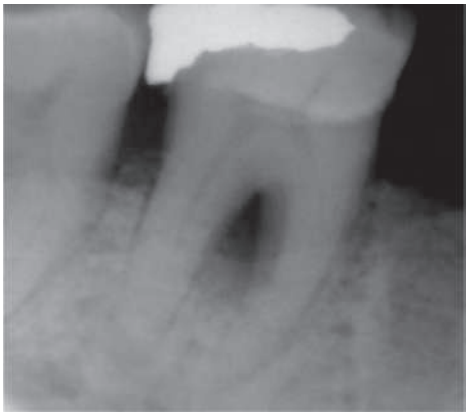


Figure 20.7 (a) This is a section through a tooth and its supportive tissues. Notice the gingival epithelium. Rete pegs have formed (strands of epithelium), stretching some distance into the lamina propria. At the alveolar crest, you can see the orientation of the periodontal fibers. Note the numerous fibroblasts in the ligament. PDL, periodontal ligament. (b) This is a section through a piece of inflamed gingival and the adjacent tooth. Most of the supportive tissue of the tooth is lost and the root surface is covered by plaque. The layer of cementum is also quite thick, indicating that the tooth originates from an old individual. Within the cementum, the incremental lines are seen. The gingiva is severely inflamed (stain: H + E). (*Courtesy: Mathias Nordvi, University of Oslo, Norway.*)

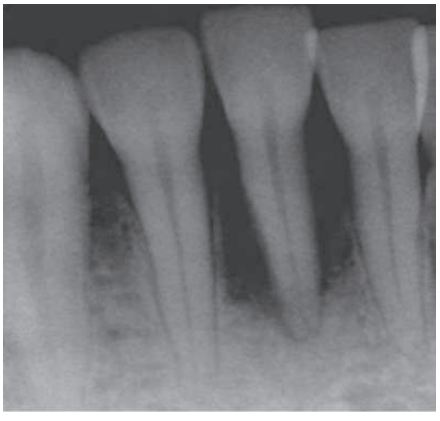


(a)

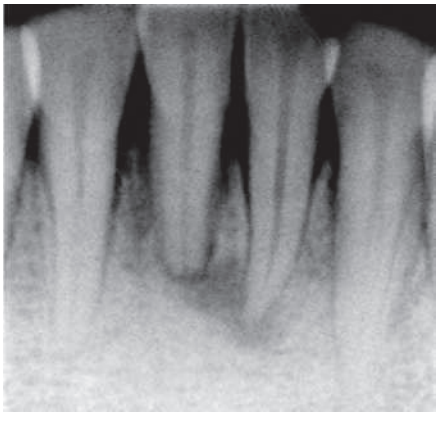


(b)

Figure 20.8 Primary periodontal lesion: (a) Classical angular bone defect without any periradicular changes indicative of a primary periodontal lesion in a mandibular molar. (b) Proximal overhang of a poor restoration causing food impaction and proximal primary periodontal lesion in a mandibular molar.



(a)

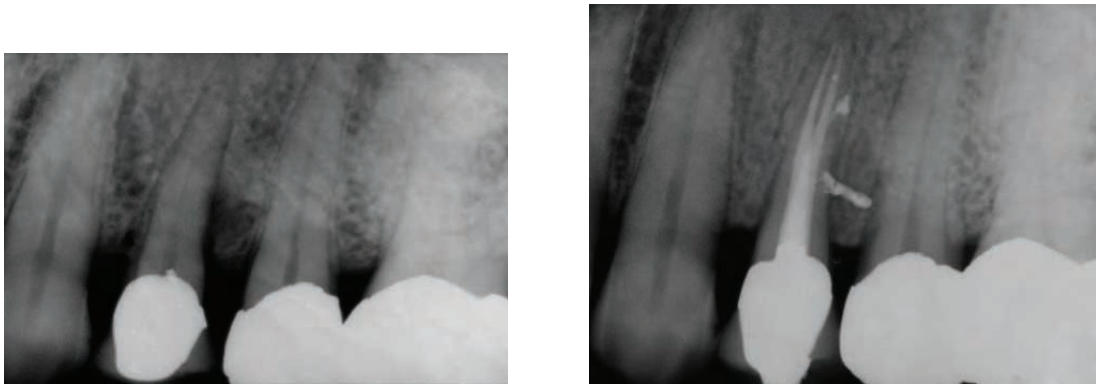


(b)



(c)

Figure 20.9 Primary periodontal lesion with secondary endodontic involvement: (a) Trauma from occlusion causing primary periodontal lesion with secondary endodontic involvement in the lower anteriors. (b) Chronic periodontitis causing secondary endodontic lesion in the mandibular central incisors. Note the periradicular radiolucency indicative of irreversible endodontic changes. (c) Proximal overhang causing a periodontal lesion leading to secondary endodontic involvement of the distal root of a mandibular molar.



(a) (b)

Figure 20.10 Primary periodontal secondary endodontic lesion in maxillary premolar: (a) Preoperative view. (b) Following endodontic therapy and periodontal therapy.

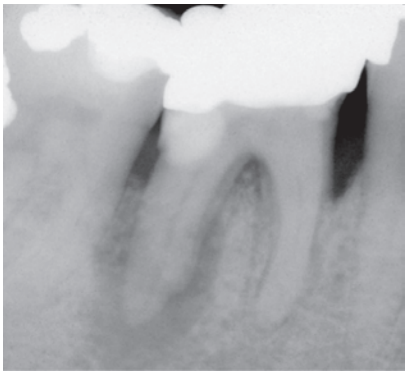


Figure 20.11 True combined endodontic and periodontal lesion in a mandibular molar. Note the proximal decay involving the pulp causing a periradicular radiolucency in the distal root indicative of the endodontic lesion which is combined with the angular bone loss caused by the periodontal lesion.

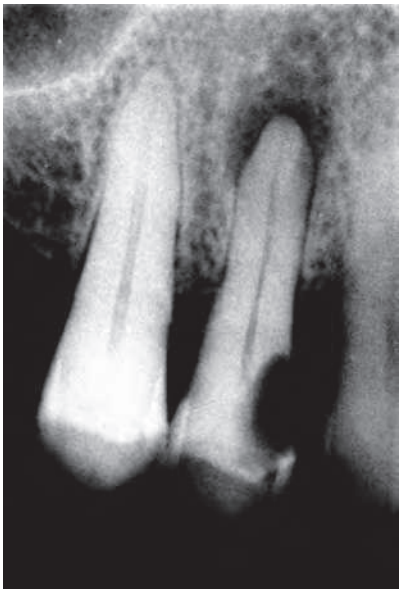


Figure 20.12 Concomitant endodontic and periodontal lesion in a maxillary premolar. Note the proximal decay involving the pulp causing a periradicular radiolucency indicative of the endodontic lesion which is independent of the horizontal bone loss caused by the periodontal lesion.

B. Lesions that Require Periodontal Treatment Procedures Only

1. Occlusal trauma causing reversible pulpitis
2. Occlusal trauma plus gingival inflammation, resulting in pocket formation
   (a) Reversible but increased pulpal sensitivity caused by trauma or, possibly, by exposed dentinal tubules
   (b) Reversible but increased pulpal sensitivity caused by uncovering lateral or accessory canals exiting into the periodontium
3. Suprabony or infrabony pocket formation treated with overzealous root planing and curettage, leading to pulpal sensitivity
4. Extensive infrabony pocket formation, extending beyond the root apex and sometimes coupled with lateral or apical resorption, yet with pulp that responds within normal limits to clinical vitality testing

C. Lesions that require combined endodontic–periodontic treatment procedures

1. Any lesion in group I that results in irreversible reactions in the attachment apparatus and requires periodontal treatment
2. Any lesion in group II that results in irreversible reactions in pulp tissue and also requires endodontic treatment

Predisposing Factors

Grossman has given the possible predisposing factors leading to combined endodontic–periodontic treatment procedures:

1. Atypical Anatomical Factors

(a) Malalignment of a tooth, a predisposing factor to trauma; examples are food impaction and occlusal trauma
(b) Presence of a multirooted tooth in a position usually occupied by a single-rooted tooth, or additional roots, separate or fused, in multirooted teeth
(c) Presence of additional canals, with resultant changes in root morphology in single and multirooted teeth
(d) Large lateral (accessory) canals in coronal and middle sections of roots

2. Trauma

(a) Combined with gingival inflammation, trauma can lead to deep periodontal pockets or, in multirooted teeth, furca exposure. If large lateral canals exit in the pocket area, the pulp will usually be exposed to the oral environment, and in addition to the periodontal problem, irreversible pulpitis may also occur
(b) Possible cause of crown fracture, root fracture, or root displacement, resulting in irreversible pulpitis, necrosis, or peri-apical disease
(c) Possible involvement of the pulp and disturbance of the periodontal membrane, with the resultant sinus tract draining through the periradicular tissue and exiting through the gingival crevice; a newly found "pathway of least resistance" that differs from the usual sinus tract, which drains through the labial or buccal mucosa
(d) Possible cellular changes in the pulp or periodontium leading to internal or external resorption associated with root perforation. Trauma to a tooth can originate from an accidental blow, cavity preparation, and other restorative procedures, tooth separation, orthodontic treatment, malocclusion, and detrimental habits. Trauma appears to be a major etiological factor in the formation of an endodontic–periodontic lesion (*refer to Chapter 19, Treatment of Traumatized Teeth*)

3. Miscellaneous Factors

(a) Iatrogenic errors, such as perforation into the furcation of multirooted teeth during root canal therapy, root perforation during postpreparation, or perforation in the apical part of a curved root during instrumentation
(b) Possibly, systemic factors, such as systemic disease as a cause of the combined lesion

SEQUENCE OF TREATMENT

Some clinicians suggest that initial treatment be either endodontic or periodontic, depending on the origin of the initiating disease. Others recommend that partial endodontic treatment be performed through canal preparation and disinfection, followed by periodontal therapy, before finally finishing the endodontic procedures once a successful periodontal result has been achieved. However, it is recommended that endodontic treatment should precede periodontal therapy, regardless of the cause of disease. For accurate diagnosis and treatment planning, the clinician should be able to differentiate between endodontic and periodontal lesions. The signs and symptoms of these two distinct pathological entities are summarized in **Tables 20.1** and **20.2**.



Clinical Note

Endodontic lesions should be treated before the management of the periodontal lesions because of the following reasons:

- Endodontic treatment is highly predictable.
- Periodontal component cannot resolve till the endodontic lesion is present.
- Progress of periodontitis is slow, with the exception of acute disease. Therefore, prompt management of the pulpal lesion is the primary concern.

DIFFERENTIATION OF A SINUS TRACT FROM AN INFRABONY POCKET

It is clinically important to differentiate between a sinus tract draining into the gingival crevice and an infrabony pocket extending to the root apex of a tooth. A sinus tract originates from the root canal and progresses occlusally from the apical foramina or from a lateral canal, whereas an infrabony pocket originates in the gingival crevice and progresses apically. Specifically, a sinus tract closes when routine endodontic procedures have been performed. Attacking the focus of infection within the root canal by instrumentation, by intracanal disinfection, or even by establishing drainage through an occlusal access opening usually results in tract closure in several days. An infrabony pocket requires periodontal therapy, with or without endodontic treatment, to facilitate healing. Fortunately, the clinical differentiation is simple because a sinus tract is narrow and can be traversed only with a gutta-percha cone, whereas an infrabony pocket, the result of extensive tissue destruction, can be probed with wider and larger instruments.

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21 Nonsurgical Endodontic Retreatment

The greatest glory in living lies not in never falling ... but in rising every time we fall.
—Nelson Mandela

Endodontic treatment is a highly predictable therapy with excellent prognosis. More than 90% of cases would heal if the therapy were done meticulously following proper protocols. Symptoms of postendodontic discomfort are usually attributed to occlusal disturbances and transient apical periodontal inflammation. Discomfort following endodontic treatment is usually present for a very short duration (few days to a week) and should resolve without the need for any clinical intervention.

Patients in whom endodontic therapy was previously done and are showing signs and symptoms of postendodontic disease would warrant retreatment procedures. The common causes for endodontic failures are given in **Box 21.1**.

The clinician when encountering a failing root canal–treated tooth has the following options of clinical management:

i. *Keeping the patient under observation*
   - Usually preferred when the patient is not convinced about the need to treat the tooth
   - Usually chosen when the tooth is clinically asymptomatic

ii. *Nonsurgical endodontic retreatment*
   - It is the ideal treatment plan for an endodontically treated tooth that is clinically symptomatic.
   - It is preferred over surgical endodontic retreatment if the clinician is able to shape and clean the root canal system predictably. A clinical case with a 14-year follow-up exemplifies the predictability of nonsurgical endodontic retreatment (**Fig. 21.1**).

iii. *Surgical endodontic retreatment*
   - Usually recommended in retreatment cases with complex anatomy that makes it difficult to reach the apical third of the root canal
   - Also recommended in cases with errors done by a previous operator that make nonsurgical endodontic retreatment technically difficult
   - Use of surgical dental operating microscope highly recommended in such cases

iv. *Extraction of the tooth*
   - It is usually recommended when both nonsurgical and surgical endodontic treatment are not possible or when the tooth is not restorable prosthodontically. It is also recommended when the patient is no longer interested in wanting to save the tooth.
   - Although prosthodontic rehabilitation with implants or fixed partial dentures is a predictable alternative after tooth extraction, every clinician should always first attempt to preserve the natural dentition and use extraction as the last treatment plan option.

Definition: According to the American Association of Endodontists (AAE), *endodontic retreatment* is a procedure to remove root canal filling materials from the tooth, revise the shape, and obturate the canals; it is usually accomplished because the original treatment appears inadequate or has failed or because the root canal has been contaminated by prolonged exposure to the oral environment.

Box 21.1

Common Causes of Failure of Root Canal Treatment

- Operator-related causes of failure
  - Improper isolation (not employing rubber dam isolation)
  - Missed root canal causing pulpal inflammation or reinfection
  - Inadequate cleaning of the root canal causing persistence of infection ***(most common cause of failure)***
  - Improper shaping causing canal blockade/ledge formation
  - Instrument separation that would prevent complete disinfection of the canal
  - Improper management of perforations (pulp chamber perforation/root canal perforation)
  - Inadequate sterilization protocols of instruments
  - Lack of proper postendodontic coronal seal causing coronal leakage and reinfection
- Non-operator-related causes of failure
  - Persistent periradicular infection
  - Extraradicular cysts
  - Vertical root fractures

OBJECTIVES

- Achieve adequate access opening of the pulp chamber in order to access the obturated root canals as well as trace any missed canals.
- Ensure complete removal of all restorative and obturating materials used by the previous operator.
- Disinfect the root canal system thoroughly to eliminate microorganisms that have either survived the previous treatment or have re entered the root canal system.
- Shape, clean, obturate and create optimal coronal seal of the retreated root canal system to achieve long- term clinical success.

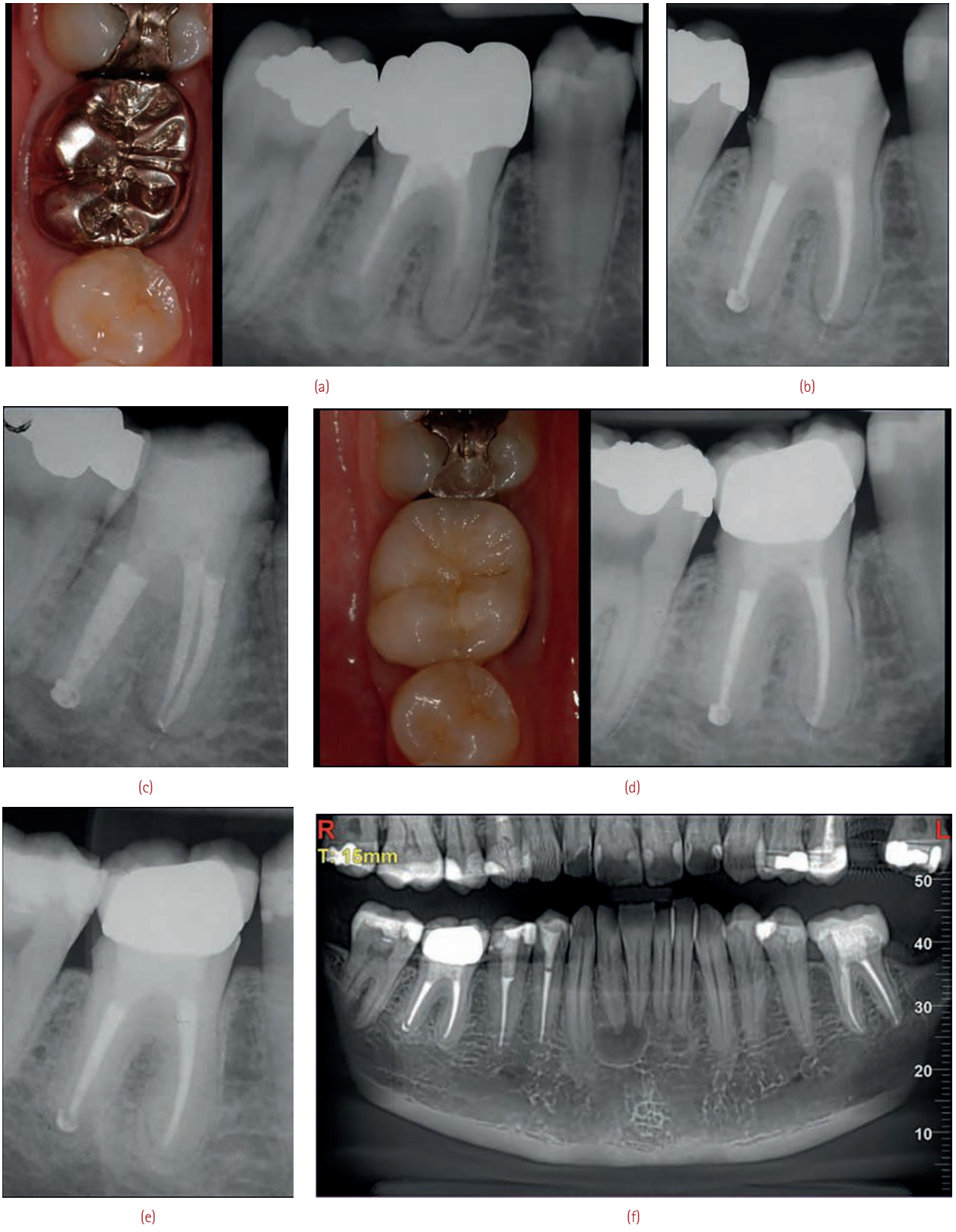


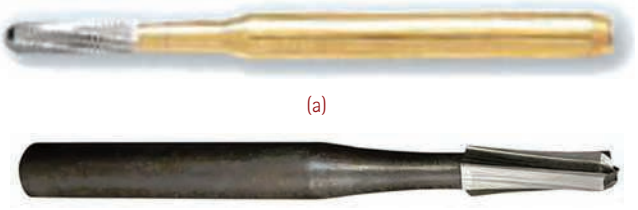
Figure 21.1 (a) Root canal–treated lower mandibular molar with periapical lesions on mesial and distal roots. The root canal filling is poor and the apex of the distal root looks slightly resorbed (year 2006). (b) Shaping completed and intracanal calcium hydroxide closed dressing given for 4 weeks. (c) Postoperative radiograph after obturation of the root canal system (warm vertical compaction—gutta-percha and ZOE sealer) and build-up with composite. (d) One-year follow-up (year 2007). (e) Twelve-year follow-up (year 2018). (f) Fourteen-year follow-up (year 2020)—CBCT done for the presence of a big lesion at level of mandibular incisors *(Case Courtesy: Filippo Cardinali.)*

RE-ENTRY INTO THE PULP CHAMBER THROUGH FULL-COVERAGE RESTORATION

When a patient presents himself/herself with an existing crown in the tooth that is planned for endodontic retreatment, the best solution is to *remove the crown* and proceed with endodontic treatment. However, if the marginal integrity of the full-coverage restoration is satisfactory, it is advisable to retain the same, and create the access through the coronal restoration.

Hence, one of the challenges in retreating endodontically failed teeth is that most of these teeth would have a full-coverage restoration that would make access into the pulp chamber difficult. The major disadvantages of access through full-coverage crowns/fixed prosthesis are the following:

- Restricted visibility
- Difficulty in maintaining orientation and parallelism of the bur according to the long axis of the tooth, especially in maxillary lateral incisors and mandibular first premolars
- Increased chances of iatrogenic mishaps
- Difficulty in removal of canal obstructions and posts
- Increased probability of missing untraced canals, recurrent caries, and crown fracture.



(a) (b)

Figure 21.2 (a) Transmetal bur. (*Courtesy: Dentsply Sirona.*) (b) Talon crown cutting bur. (*Courtesy: Tri Hawk.*)

Clinical Note

- To cut through metal crowns, carbide burs are recommended. Examples include Talon burs (Tri Hawk) or Transmetal bur (Dentsply Sirona) (**Figs 21.2** and **21.3**).
- To remove porcelain from porcelain-fused-to-metal (PFM) crowns, the use of round diamonds with copious coolant water spray is recommended.
- Special instruments that aid in the lifting of the crown without the fear of damaging the underlying tooth structures are also recommended. These include special chisels and forceps or instruments such as WAM Key (**Fig. 21.4**).



(a) (b) (c) (d)

Figure 21.3 (a–c) Transmetal bur being employed to create a buccal window to act as leverage to remove the crown. (d) Tooth after crown removal.



Figure 21.4 WAM Key. (*Courtesy: WAM.*)

OBSTRUCTION FROM PREVIOUS OBTURATING MATERIALS

When retreatment of a previously endodontically treated tooth becomes necessary, the filling material must be removed or bypassed; otherwise, salvaging the tooth from extraction may require an endodontic surgical procedure. Because most teeth to be retreated are sealed with gutta-percha, and in some cases silver points, the following sections discuss the removal of these materials from root canals.

REMOVAL OF GUTTA-PERCHA

Gutta-percha and sealer can be removed by the application of the following:

i. Rotary instrumentation
ii. Solvents
iii. Heat carrier instruments
iv. Ultrasonics
v. Combination of the above

- One of the most common methods for removing gutta-percha obturation is by using rotary instrumentation. This can be achieved with normal nickel titanium shaping instruments; however, there are specific rotary retreatment files that are also available, for example, HyFlex Remover (Coltene) and ProTaper Universal retreatment files (Dentsply Sirona) (**Fig. 21.5**).
- One of the other methods for removing gutta-percha from the orifice and middle root canal is to use a solvent, which softens the gutta-percha and permits its removal through sequential instrumentation.
- Chloroform was the most popular solvent because of its efficiency. However, the use of chloroform is no longer recommended because of its reported toxicity and potential carcinogenicity.
- Some of the popular commercially available solvents used are Endosolv E and Endosolv R (Septodont) (**Fig. 21.6**). The Endosolv E is used for dissolving obturation materials based on zinc oxide and eugenol while Endosolv R is recommended for resin-based pastes and sealers.
- Other gutta-percha solvents that are also available include xylene, eucalyptol, and halothane.



(a)

(b)

Figure 21.5 (a) HyFlex Remover. (*Courtesy: Coltene.*) (b) ProTaper Universal Retreatment files. (*Courtesy: Dentsply Sirona.*)



Figure 21.6 Endosolv E and Endosolv R solvents. (*Courtesy: Septodont.*)

- Solvents should be employed cautiously and should be administered a few drops at a time. The operator must use caution because these solutions frequently escape from the syringe needle without any apparent pressure on the plunger and there is no control over the depth of action of these solvents; hence, they are not recommended for apical third gutta-percha removal (**Fig. 21.7**).
- Gutta-percha can also be removed from the pulp chamber by using a heat carrier and searing the exposed gutta-percha. However, this technique is slower and would not allow complete removal of the obturating material from

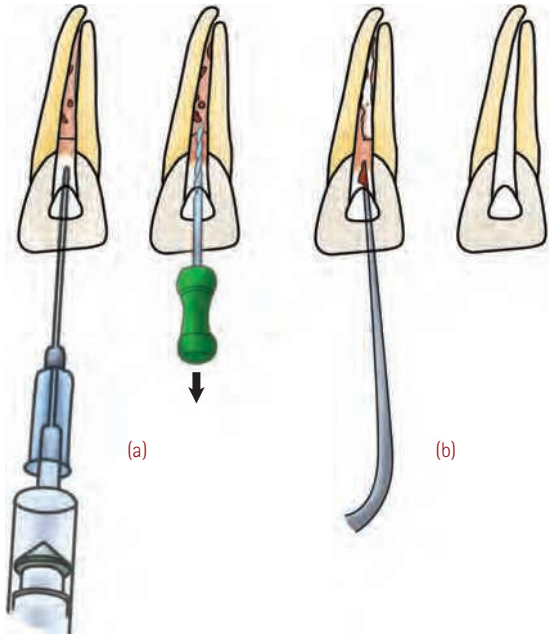


Figure 21.7 Gutta-percha can be removed (a) by the solvent action with the aid of files or (b) by means of a heated instrument or ultrasonic tips with the aid of files.

the root canals. It is recommended when plastic core Thermafil obturators are to be removed.

- Ultrasonically activated files are recommended for use in penetrating hard-set pastes. This is technique sensitive as excessive force might cause breakage of the ultrasonic files and hence should be used cautiously.

REMOVAL OF SILVER POINTS

A silver point is not removed as easily as a gutta-percha cone unless the butt end of the silver cone extends into the pulp chamber. In such cases, the butt end of the silver point is vibrated with an ultrasonic scaler to break the cementing media. The cone is then grasped with a pair of narrow-beaked (Stieglitz) pliers and is removed (**Figs 21.8** and **21.9**). If the silver cone extends only slightly into the pulp chamber, it can often be removed by vibration with an ultrasonic scaler until it becomes loose.

RECOMMENDED CLINICAL PROTOCOL FOR RETREATMENT CASES

- Most clinicians use a combination of the above-mentioned available retreatment techniques according to the complexity of each retreatment case.
- A solvent (few drops only) is initially used to soften the coronal third of the obturating material. Care should be taken to avoid the use of solvents in the middle and apical thirds of a root canal.
- After initial softening of the coronal third gutta-percha, a stiffer smaller sized hand instrument is used to negotiate and create a glide path inside the obturated canal.

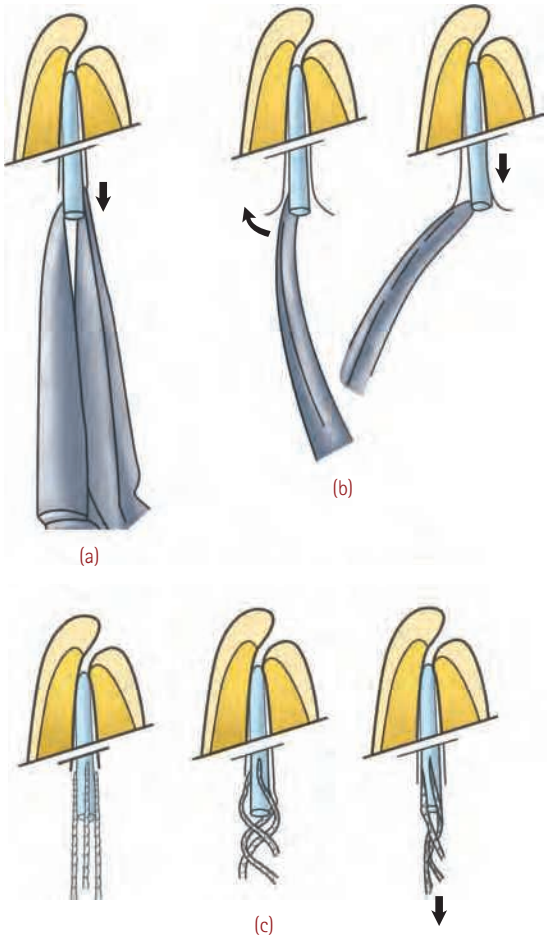
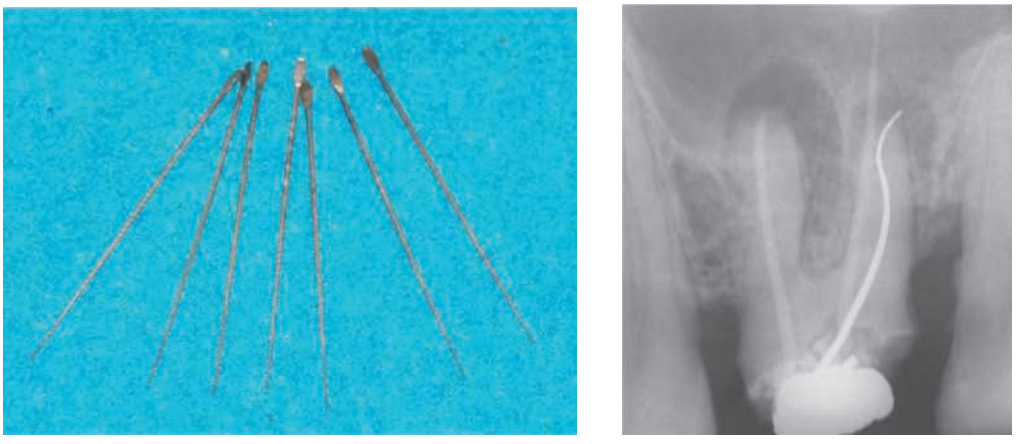


Figure 21.8 Removal of silver points: (a) Silver points can be loosened by vibrating the butt end of the silver cone with an ultrasonic scaler. The cone may then be removed with Stieglitz pliers or (b) endodontic spoon excavators. (c) If the silver point butt is below the root canal orifice, twisting three Hedstrom files around the silver cone may produce enough grip to remove the silver cone.

- Rotary or retreatment files are then used to remove the remaining gutta-percha and negotiate the canal till the established working length.
- Residual sealer and obturating material need to be removed from the canal using a combination of hand files along with copious irrigation. Stiffer hand instruments such as the Micro-Debriders (Dentsply Sirona) are also useful (**Fig. 21.10**).
- Frequent irrigant activation is recommended to ensure that the remnants of obturation do not block the canal inadvertently.
- Sequential radiographs would also help a clinician in negotiating the canal as they proceed apically till the working length.
- Secondary endodontic infections are more resistant to therapy; hence, it is recommended to perform multiple sitting endodontic therapy for infected retreatment cases. The role of intracanal medicament is crucial in such cases



(a) (b)



(c)



(d) (e)

Figure 21.9 (a) Silver points. (b) Endodontic failure in a maxillary molar treated with a silver point in the distal canal and gutta-percha in the mesial and palatal canals. (c) Stieglitz forceps. (d) Silver point retrieved with the Stieglitz forceps. (e) Retreatment completed and postobturation view.



Figure 21.10 Micro-Debriders have offset handles to enhance vision with 16 mm of efficient Hedstrom-type cutting blades. (*Courtesy: Dentsply Sirona.*)

and calcium hydroxide is the most popular medicament employed. (Refer Chapter 15.)

REMOVAL OF SEPARATED INSTRUMENTS

Instruments separate or break only when they are used incorrectly or overused. Most common causes of instrument separation are the following:

- Inadequate access opening
- Absence of glide path
- Overuse of the instrument
- Excessive apical pressure during shaping
- Larger sized/larger taper instrument in extremely thin and curved canals

- Operator inexperience
- Poor quality manufacturing process
- Using the instrument with improper torque/speed

The best method to overcome this problem is to avoid instrument separation. **Box 21.2** provides guidelines for the same. If the instrument fractures in narrow canals or in the critical apical third of the canal, it becomes very difficult to either remove or bypass the instrument.

Separated instruments in the coronal third of the canal (**Fig. 21.11b**) can be removed and the canal can be negotiated till the apex. However, if the separation occurs beyond the curvature, in the middle and apical third of the canal (**Fig. 21.11a**), or in narrow canals, then attempts to bypass the instrument should be undertaken carefully with smaller sized instruments before attempting to retrieve the instrument.

Box 21.2

Parashos and Messer's Recommendations to Minimize the Incidence of Instrument Separation

- Create a glide path and patency with small hand files.
- Ensure straight-line access and good finger rests.
- Use a crown-down shaping technique depending on the instrument system.
- Use stiffer, larger, and stronger files (such as orifice shapers) to create a coronal shape before using the narrower, more fragile instruments in the apical regions.
- Use a light touch on the instrument; never push hard.
- Use a touch-retract action with large increments allowed by the particular canal anatomy and instrument design characteristics.
- Avoid jerking or hurrying of instrumentation.
- The files used in narrow and curved canals have to be replaced immediately.
- Examine the used files regularly, preferably under magnification.
- The canal should be flooded with sodium hypochlorite as the instrument is passed through the canal.
- Avoid keeping the file in one spot, particularly in curved canals.

Clinical Note

- *Cyclic fatigue* or multiple use of the same instrument is the primary cause of instrument separation.
- Other causes include those related to *torsional fatigue* and carelessness in the instrumentation technique.
- Hedstrom files are no longer indicated for shaping the root canal system due to increased incidence of shaping errors.

The prognosis and management of a separated instrument inside a canal are dependent on the following:

- Level of instrument separation in the canal (coronal, middle, or apical third)
- Size of the instrument
- Degree of infection beyond the level of the separation
- Operator skill and necessary armamentarium including dental operating microscope
- Patient motivation and decision of the future course of treatment

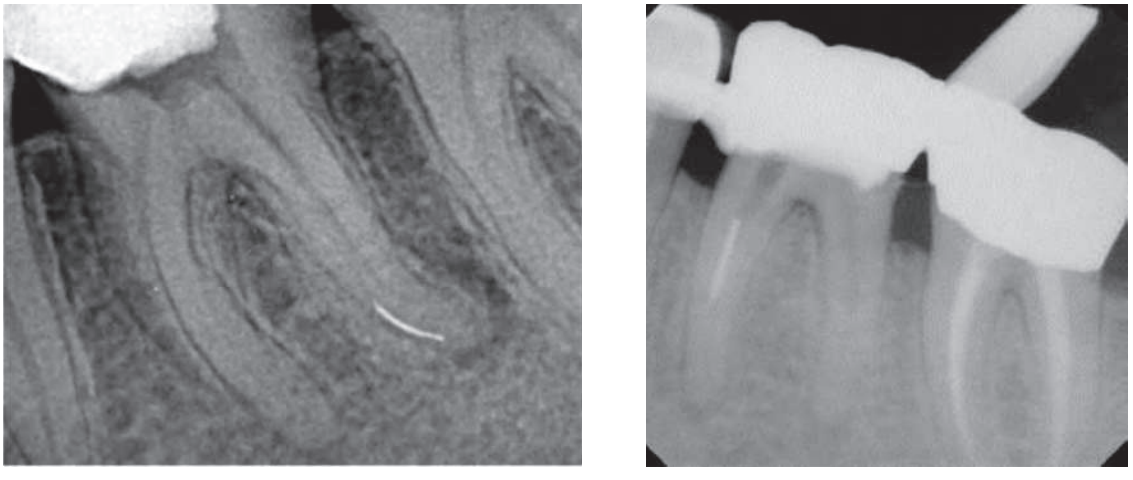
These and other factors which should influence the clinician's decision on the management of this error are summarized in **Figure 21.12**.

INSTRUMENT REMOVAL TREATMENT PLAN

Based on these factors, one of the following three treatment plans can be attempted:

1. Instrument retrieval using ultrasonics or wire loop and tube technique
2. Bypassing the instrument and making it part of the obturation (**Figs 21.13** and **21.14**)
3. Surgical intervention in the form of hemisection of the root or root resection in roots with apical third instrument separation

Most endodontists prefer ultrasonic instrumentation for the retrieval of separated instruments, as it is the most



(a) (b)

Figure 21.11 (a) Apical third fracture of an instrument. (b) Coronal third fracture of an instrument.

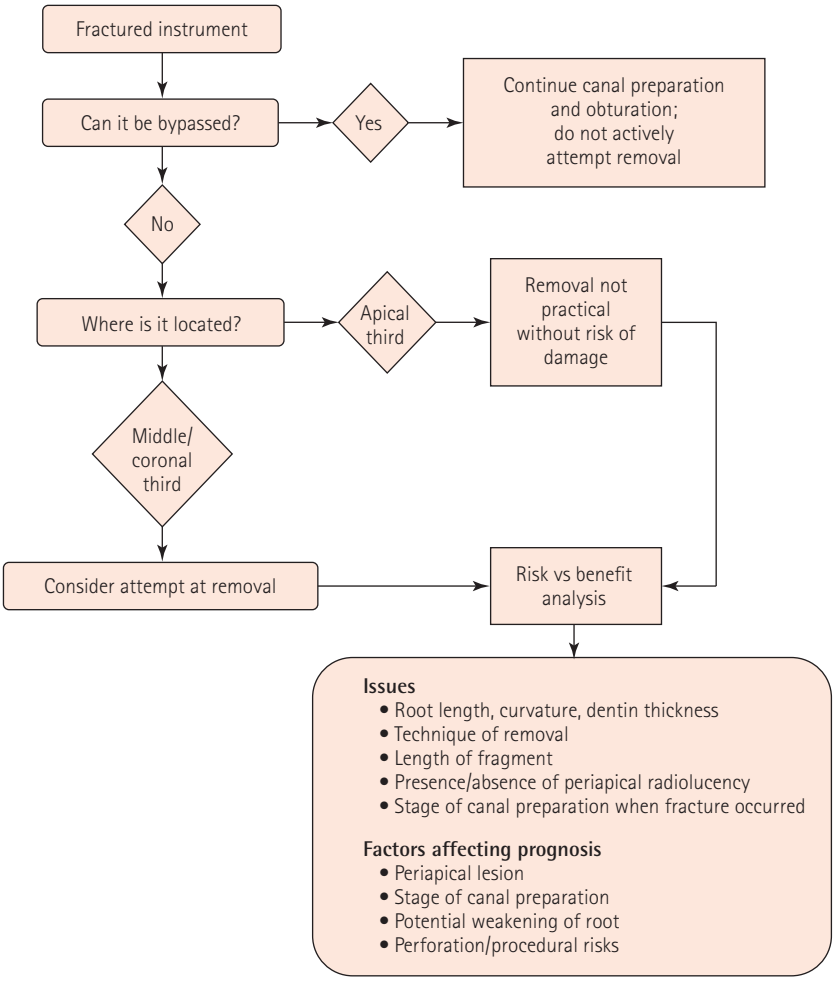


Figure 21.12 Decision-making flowchart for management of fractured endodontic instruments. (Adapted from Parashos, P., and Messer, H.: *J. Endod.*, **32**:1031–43, 2006.)

conservative of all the available methods. Ultrasonics for instrument retrieval can be employed in two ways:

1. *Ultrasonic tips:* These are specialized tips made of different alloys and come in varying tapers and lengths for removing instruments at different levels of the root canal (**Fig. 21.15**). These tips are clinically used with ultrasonic scalers at low-energy intensities to cut dentin around the broken instrument and vibrate the instrument out. Some common examples include the following:
   a. Stainless steel tips, for example, ET20 tip (Acteon)
   b. Stainless steel coated with diamond tips, for example, ET20D tip (Acteon)
   c. Titanium or titanium coated with zirconium nitride tips, for example, ProUltra Endo Tips (Dentsply Sirona)
   d. Titanium niobium tips, for example, ET25 tip (Acteon)

   The ultrasonic vibrations tend to loosen the instrument and removal is made possible (**Fig. 21.16**).
2. *Ultrasonic files:* These are traditional stainless steel files that are used with special adapters connected to ultrasonic scalers that enable the files to be vibrated using the ultrasonic energy. U files (MANI) are commonly employed using this method (**Fig. 21.17**).

Other commercially available kits for retreatment include the following:

- Endo Extractor (Brasseler)
- Masserann Kit (Medidenta International)
- Extractor system (Roydent)
- Instrument Removal System (Dentsply Sirona)
- Separated Instrument Retrieval (S.I.R.) System (Vista Dental Products)
- Mounce extractor (SybronEndo)

The wire loop and tube technique is another efficient method to remove separated instruments that are either long or present deep inside the canal, sometimes even beyond the level of curvature. Either wire loops can be custom prepared as depicted in **Figure 21.18** or commercially available kits such as the BTR Pen (*Cerkamed*) can also be used (**Figs 21.19** and **21.20**).

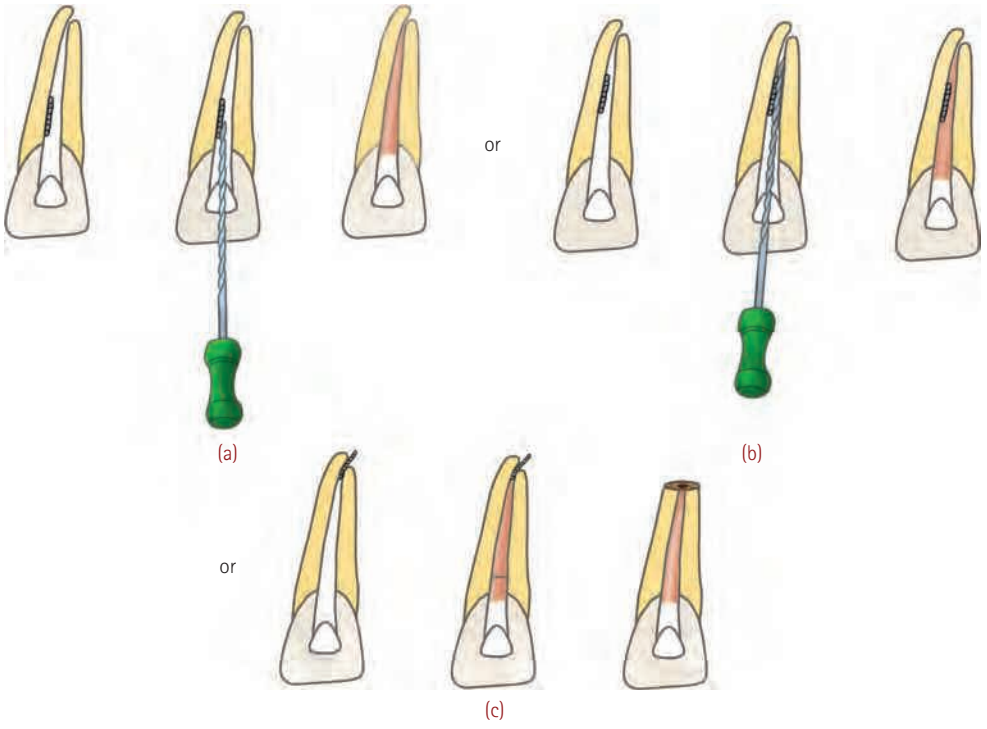


Figure 21.13 (a) Fractured segment of an instrument can sometimes be removed by bypassing the segment with a file, engaging the segment, and pulling it out. (b) If the segment cannot be removed, one should attempt to bypass it, clean and shape the root canal, and incorporate the segment into the obturation. (c) If the instrument segment is extruding beyond the apical third of the canal, the root canal should be cleaned and shaped to the instrument segment, it should be obturated, and a surgical approach of a root end resection should be considered.

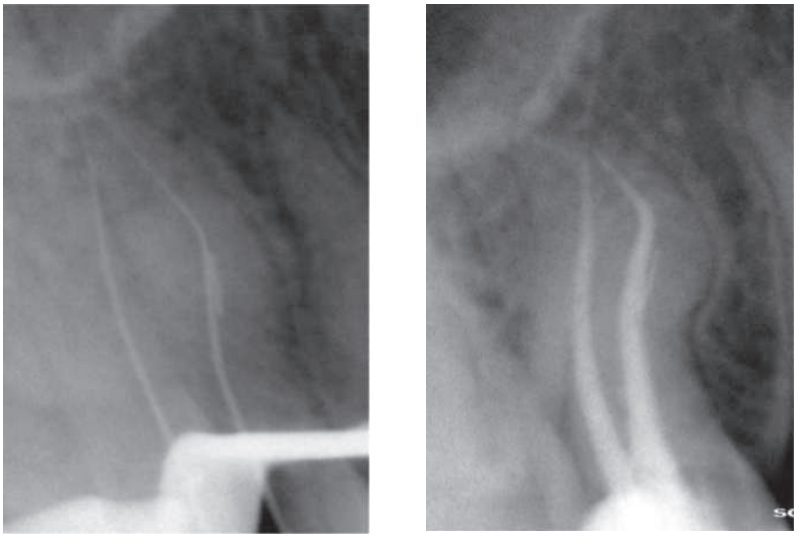
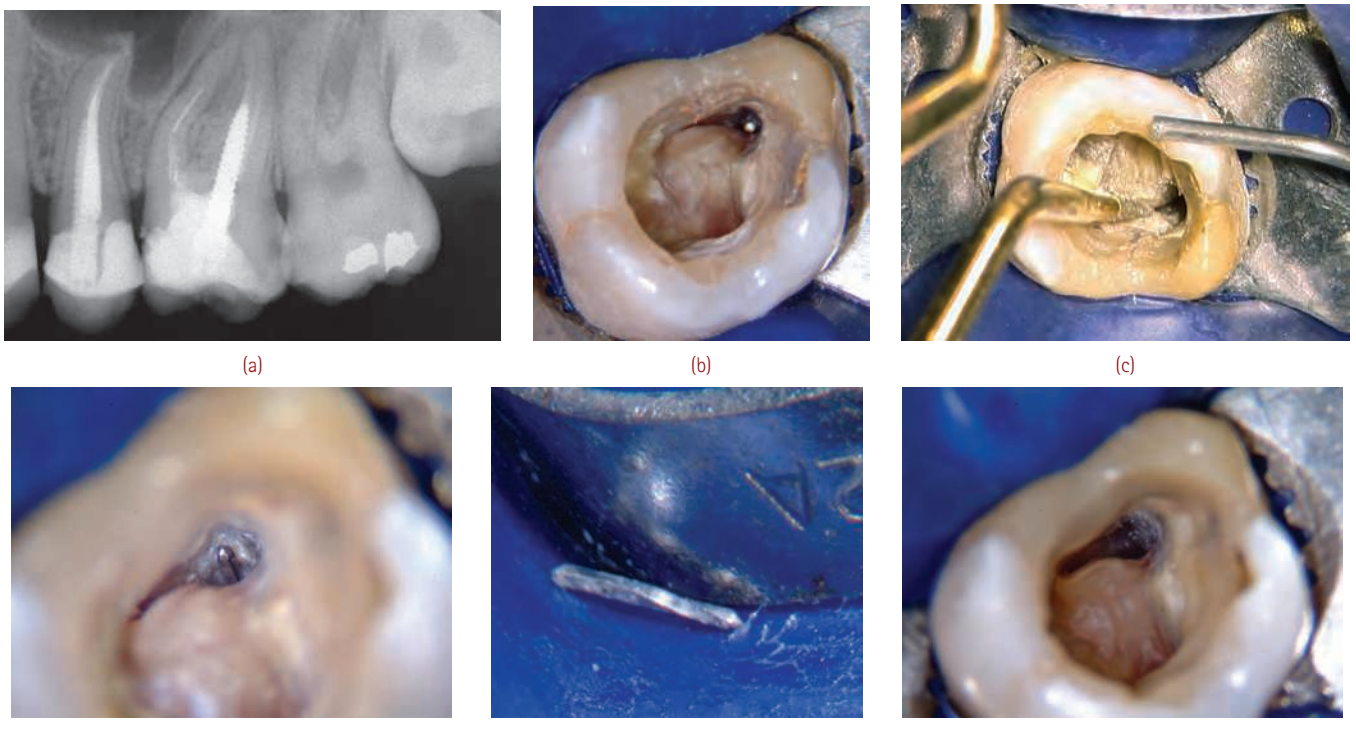


Figure 21.14 (a) Fractured instrument in the middle third of the buccal canal bypassed with the help of smaller sized instruments in a maxillary premolar. (b) Cleaning and shaping completed up to the apex and obturation completed with the separated instrument being part of the final filling.



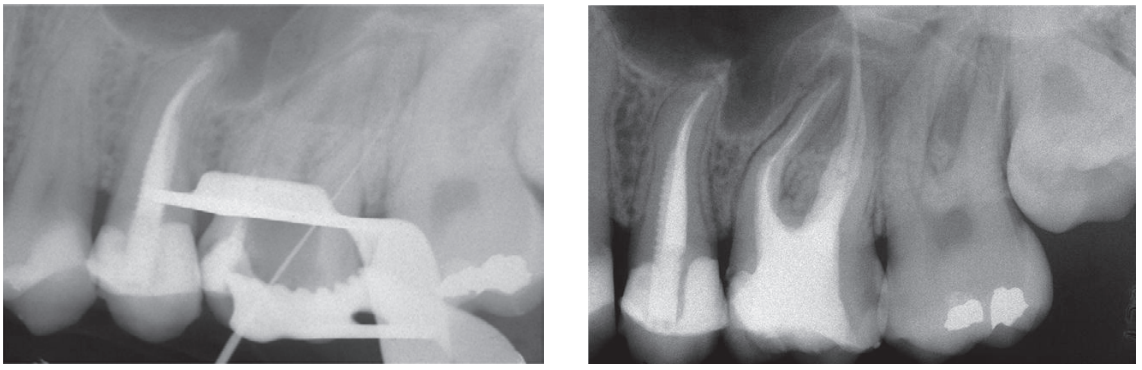
(a) (b) (c) (d)

Figure 21.15 (a) ProUltra zirconium nitride. (b) ProUltra titanium tips. (*Courtesy: Dentsply Sirona.*) (c) ET 20 tip. (d) ET 25 tip. (*Courtesy: Acteon.*)



(a) (b) (c) (d) (e) (f)

Figure 21.16 (a) A preoperative radiograph of an endodontically failing left first molar. The tooth has a screw post in the palatal canal and a broken instrument in the mesiobuccal canal. (b) After removing the screw post and cleaning the pulp chamber, now the most coronal portion of the fragment is evident under the operating microscope. (c) The ProUltra #4 ultrasonic tip is isolating the fragment and transmitting vibrations, while the dental assistant is blowing air using the Stropko irrigator. (d) Now the fragment is more evident. (e) The fragment has been removed with ultrasonics and is now on the rubber dam, near the rubber dam clamp. (f) The clinical image confirms the removal of the fragment. *(continued)*



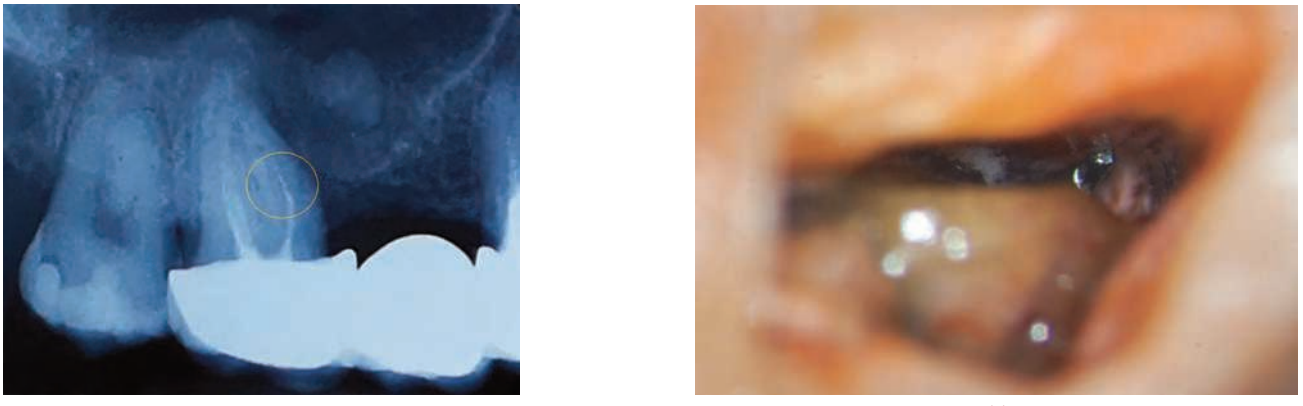
(g) (h)

Figure 21.16 *(continued)* (g) The radiographic image confirms the removal of the fragment. (h) Postoperative radiograph. (*Courtesy: Arnaldo Castellucci, Italy.*)



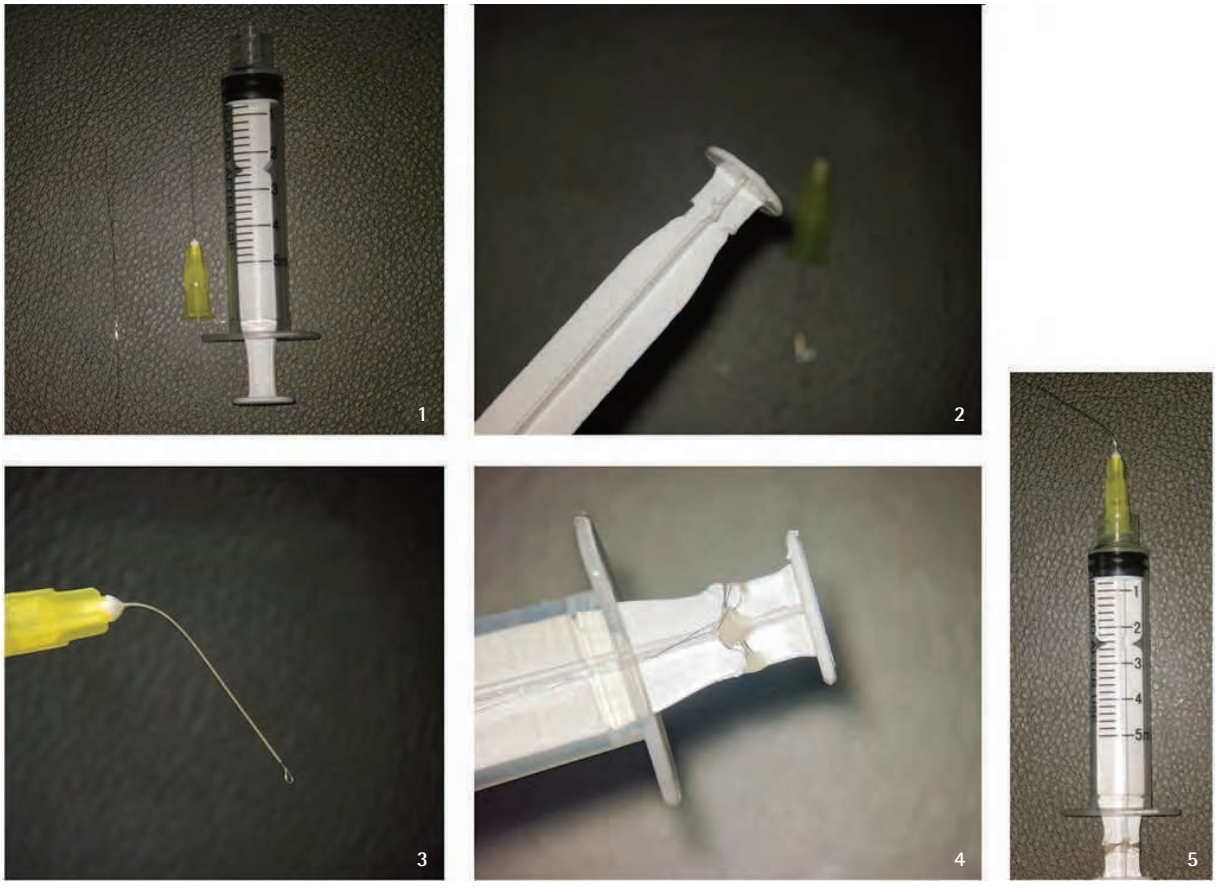
(a) (b)

Figure 21.17 (a) Endo Chuck for ultrasonic files. (*Courtesy: EMS.*) (b) U files. (*Courtesy: MANI.*)

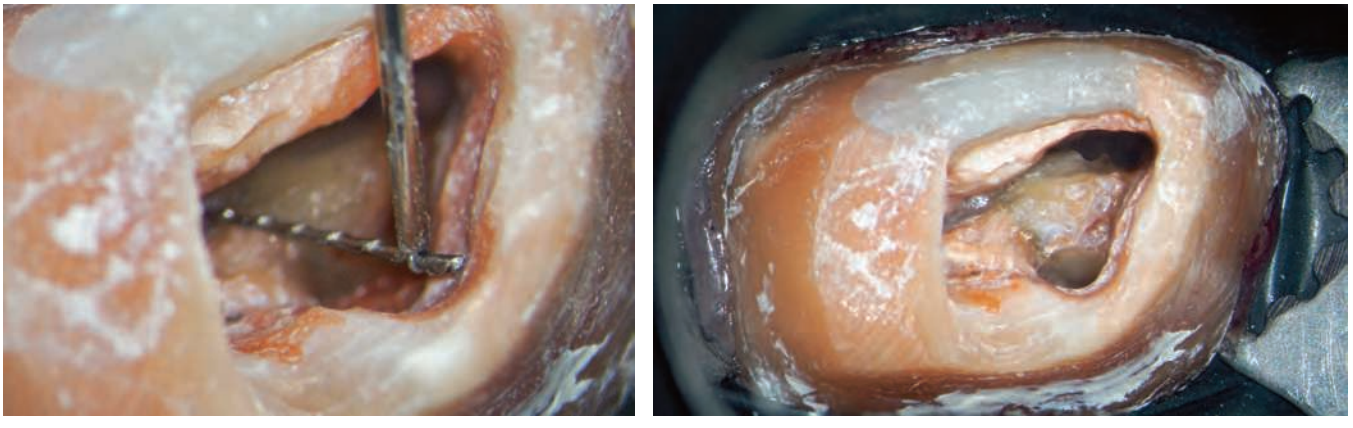


(a) (b)

Figure 21.18 (a) Chronic alveolar abscess in a root canal–treated maxillary molar with radiographic evidence of a separated instrument in the mesial canal. (b) Separated instrument visualized under the microscope. *(continued)*



(c)



(d) (e)

Figure 21.18 *(continued)* (c) Custom-made loop device assembled. Self made loop device for separated instrument retrieval (c1) Armamentarium - 0.075 mm stainless steel wire available online (30 cm long), a plain 2.5 mL syringe and a 27 g open vent irrigating needle - remove the vent with scissors. (c2) Remove the plunger, make some notches at the end of the plunger. (c3) Bend the wire in half, put the ends through the irrigating needle, and bend the needle. (c4) Pass the wire through the syringe body, put the plunger back in, and loop the wire ends through the notches at the end of the plunger, then fixate the wire with fluid composite. (c5) Self made loop device assambled, it can be maneuvered with one hand. (d) Separated instrument retrieved. (e) Canals shaped and cleaned. *(continued)*

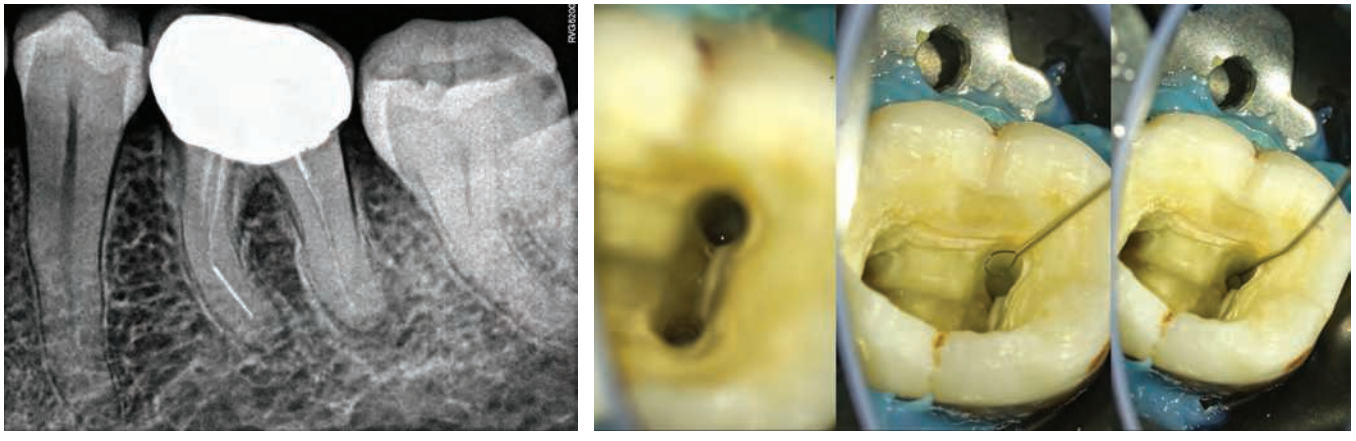


(f) (g)

Figure 21.18 *(continued)* (f) Postobturation view. (g) Follow-up X-ray revealing resolution of disease. (*Case Courtesy: Sergiu Nicola, Romania.*)

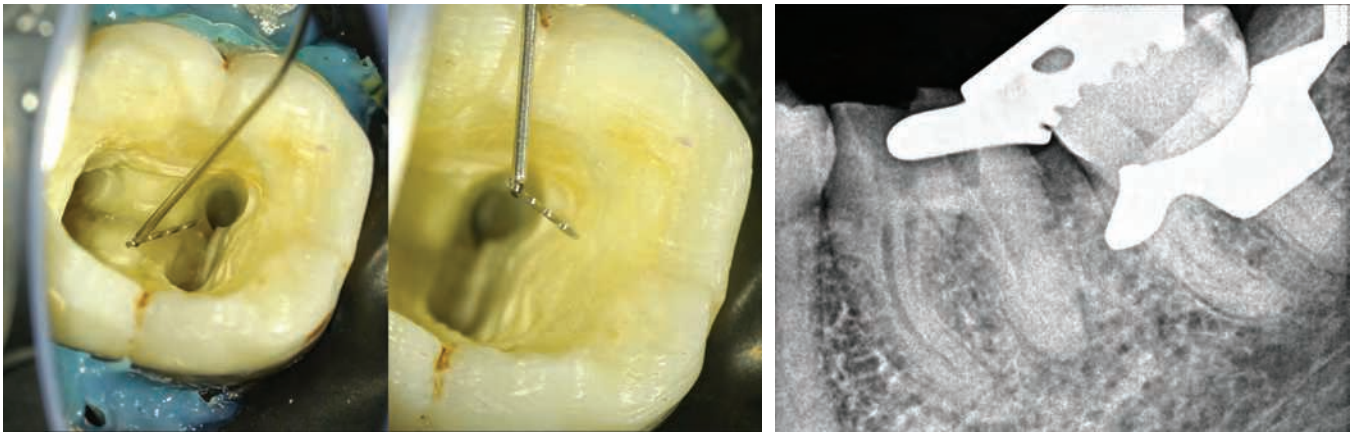


Figure 21.19 BTR pen. (*Courtesy : Cerkamed.*)

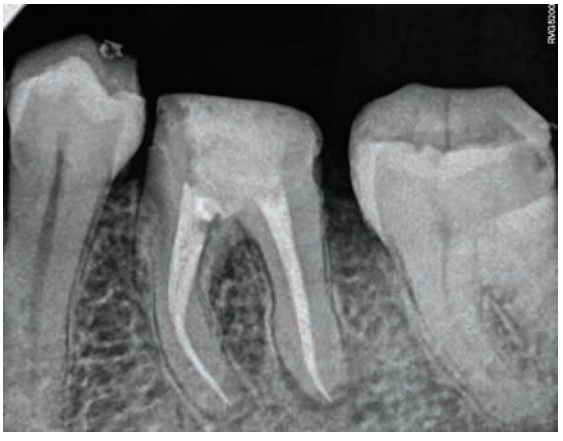


(a) (b)

Figure 21.20 (a) Preoperative x-ray showing separated instrument beyond the level of curvature in the apical third of the mesiobuccal canal of a lower first molar (b) Use of a BTR pen loop to engage the coronal third of the fragment after creating a channel path. *(continued)*



(c) (d)



(d)

Figure 21.20 *(continued)* (c) Instrument retrieved using the wire and loop technique (d) IOPA view of the canal after removal of the instrument fragment (e) Post obturation view of the root canals.

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22 Endodontic Surgery

We are what we repeatedly do. Excellence, then, is not an act, but a habit.
—Aristotle

The scope of endodontic surgery has extended beyond root-end resection to include other forms of periradicular surgery, fistulative surgery, corrective surgery, and intentional replantation. Root-end resection is still the most common form of periradicular surgery.

In general practice, the number of cases being indicated for root-end surgery has drastically reduced over a period of time. This may be due to the fact that today the science of endodontics has a better understanding of the biological principles of shaping and cleaning. In the past few decades, endodontics was more of a biological science than mere chemomechanical debridement. There has been a tremendous improvement in the available materials and instruments for shaping and cleaning. With the present knowledge of internal anatomy of pulp space, microbiology, and disinfection of the pulp space, and also with the introduction of rotary and microendodontic instrumentation, clinicians are now better equipped to produce a more predictable disinfection of the pulp space.

There has been a gradual paradigm shift from surgical to nonsurgical treatment over the past few decades. However, nonsurgical management may not be always successful. Even if nonsurgical treatment is unsuccessful, the current concept is to do an introspection of the quality of nonsurgical treatment before selecting surgical intervention. If the initial endodontic treatment of a tooth is not satisfactory, then one should attempt nonsurgical retreatment of that tooth first.

The view that endodontic surgery is the last resort is based on past experience with instruments that were unsuitable. Also, the vision available at the surgical site was inadequate and the incidence of postoperative complications was high. Fortunately, today the endodontist is equipped with better magnification, illumination, and instruments. The present era of microsurgery is with surgical operating microscopes, ultrasonic tips for retropreparation, low-speed high-torque motors, and miniaturized surgical instruments for root-end surgery, and all these have resulted in better success rates.

Clinical Note

The success rate of surgical endodontics is high, about 73–99%, depending on the criteria used for evaluating success.

OBJECTIVES AND RATIONALE FOR SURGERY

- *Curettage:* Effective curettage of the pathologically affected periradicular tissue which cannot be accessed in an orthograde approach. This includes therapy-resistant granuloma, true cysts, and foreign body reactions
- *Resection:* Surgical resection of root apex in cases where the apical ramifications cannot be eliminated in a nonsurgical endodontic treatment or surgical resection of a root in cases of poor periodontal support
- *Inspection:* Inspection of the periradicular area to ascertain causes of failure, inspection of isthmus, and trace accessory canals in nonsurgical endodontic cases that are clinically failing

INDICATIONS

Evidence-based endodontic literature has led to substantial reduction in the indications for root-end surgery. *It is recognized that nonsurgical treatment is the choice in most cases.* However, the following indications may have to be considered (**Fig. 22.1**):

- *Failure of nonsurgical endodontic treatment:* Persistence of symptoms in teeth in which radiographically adequate nonsurgical endodontic therapy has been completed and nonsurgical retreatment is not possible or practical is an indication, for example, an endodontically treated tooth which develops a periradicular pathosis and where a patient has a well-constructed superstructure of an esthetically pleasing and functionally efficient fixed prosthodontic appliance.
- *Failure of nonsurgical endodontic retreatment:* Periradicular surgery should be considered to identify and rectify the cause for the persistence of symptoms in patients even after nonsurgical retreatment. Nonsurgical treatment should have been rendered at least twice in such cases before opting for surgery.
- *Failure of previous surgery:* Endodontic surgery might fail due to a variety of reasons including lack of employing microsurgical instruments and magnification aids such as a dental operating microscope (DOM). Resurgery is indicated in such cases.

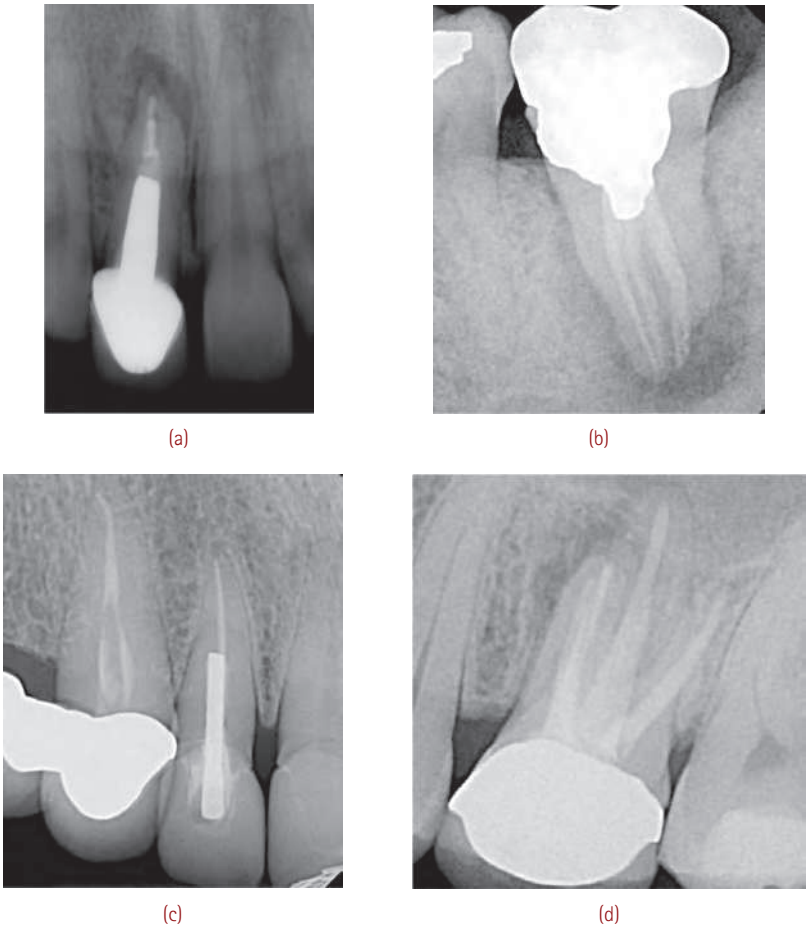


Figure 22.1 Cases illustrating indications for endodontic surgery: (a and b) Persistent periradicular pathology in root canal–treated teeth. (c) Perforation of the root due to improper post placement. (d) Persistent pain due to overfilling of the canals.

- *Anatomical problems:* When the endodontist is unable to reach the apical constriction due to non-negotiable or blocked canal, or severe root curvature, it prevents adequate cleaning and shaping of the apical third of the root canal.
- *Iatrogenic errors:* Errors caused during root canal therapy may include ledging of canals, blockage from debris, separated instruments, overfilling of canals leading to foreign body reaction, and apical canal transportation. This reduces the prognosis of nonsurgical retreatment. In such cases, a surgical approach is advisable.
- *Horizontal apical root fracture:* Traumatic injuries leading to horizontal apical root fracture might need surgical intervention if the apical segment becomes necrotic and if nonsurgical treatment is not possible.
- *Exploratory surgery and biopsy:* This is a rare indication in teeth where a fracture is suspected or in teeth with vital pulp with a radicular radiolucency as in patients with a previous history of malignancy.
- *Periodontal considerations:* Hemisection and radisection are planned in cases where the periodontal support of one of the roots goes beyond repair.

CONTRAINDICATIONS

There are few absolute contraindications for endodontic microsurgery. The following factors play a major role in the surgical endodontics:

- Inadequate periodontal support and active uncontrollable periodontal disease
- Poor restorability with a postendodontic restoration
- Lesions situated very close to important anatomical structures such as the inferior alveolar nerve, lingual nerve, mental foramen, and maxillary sinus when there is a high risk of damage to these structures
- Systemic complications of patients such as bleeding disorders, severe heart disease such as a patient recuperating from a myocardial infarction, and immunocompromised patients
- Practitioner's skill and experience with microsurgical treatment plays an important role

TREATMENT PLANNING AND PRESURGICAL NOTES FOR PERIRADICULAR SURGERY

Meticulous planning is required presurgically before deciding to subject the patient to surgical endodontics (**Fig. 22.2**).

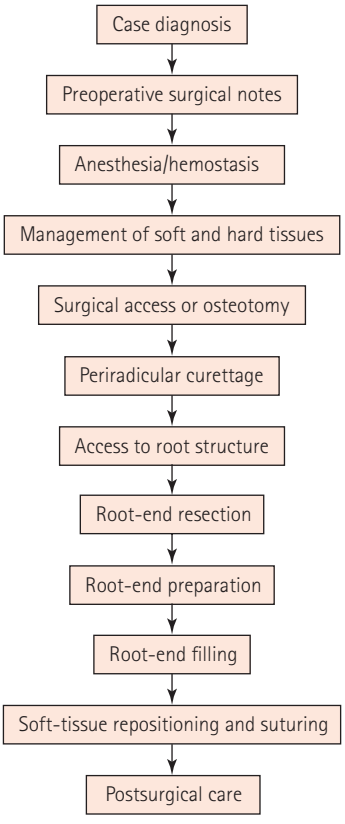


Figure 22.2 Steps in endosurgery.

Most surgical endodontic procedures must be carried out by qualified, well-trained, and experienced endodontists. Clinical surgical endodontic skills are different from those required for other oral surgical procedures in dentistry. One must know his/her limitations of clinical skills before performing surgical endodontics. Endodontists or general dentists should observe standard of care whenever they perform endodontic surgery. The surgical procedures have to be explained in detail to the patient which should include the presurgical, surgical, and postsurgical care. It is mandatory for every endodontist to obtain an *informed consent* from the patient or from the patient's close relatives prior to the surgery.

Most endodontists prefer to put their patients on chlorhexidine gluconate mouthwash 1 day prior and on the day of surgery and for 4–5 days after the surgery. This should reduce the number of colonies of microorganisms and markedly improve the environment for healing in the postsurgical phase.

The basic tenets include the following:

- Preoperative medical history and oral and radiographic examination should be completed in a written format as a routine protocol.
- An interaction with the patient
  - Establish lines of communication with the patient at this stage. Show concern before surgery.
  - Have a frank discussion about prognosis including guarded prognosis and postsurgical scenario.
  - Discuss anatomical structure that may be encountered.
  - Written pre- and postoperative instructions should follow after explanation (**Box 22.1**).
- Survey of major systems such as cardiovascular, respiratory, gastrointestinal, endocrine, and central nervous system.

Patients who are medically compromised should have a course of presurgical antibiotic therapy and physician's fitness for surgery should be obtained. If necessary, get information from the physician or patient about the intake of drug schedule so as to rule out any drug taken that interferes with clotting mechanism. The specific group of drugs may have to be withdrawn a couple of days before surgery.

Box 22.1

Information and Consultation Sheet for Patients Requiring Endodontic Surgery

Informed consent: Prior to any treatment, you must be informed and understand:

- What will be done?
- How will it be done?
- Why will it be done?
- What constitutes a successful result (healing)?
- How likely are your chances of attaining success (healing)?
- What alternative treatments are available to you?
- What are the risks that you may encounter?

You may also be asked to sign a form granting the doctor permission to treat you with your full knowledge and understanding of the above.

Generally:

- Surgical endodontics is a painless procedure.
- Treatment is usually accomplished in the dental chair, using the same kind of anesthesia as for fillings.
- Reactions can occur after treatment, such as:
  - Sore tooth and gum (pain)
  - Swelling, varying from slight to large
  - Black-and-blue marks
  - Paresthesia: A numbness or tingling sensation that persists in the treatment area, mainly the lower jaw, but usually disappears in time

Although these reactions do not occur routinely and are not usually dangerous, if any cause you concern, please call the office and notify the doctor so that he/she can continue to care for you properly.

- Routine instructions will be given to you immediately following surgical treatment, regarding home care, diet, and medication.
- No tooth will be treated unless there is a reasonable chance for success. If the chances for success are below average, you will be informed.
- On completion of surgical endodontics, you will have to restore the surgically treated tooth with a filling or crown.

PREMEDICATION

Premedication becomes necessary when a patient remains overly anxious by the preoperative consultation. Prior to endomicrosurgery, several medications have been suggested. The prescription of presurgical antibiotic therapy is debatable.

Clinical Note

- Most clinicians prescribe 400 or 800 mg ibuprofen per day immediately prior to surgery and mostly advise to continue for 48 hours postoperatively. This would take care of the anticipated swelling or pain.
- Administering 5 mg valium on the previous night of surgery and on the morning of surgery would take care of patients' anxiety.
- Antibiotic prophylaxis is mandatory in medically compromised patients. The American Heart Association's updated protocols may be observed when cardiovascular system is involved. (*Refer to Chapter 8.*)
- Generally antibiotic prescription should be avoided; however, when indicated in clinical situations after eliciting a full medical history of the patient, amoxicillin 500 mg t.i.d. for 7 days or clindamycin 300 mg q.i.d. for a week for patients who are allergic to penicillin is recommended.

STAGES IN SURGICAL ENDODONTICS

MANDATORY INVESTIGATIONS PRIOR TO SURGERY

A careful evaluation of the medical history of the person undergoing periradicular surgery is mandatory to rule out any systemic condition or bleeding diathesis.

Mandatory investigations before surgery are as follows:

- Bleeding time
- Clotting time
- Prothrombin time
- Thrombin time
- Partial thromboplastin time
- Activated partial thromboplastin time

Diseases which can be encountered are as follows:

- Diseases with defective coagulation
  - Hemophilia
  - Christmas disease
- Conditions in which there is hypoprothrombinemia
- Thrombocytopenia
- Abnormalities of capillaries
  - Purpura
  - Ehlers–Danlos syndrome
  - von Willebrand's disease
  - Acute leukemias
- Patients on antiplatelet and anticoagulant therapy

ENDODONTIC MICROSURGERY

Dr. Harvey Apothkar coined the term *microdentistry* in 1980. Microsurgery is applicable to endodontic surgeries today.

Definition: *Microsurgery is defined as a surgical procedure on exceptionally small and complex anatomical structures with a DOM.* The microscope enables the surgeon to assess pathologic causes more precisely and remove the pathologic lesion with far greater precision, thus minimizing tissue damage during surgery (**Fig. 22.3**). Refer Chapter 9 for more details on magnification in endodontics.

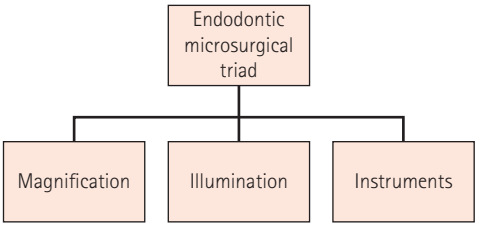


Figure 22.3 Endodontic microsurgical triad.

A. MAGNIFICATION

The present DOMs can be configurated to magnification levels up to ×40 and beyond.

- *Low-range magnification (×2.5 to ×8):* The lower range is for orientation of the surgical field and allows wide inspection of the field of view.
- *Midrange magnification (×8 to ×14):* Midrange is for the surgical procedures including curettage of the granulation tissue, resection of the root tip, root-end preparation, and root-end filling.
- *High-range magnification (×14 to ×30):* This is used for observing the finer details and documentation purposes.

With DOMs, one can visualize the surgical field and evaluate the surgical technique. The magnification of a microscope is determined by the following:

- Power of the eyepiece
- Focal length of the binoculars
- Magnification change factor
- Focal length of the objective lens

B. ILLUMINATION

Illumination with DOMs is coaxial with the line of sight. This means that the light is focused between the eyes in such a fashion that you can look into the surgical site without seeing any shadow. Elimination of the shadow is made possible by using Galilean optics, which focuses at infinity and sends parallel beams of light to each eye. With parallel light, the operator's eyes are at rest and therefore lengthy operations can be performed without eye fatigue.

Magnification and illumination with the DOMs has helped the endodontists to introduce microsurgery into surgical endodontics. This, in turn, has helped the endodontists to minimize trauma and enhance the surgical results. The DOMs have benefited treatment protocols in periradicular surgery.

A beam splitter can be inserted into the pathway of light as it returns to the operator's eyes. The function of a beam splitter is to supply light to an accessory such as a video camera or digital still camera. In addition, an assistant articulating binocular can be added to the microscope array (**Fig. 22.4**).



Figure 22.4 DOM with beam splitter for documentation. (*Courtesy: Global Microscopes.*)

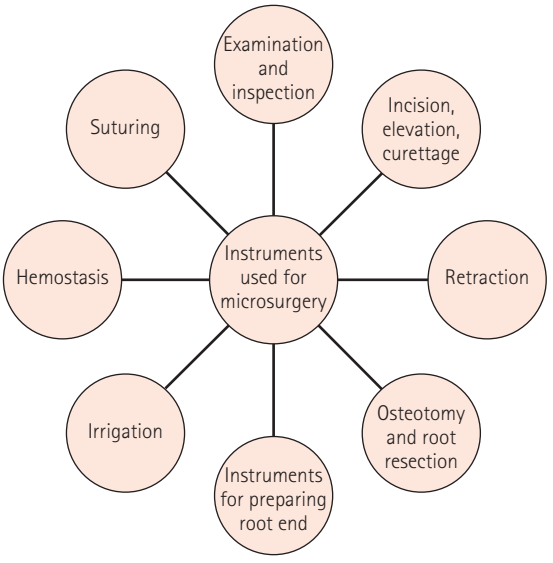


Figure 22.5 Categories of microsurgical endodontic instruments.

The DOM not only has become a vital armamentarium in microsurgical endodontics but also plays a key role in enhancing the quality and precision of routine nonsurgical endodontic therapy. The arrival of DOMs has also brought in revolutionary changes in instruments and instrumentation techniques. The introduction of ultrasonic instruments has made minimal and precise retropreparation feasible during root-end surgery. The introduction of mineral trioxide aggregate (MTA) as a new root-end filling material has also improved the clinical outcomes of periradicular surgeries.

C. INSTRUMENTS FOR ENDODONTIC MICROSURGERY

These instruments can be categorized accordingly (**Fig. 22.5**):

- *Examination and inspection instruments*
  - Micromirrors (**Fig. 22.6**)
  - Periodontal probe
  - Endodontic explorer (DG16)
- *Incision, elevation, and curettage instruments*
  - 15c blade and handle (for incision). There is a long handle and a mini-blade especially useful for molar surgery. The blade is small enough to manage the interproximal papilla and large enough to make a vertical releasing incision in one stroke (**Fig. 22.7a**)
  - Molt curette no. 2–4 is a very useful instrument for elevating and curettage. The design of the working end is such that the working tip is sharp, which facilitates easy elevation of a full-thickness flap along with the periosteum
  - Jacquette curettes and mini-Jacquette curettes—sharp curettes are used to spoon out the lesion (**Fig. 22.7b**)
  - Periosteal soft-tissue elevator or periosteal elevators

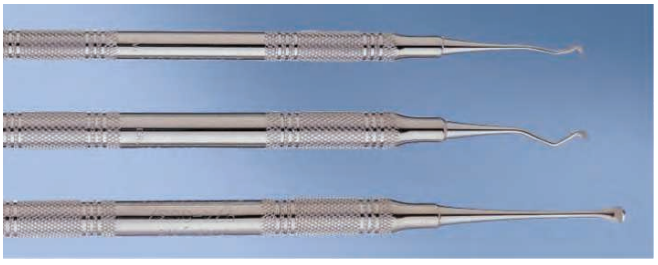


Figure 22.6 Micromirrors (*Courtesy: SybronEndo.*)

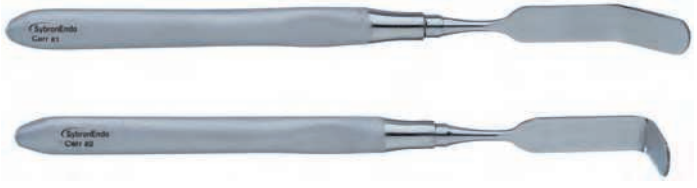
- *Retraction instruments* (**Fig. 22.7c**)
  - KP-1, -2, and -3 retractors
  - Carr #1, 45° retractor serrated edge for posterior applications
  - Carr #2, 90° retractor serrated edge for anterior applications
- *Osteotomy and apical root resection instruments*
  - Impact Air 45° handpiece (**Fig. 22.7d**)
  - Lindemann burs
  - Micromirrors and microexplorers
- *Instruments for preparing root end*
  - Microsurgical ultrasonic instruments
  - MTA root-end filling material
- *Irrigational instruments*
  - Stropko irrigator (**Fig. 22.7e**)
  - Microsuction (**Fig. 22.7f**)
- *Hemostasis instruments and materials*
- *Suturing materials*
  - Sutures
    - Silk sutures are nonabsorbable, multifilamentous, and braided.
    - Gut sutures are derived from sheep or bovine intestines and are absorbable in nature.



(a)



(b)



(c)



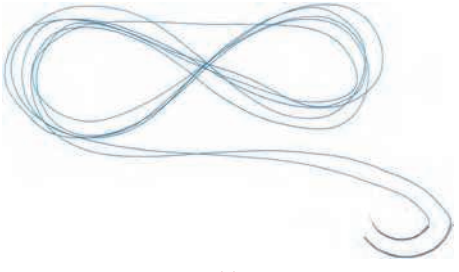
(d)



(e)



(f)



(g)

Figure 22.7 Micromirrors. (a) Blades and handle for endodontic microsurgery. (b) Minicurettes. (c) Retractors. (d) Impact Air 45° handpiece. (e) Stropko irrigator. (f) Microsuction. (g) Microsutures. (*Courtesy: SybronEndo.*)

- The Tevdek sutures are one-third stronger than silk and are coated with impregnated Teflon, originally designated for cardiac surgery due to their strength and low friction while moving through tissue and due to their nonstick surface that causes less bacterial adhesion (**Fig. 22.7g**).

– Tweezers, forceps, scissors, and needle holders
– Needles

CLASSIFICATION

I. Gutmann's classification of endodontic surgery (**Box 22.2**)
II. Kim's classification of microsurgical cases (**Box 22.3**)

Box 22.2

Gutmann's Classification of Endodontic Surgery

1. Fistulative surgery
   (a) Incision and drainage (I&D)
   (b) Cortical trephination
   (c) Decompression procedures
2. Periradicular surgery
   (a) Curettage
   (b) Root-end resection
   (c) Root-end preparation
   (d) Root-end filling
3. Corrective surgery
   (a) Perforation repair
      (i) Mechanical (iatrogenic)
      (ii) Resorptive
   (b) Periodontal management
      (i) Root resection
      (ii) Tooth resection
   (c) Intentional replantation

Box 22.3

Kim's Classification of Microsurgical Cases (Fig. 22.8)

- *Class A*: Represents a tooth with no periradicular lesion, no mobility, and normal pocket depth. The clinical symptoms have not resolved, although nonsurgical options have been exhausted. Clinical symptoms are the only reason for the surgery
- *Class B*: Represents a tooth with a small periradicular lesion with clinical symptoms. The tooth has normal periodontal probing depth and no mobility. The teeth in this class are ideal candidates for microsurgery
- *Class C*: Represents a tooth that has a large periradicular lesion, progressing coronally; without periodontal pocket and mobility
- *Class D*: Represents a tooth that is clinically similar to that in Class C, but has deep periodontal pockets
- *Class E*: Represents a tooth that has a large periradicular lesion with an endodontic–periodontal communication to the apex, but no obvious fracture
- *Class F*: Represents a tooth with an apical lesion and complete denudation of the buccal plate, but no mobility

LOCAL ANESTHESIA AND HEMOSTASIS FOR A BLOODLESS OPERATION FIELD

During periradicular surgical procedures, it is important to realize that the endodontist must achieve maximum depth of anesthesia for longer periods of time than when other dental procedures are carried out. It is imperative that profound, prolonged, and maximum hemostasis be achieved.

Clinical Note

- With its ability to produce profound and prolonged anesthesia and low potential for allergic reactions, lidocaine (Xylocaine) is the choice of anesthetic for periradicular surgeries. Lidocaine (2%) with 1:50,000 epinephrine is administered. Further more, lidocaine has a history of high clinical success rate.
- The amide group of local anesthetics including lidocaine (Xylocaine), mepivacaine (Carbocaine), prilocaine (Citanest), bupivacaine (Marcaine), etidocaine (Duranest), and articaine (Ultracaine) undergo a complex metabolic breakdown in the liver.
- Amide local anesthetic agents should be administered with caution in patients with known liver dysfunction due to their potential for a high systemic blood concentration of the drug. They are also administered with caution in patients with renal dysfunction.
- If the amide anesthetic agent is an absolute contraindication, then the ester agents such as procaine and propoxycaine with levonordefrin (procaine with Neo-Cobefrin) are the only choice.

Effective hemostasis is critically important during endodontic microsurgery because uncontrolled bleeding in the surgical site obscures the anatomical landmarks guiding the surgeon. It is therefore not surprising that one of the most frequently asked questions about endodontic microsurgery is on effective management of bleeding in the osteotomy site and inside the bony crypt.

Effective hemostasis is a prerequisite for endodontic microsurgery and successful hemostasis begins with effective local anesthesia. Surgeons must understand the normal clotting mechanism and normal clotting time of human blood; it takes several minutes for the blood to begin clotting.

VASOCONSTRICTORS

To obtain hemostasis, *vasoconstrictors* are always a constituent of local anesthetics used in periradicular surgeries. The vasoconstrictor agent used in local anesthetics will have an effect on both the duration of anesthesia and the quality of hemorrhage control in the surgical area.

Clinical Note

- Epinephrine is the vasoconstrictor of choice and is the most efficient and widely used vasoconstrictor agent in local anesthetics. The advantage of including epinephrine outweighs any potential deleterious effects of the agents.

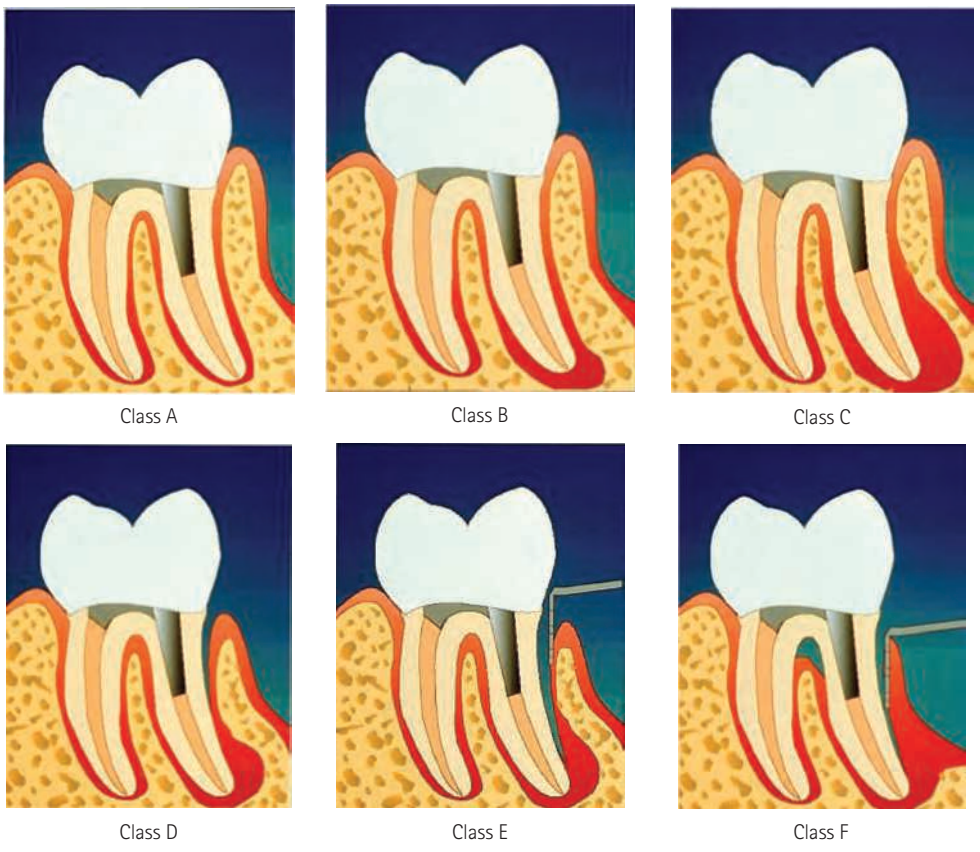


Figure 22.8 Classification of microsurgical cases. (*Courtesy: Syngcuk Kim, University of Pennsylvania, USA.*)

- Normally, profound anesthesia with an agent containing 1:50,000 parts epinephrine is adequate to achieve a blood-free field.
- Both buccal and lingual or palatal injections are required to achieve profound anesthesia and effective hemostasis.
- According to Miliam et al., profound nerve block anesthesia can be achieved with a local anesthetic containing dilute 1:100,000 or 1:200,000 epinephrine. However, at times, an additional local infiltration of the local anesthetic with a higher concentration of epinephrine (1:50,000) in the anesthetic solution is always required to obtain local hemostasis.
- *Safety limit:* According to the American Dental Association, the maximal permissible safety dosage of epinephrine for a healthy adult is 200 µg/day. Thus, it requires 10 carpules of 1:50,000 epinephrine containing 2% lidocaine to reach the danger limit.

It should also be well understood that infiltration sites for periradicular surgery are always multiple and involve deposition of anesthetic throughout the entire surgical area in the alveolar mucosa just superficial to the periosteum at the level of root apices. Apart from the routine anesthetic techniques of nerve block anesthesia, other standard techniques may be observed to obtain profound local anesthesia.

CLINICAL MANAGEMENT OF HEMORRHAGE IN A NORMAL PATIENT

- Incision planning
- Use of hemostats
- Hemostasis through application of pressure
- Hemostatic agents (**Fig. 22.9**)
- Hypotensive anesthesia and vasoconstrictors

TYPES OF HEMOSTATIC AGENTS USED IN PERIRADICULAR SURGERY

- Ferric sulfate solution
- Cotton pellets soaked with epinephrine
- Bone wax
- Gelfoam
- Surgicel
- Thrombin
- Calcium sulfate
- Collagen products

Clinical Note

- Epinephrine pellets (Racellet) used alone or in conjunction with a ferric sulfate–soaked pellet are effective topical hemostats when applied in the bony crypt with light pressure. True epinephrine allergy is extremely rare.
- Attempts to improve hemostasis by injection into soft or osseous tissues after the incision has been made are ineffective because powerful vasodilators at the incision site override the effect of the vasoconstrictors.

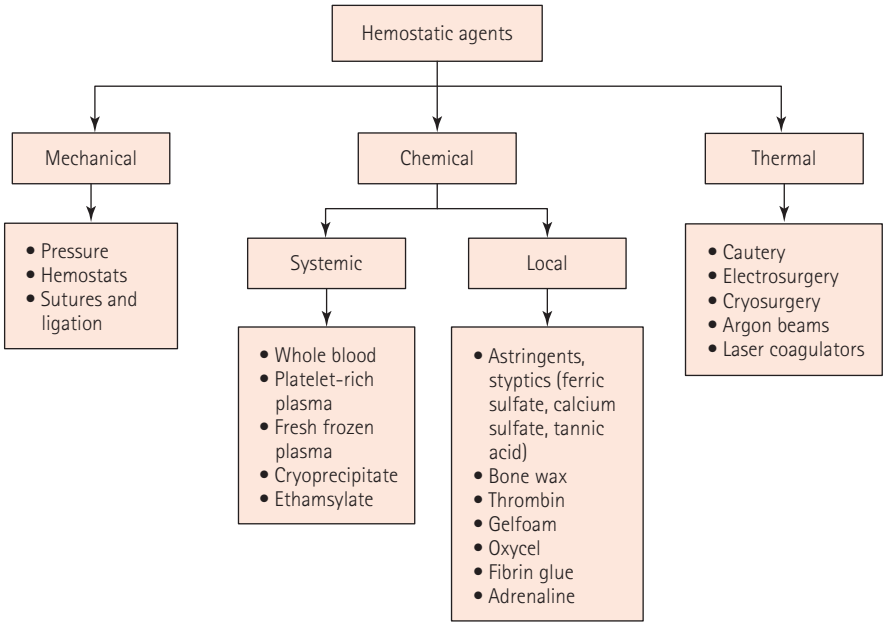


Figure 22.9 The use of hemostatic agents in periradicular surgery.

SOFT-TISSUE MANAGEMENT

The final goal in endodontic surgical procedures is to get rid of the periradicular pathosis and at the same time preservation of the soft and hard tissues. The original contour of tissues is retained as far as possible. Especially in the anterior esthetic zone, one has to retain the interdental papilla and gingival contour and manage the frenal attachment. Once it was thought that the only function of the interdental papilla was to deflect food. Periodontists are of the opinion that the role of the interdental papilla is broader and complex; it is more of a biological barrier to the periodontium from the oral environment. The greatest challenge in periodontal reconstructive surgery is complete and predictable restoration of the lost interdental papilla. The final word is to consider classical and modern soft-tissue strategies in order to fulfill the current esthetic and functional demands.

FLAP DESIGN AND PREPARATION

Based on several studies, there are several flap designs suggested by endodontists. However, all the flap designs have both advantages and disadvantages and no single flap design is amenable to all the surgical cases. To obtain a good surgical access, one must select an appropriate flap design depending on several factors. Each endosurgical case may require a specific flap design based on the size, site, and proximity to anatomical structures (**Boxes 22.4** and **22.5**).

The following paragraphs present the classification of the various types of periradicular surgical flaps.

- In a flap design, if there is a *single vertical releasing incision*, it is called *a triangular flap*, while a *rectangular flap* is with *two vertical releasing incisions*. With the rectangular design, it is recommended that the base of the flap should be as wide as the top so that the incision follows the direction of the tissue fibers and the blood vessels. If one follows this concept, fewer fibers and blood vessels are severed, and in the postoperative phase, sutured incisions are hardly noticeable because they quickly heal.
- *Semilunar flap* has been found suitable only for *incision* and *drainage*. This flap has limited access to the surgical area and has poor visibility. Once the semilunar flap is elevated, it is extremely difficult to modify once the

Box 22.4

Ground Rules for Placing Incision for Periradicular Surgery

- Tissue incisions, elevations, and retractions are performed meticulously in a manner that facilitates healing by primary intention.
- A complete and sharp incision deep into the bone at one stroke is mandatory. Incision is made through the gingiva and the periosteum to the cortical bone using firm pressure and one single stroke. Multiple incision lines will result in improper suturing and delayed healing and scar formation as well.
- Vertical releasing incisions are never placed on the radicular bone. The vertical releasing incisions are placed on the interdental bone.
- Classical time-tested BP handle grips and supports are used while placing incisions.
- There should be minimum trauma to the remaining tissues.
- Care should be taken of the incised flap under moist and retracted conditions with tissue retractor.
- Releasing incisions may be required for efficient suturing.
- The interdental papilla has to be protected and preserved in both anterior esthetic zones and posterior regions.
- Atraumatic tissue handling is mandatory to obtain a scar-free healing. This in turn makes way for a more predictable healing.

Box 22.5

Periradicular Surgical Flap Designs

1. *Full mucoperiosteal flaps* (**Fig. 22.10**)
   a. Triangular (single vertical releasing incision)
   b. Rectangular (double vertical releasing incision)
   c. Trapezoidal (broad-based rectangular)
   d. Horizontal (envelope)
   e. Papilla-based flap
2. *Limited mucoperiosteal flaps*
   a. Submarginal curved (semilunar)
   b. Submarginal scalloped rectangular (Luebke-Ochsenbein)

surgery has started. With the semilunar flap, there are more chances of scar formation as well as puckering in if there is no cortical bone support for the flap.

- *Sulcular or full-thickness flap* (**Fig. 22.10**) requires both horizontal and vertical incisions. The horizontal incision extends from the gingival sulcus through the fibers of the periodontal ligament to the crestal bone. The incision should pass through the mid-col area separating the buccal and lingual papillae. The vertical incision should be made between the two root eminences. This is important because the mucosa is thin over the root eminence and tears easily. Even though this flap design provides the best access to all surgical sites in the oral cavity, approximating the flap back to position and restoring the original interdental papilla back to shape may be laborious. Postoperatively, if care has not been taken to position the flap back meticulously, there can be esthetic problems in the anterior region. In the postoperative healing phase, there can be some amount of recession and the best of endodontic surgeons may not be able to restore the contour of the soft tissues in the anterior esthetic zone.
- The submarginal scalloped rectangular flap, also called *Luebke-Ochsenbein flap*, is ideal for crowned teeth when open crown margins after surgery are an esthetic concern. The Luebke-Ochsenbein flap (**Fig. 22.11**) is often described as that consisting of two vertical incisions and one horizontal scalloped incision away from the gingival tissues, i.e., around 3–5 mm away from the gingival attachment. With this scalloped horizontal incision, the attached gingiva around the gingival margins remains intact and one can be assured of preserving the existing esthetics. While designing this flap, the two vertical incisions are to remain parallel to each other so that the width of the flap at the base is same as it is at the top. It is important to observe here that the horizontal scalloped incision placed in the middle of the attached gingiva should have an angle of 45° to the cortical plate which provides the widest cut surface allowing for meticulous adaptation when the flap is repositioned.

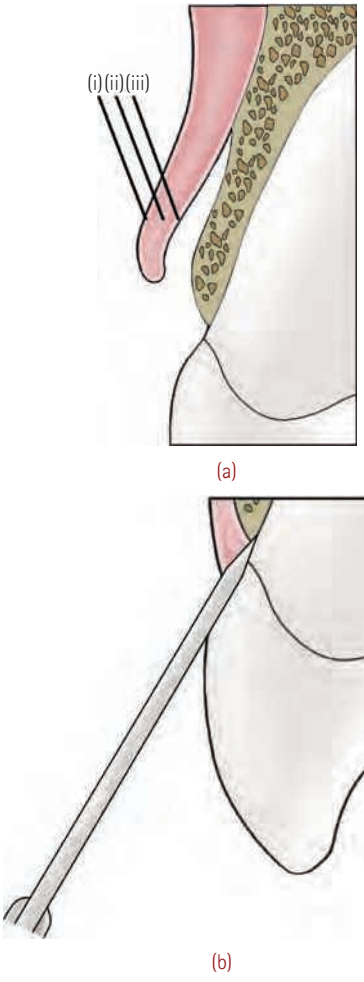


Figure 22.10 (a) The mucoperiosteal flap includes the (i) mucosa, (ii) connective tissue, and (iii) periosteum. (b) To elevate the mucoperiosteal flap, the incision must be made to the bone.

Clinical Note

- The design of choice for endodontic microsurgery is the *sulcular full-thickness flap*.
- The ***papilla-based flap is recommended*** as the design of choice for a recession-free healing.
- The mucogingival flap or Luebke-Ochsenbein flap is preferred for crowned anterior teeth for esthetic reasons. This flap, which includes scalloped horizontal incision, provides a guide for meticulous repositioning of the flap.

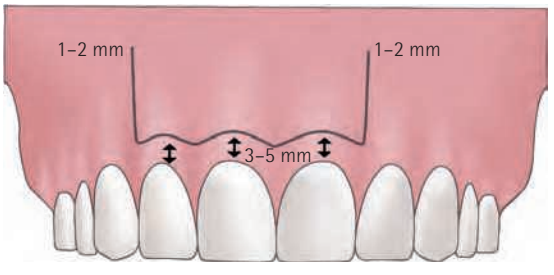


Figure 22.11 The Luebke-Ochsenbein design connects a scalloped horizontal incision in the attached gingiva with two apically directed vertical incisions. The incisions extend from a point 1–2 mm short of entering the mucobuccal fold to a point on the attached gingiva 3–5 mm above or below the marginal gingiva and sulcus depth.

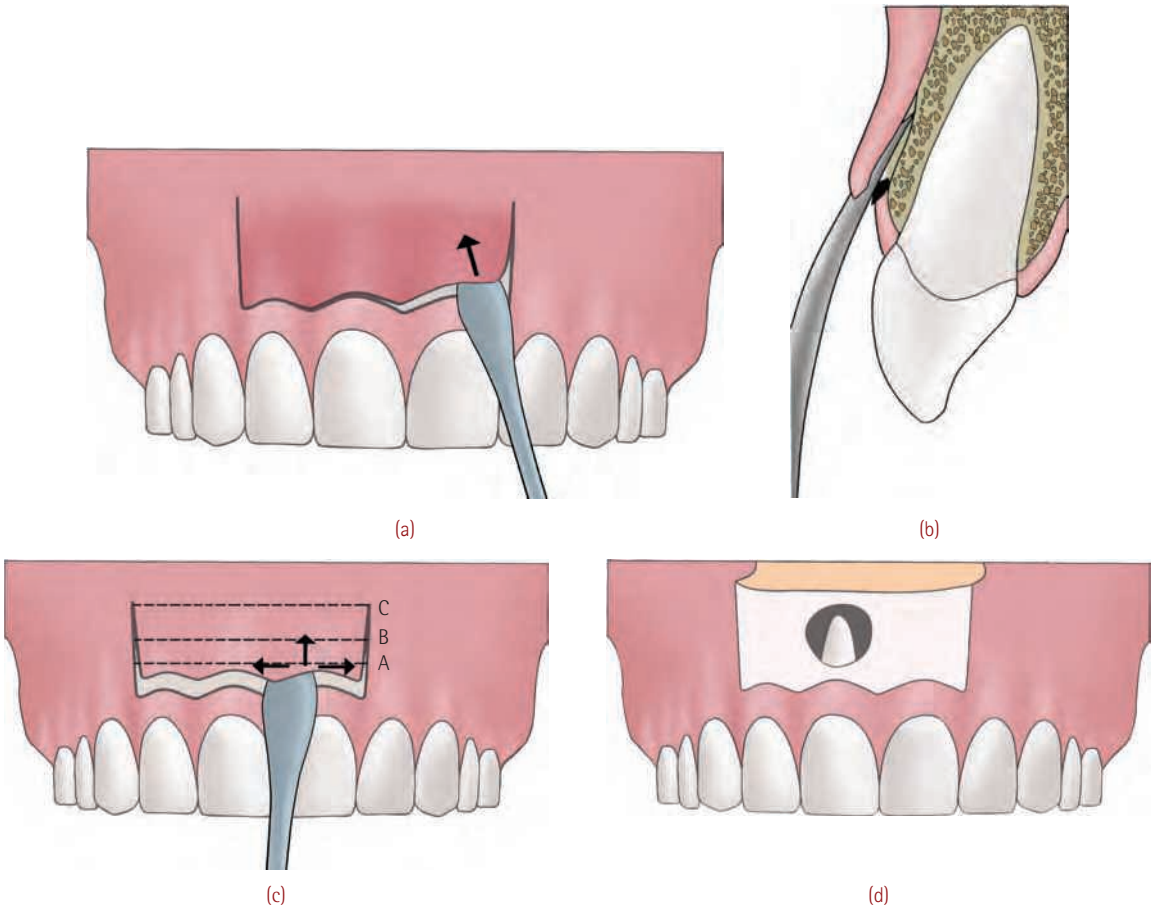


Figure 22.12 (a and b) Raising a Luebke-Ochsenbein flap: the elevator edge, with its concave surface facing the bone, cleaves the periosteum from the bone apically and laterally until the bone above the lesion is exposed. (c) The periosteal elevator should be moved laterally and apically without losing contact with the bone. (d) The extent of the flap should be sufficient enough to expose bone above, below, and around the lesion.

FLAP ELEVATION

Even though several types of elevators are available, the Molt curette no. 2–4 is suitable for both elevation and curetting with minimum trauma. One has to gently use the elevator against the bone taking care not to tear the flap. It is necessary to reflect the flap along with the periosteum to minimize bleeding during the surgical procedure (**Fig. 22.12**).

FLAP RETRACTION

Flap retraction is required for proper visibility and access to the surgical area. Several types of retractors are available and are designed to have wider and thinner working ends than standard retractors.

HARD-TISSUE CONSIDERATIONS

OSTEOTOMY

Osteotomy involves the removal of cortical plate to expose the root end in microendodontic surgical procedures. Once the flap has been elevated and placed in retracted position, the surgical area is taken into control.

Technique

- Hemostasis is the primary issue at this stage of surgery.
- In most of the clinical cases, there is a breach in the cortical plate and this can be located around the root apex by gently probing with a DG16 explorer, and if the breach is located, the explorer will sink and this could be the starting point for an efficient osteotomy. However, in most cystic pathosis, the cortical plate is thinned out due to the growth of the cyst and has an eggshell crackling appearance. In these situations, the cortical plate can be peeled off leaving the cystic lining which balloons out once the cortical plate is removed.
- If the cortical plate is intact, obtain a periapical radiograph after marking the approximate root-end portion of the cortical plate with a small piece of sterile GP stick. This will indicate the approximate location of the apex and the apical pathosis.

- *Endometrics* concept can be applied to locate the root end and periapical pathosis with the help of diagnostic preoperative radiograph. Endometrics simply involves transfer of the anatomical landmark, e.g., root tip, from a periapical radiograph on to the soft tissues in the surgical area both while placing an incision and while carrying out osteotomy procedures, especially if there is an unbreached thick cortical plate present. Now the cortical plate can be removed conveniently.
- For cutting bone, effect of heat, cutting speed of the bur, and coolant employed are the major factors to be taken into consideration. High-torque, low-speed instrument is preferred with an external coolant directed against the cutting bone. This will reduce the heat.
- However, one must remember that it is the bur that gets heated on rotation and gets transferred to the bone. Hence, cooling the cutting instrument externally or internally is most effective. The ideal coolant is either normal saline or distilled water.
- While carrying out osteotomy, the cardinal rule is to study the periapical radiographs or orthopantogram (OPG) meticulously to have an idea of the anatomical structures involved in the surgery in both the anterior and posterior regions. Most endodontists prefer to go in for Impact Air 45° handpiece and Lindeman bur or #6 or #8 round bur or #57 fissure bur for an effective atraumatic osteotomy (**Figs 22.13** and **22.14**).

APICAL CURETTAGE

Once the osteotomy has been satisfactorily completed, the pathosis present in the periapex has to be curetted with Molt curette no. 2–4. Alternatively, Jaquette 34–35 curette can be used to completely remove the granular tissue or cystic pathosis with cystic lining. The granulation tissue is curetted out from the palatal or lingual aspect of the root tip also. It is very vascular and hence hemostasis has to be achieved. Granulation tissue once completely removed and apical 3 mm

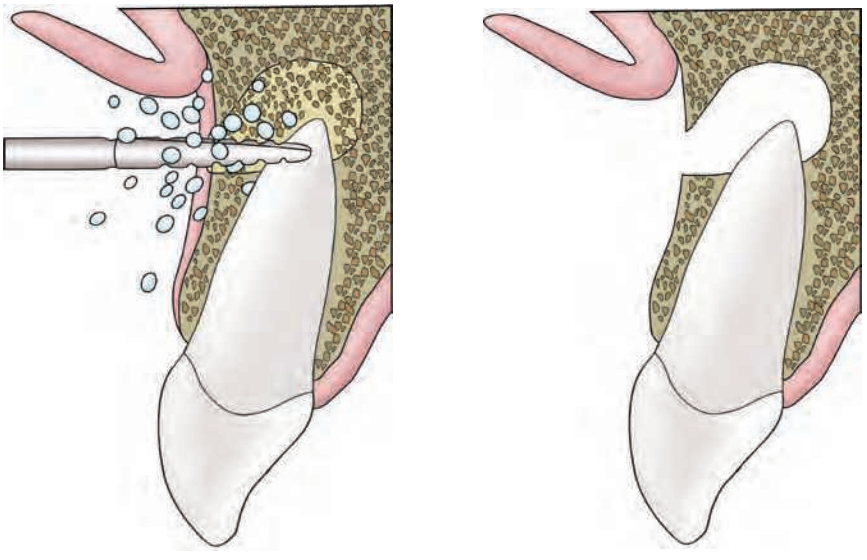


Figure 22.13 (a) The size of the osteotomy should be minimal enough to hasten healing while being large enough to microscopically access, examine, explore, and instrument the root apex. (b) An ideal and adequate osteotomy (4 mm in diameter).

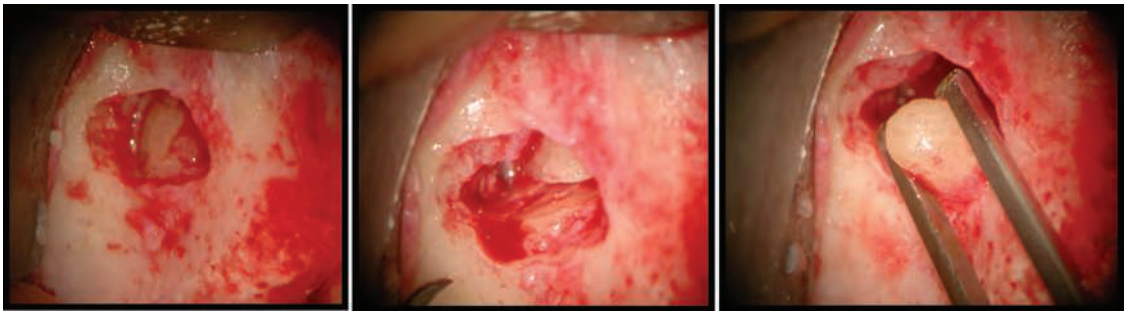


Figure 22.14 Ideal size of osteotomy is considered to be 4 mm in diameter allowing a 3-mm ultrasonic tip to move freely in the bone crypt. (*Courtesy: Meetu Kohli and Syngcuk Kim, University of Pennsylvania, USA.*)

of the root is clearly located, it is now ready for the next phase of surgery, the root-end resection if and when indicated.

APICAL ROOT-END RESECTION

For control of hemorrhage, always aim at the dry surgical field since only then visibility becomes very clear. There can be sometimes continuous hemorrhage from the bone even after completely removing all possible granulation tissue. This hemorrhage is possibly due to opening up of a nutrient-feeding vessel within the bone.

The apical 3 mm of the root tip is resected perpendicular to the long axis of the root. For this phase of endodontic microsurgery setting, the microscope in a low-magnification mode is useful. This procedure of root-end resection is carried out with great care with the help of a bur in an Impact Air 45° handpiece.

The cut root end is examined with medium magnification for the accuracy of the cut and any leftover cystic lining, cystic pathosis, or granulation tissue. This is done to determine whether the entire 3-mm tip is removed or not.

Clinical Note

It is believed that about 93% of the lateral canals and 98% of apical ramifications are removed when 3 mm of the root apex is resected (**Fig. 22.15**).

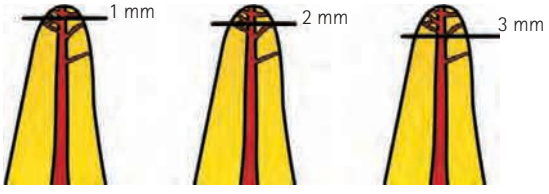


Figure 22.15 Frequency of apical ramifications and lateral canals. An apical resection of 3 mm is needed to eliminate the majority of apical ramifications and lateral canals.

ROOT-END PREPARATION

Traditionally, slow-speed burs were employed to do retropreparation. Presently, all root-end preparations are recommended to be prepared with *ultrasonic retrotips* such as the KiS ultrasonic tips (**Fig. 22.16**) used in conjunction with ultrasonic units (**Fig. 22.17**).

The ultrasonic retrotips have increased cutting efficiency, leaving the dentin surface smooth, yet microscopically rough,



Figure 22.16 KiS ultrasonic tips.



(a) (b)

Figure 22.17 (a) Satelec P5 ultrasonic unit. (b) EMS ultrasonic unit.

which results in better adaptation of filling materials, fewer microfractures, and less leakage. These retrotips are either stainless steel, diamond-coated, or made of zirconium nitride.

Advantages of Ultrasonic Retrotips in Endodontic Surgery

- Size in osteotomy preparation is reduced to less than 5 mm. The ideal diameter needed is only 4 mm, thereby allowing a 3-mm ultrasonic tip to move freely within the bone crypt
- Reduced size of osteotomy leads to faster and better healing of the surgical wound
- More precise and efficient retropreparation than when compared with burs
- Reduced risk of lingual perforation of the root-end cavity preparation
- Access to the root end is easier and more predictable in terms of the final preparation design
- It is an efficient method to manage the isthmus area between the root canals within one root
- It allows cleaner and deeper root-end cavities which helps in improving the prognosis of the procedure

Retro/root-end preparations are usually 3 mm deep with ultrasonic tips. Final inspection with a retromirror should show no gutta-percha remaining in the 3-mm depth of preparation (**Figs 22.18–22.21**).

PREPARING THE ROOT END FOR A ROOT-END RESTORATION

The area is dried and isolated after irrigation with normal saline or distilled water. The root canal seen through the cut end of the root is located.

Root-End Filling Materials

- Tricalcium silicate cement
- MTA
- Intermediate restorative material (IRM)
- SuperEBA
- Glass ionomer cement
- Diaket
- Composite resins and resin ionomer hybrids

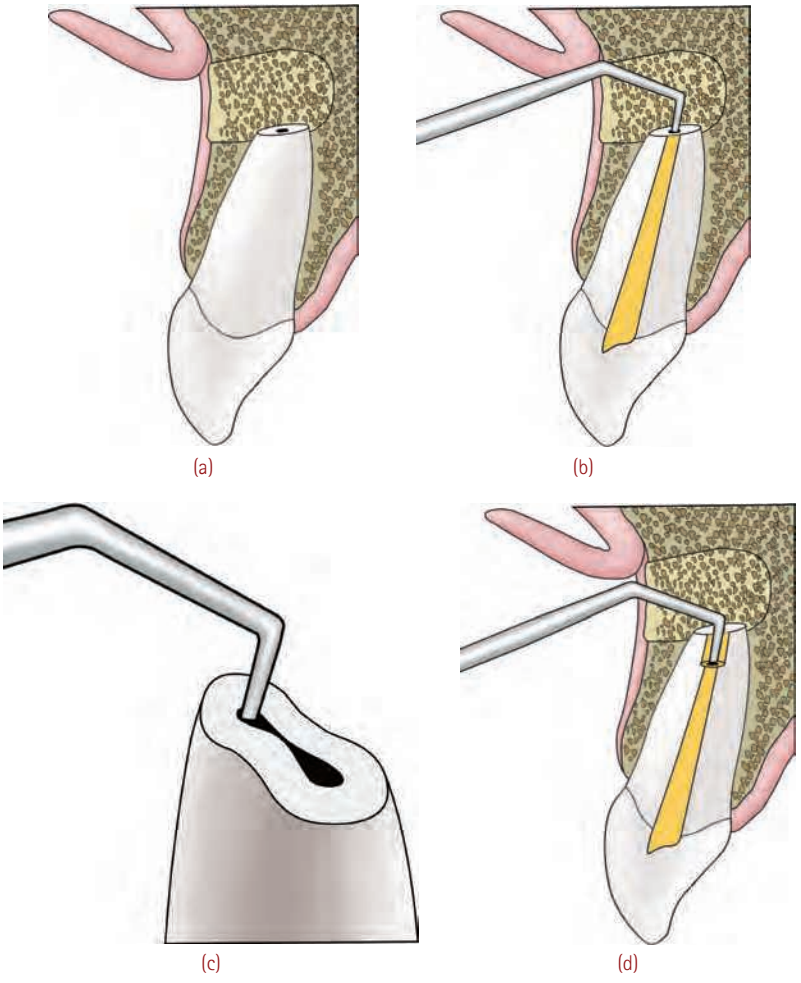
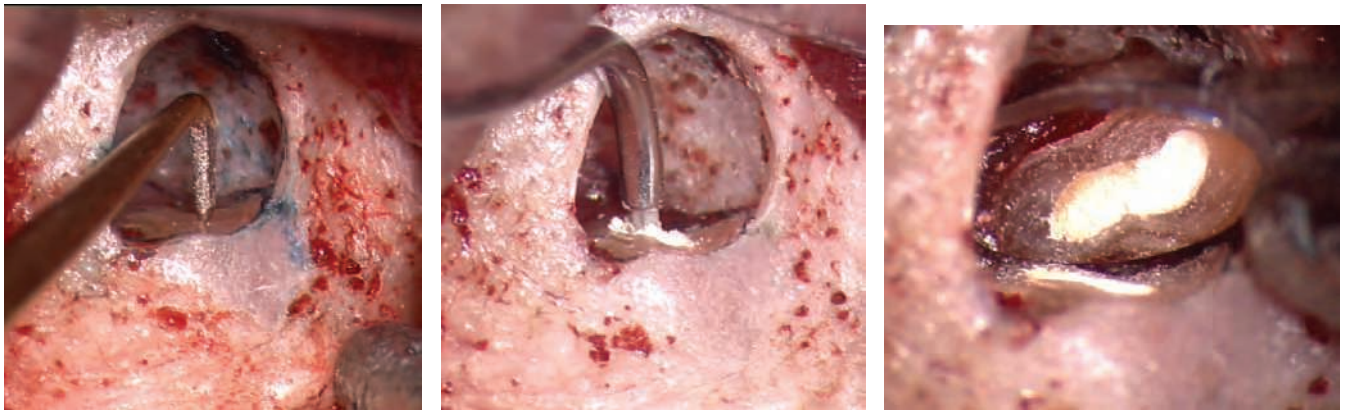
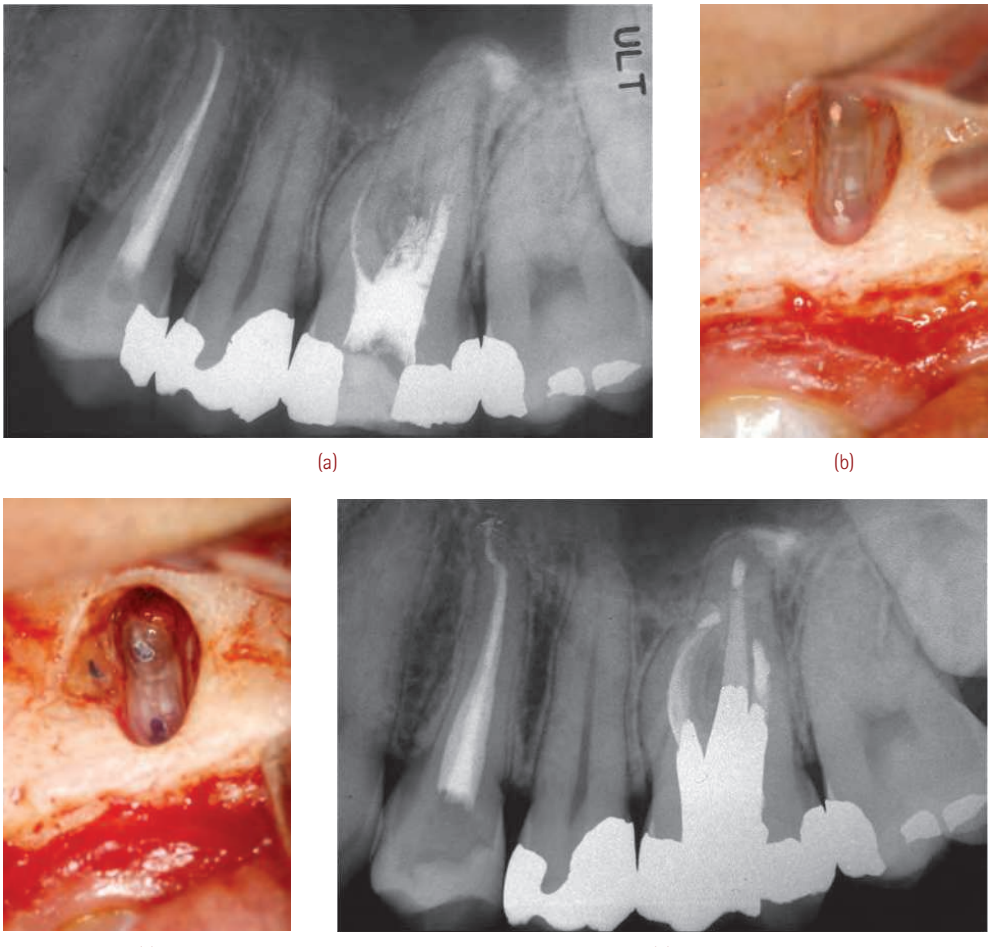


Figure 22.18 (a) Schematic representation of root-end resection. (b) Ultrasonic retrotip being employed to begin the retropreparation. (c) Isthmus region is best negotiated with an ultrasonic retrotip. (d) A depth of 3 mm is the depth of an ideal retropreparation.



(a) (b) (c)

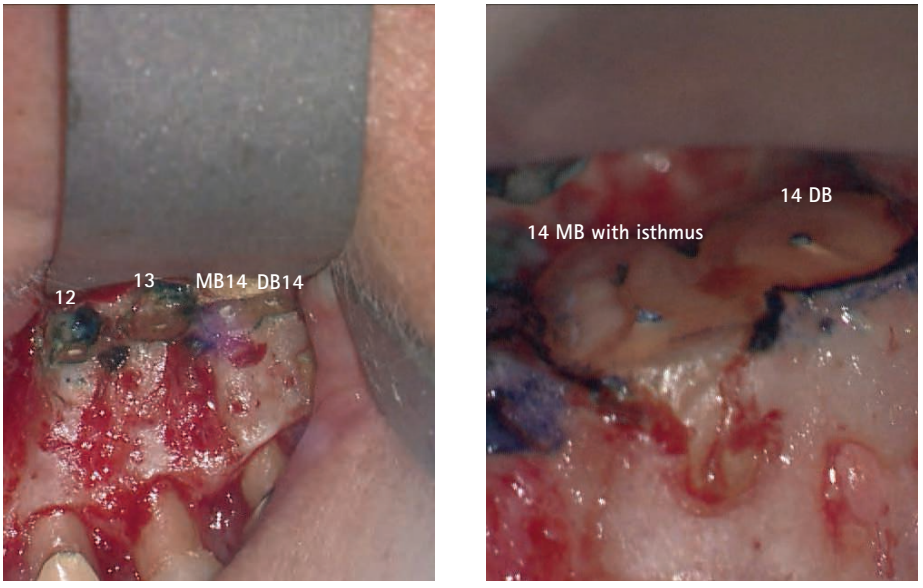
Figure 22.19 (a) Ultrasonic retrotip being employed to create a 3-mm retropreparation. (b) Placement of the retrofill material. (c) Postoperative view. (*Courtesy: Arnaldo Castelluci, Italy.*)



(a) (b)

(c) (d)

Figure 22.20 (a) Preoperative radiograph of an endodontically treated maxillary molar requiring endodontic microsurgery. (b) After root resection of all the three roots. (c) Retrofilling completed in all the three roots. (d) Two-year follow-up radiograph showing good healing. (*Courtesy: Arnaldo Castelluci, Italy.*)



(a) (b)

Figure 22.21 (a) Clinical view of endodontic microsurgery involving the roots of a maxillary lateral incisor, canine, and the first premolar. (b) Higher magnification showing the isthmus region of the mesiobuccal root of the first premolar. (*Courtesy: Meetu Kohli and Syngcuk Kim, University of Pennsylvania, USA.*)

Clinical Note

- Amalgam was once the most common root-end filling material, but it is not recommended presently due to corrosion and dimensional changes, unsightly amalgam tattoos, biocompatibility, and safety issues.
- Tricalcium silicate cements/MTA is the recommended root-end filling material of choice.
- IRM and SuperEBA are other commonly recommended alternatives.

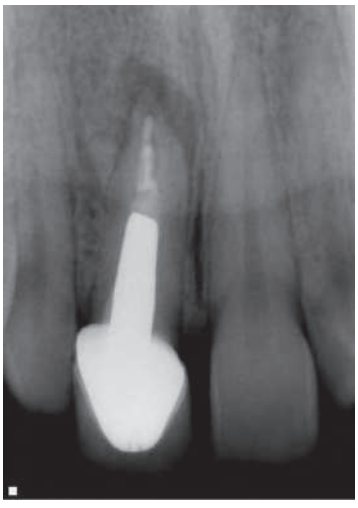
If tricalcium silicate cements/MTA is the material of choice, the preparation is restored using the instruments available with tricalcium silicate cements/MTA root-end restoration setup (**Fig. 22.22**). Once the root end is restored, it is burnished to a concave finish. Tricalcium silicate cements/MTA takes some time to set, after which the area is cleaned of all debris, irrigated with normal saline, and dried with sterile gauze. Before approximating the retracted flap, a confirmatory radiograph is taken to see whether the root tip has been completely removed and the root-end restoration is in place (**Figs 22.23** and **22.24**).

Some hemorrhage is allowed to occur before suturing is attempted. The retracted flap has to be carefully handled and approximated back to the original position from where it was elevated and covered with moist gauze so that the flap will get back its elasticity and physiologic moistness. This will lead the path to easy approximation and suturing.

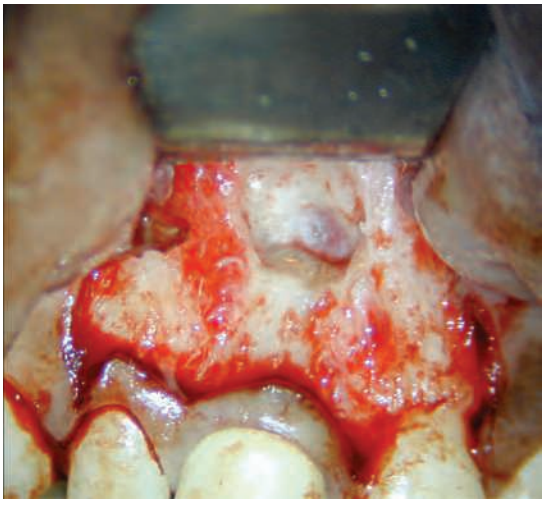


(a) (b)

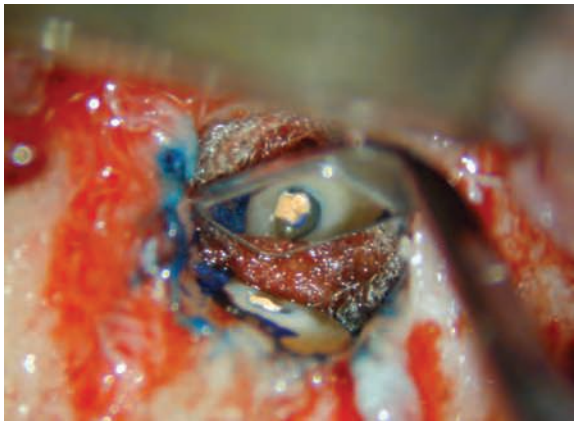
Figure 22.22 (a) Microapical placement (MAP) carrier. (b) Microtips for tricalcium silicate cements/MTA placement. (*Courtesy: Produits Dentaire SA.*)



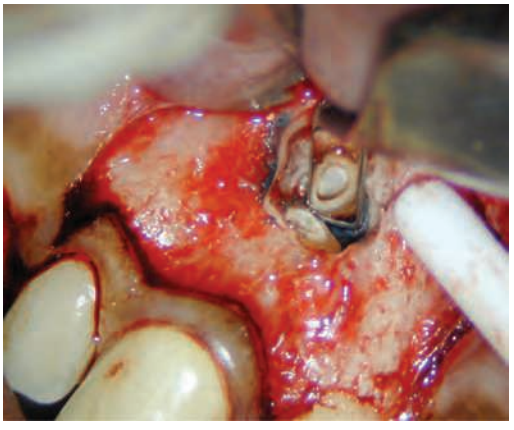
(a)



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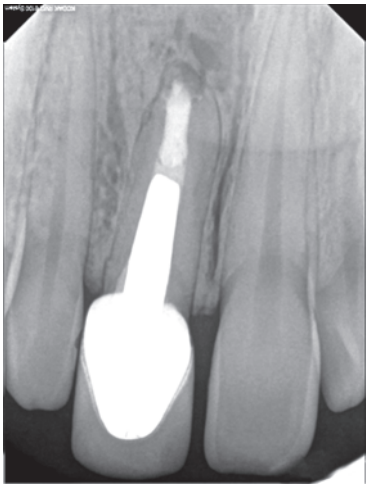
(c)



(d)



(e)



(f)

Figure 22.23 (a) Preoperative radiograph of maxillary central incisor with a post and core restoration requiring surgical endodontic intervention. (b) Osteotomy and root resection completed. (c) Retropreparation with ultrasonic retrotips. (d) Tricalcium silicate cements/MTA placement. (e) Postoperative view. (f) Healing after 2-year follow-up. (*Courtesy: Sashi Nallapati, Jamaica.*)

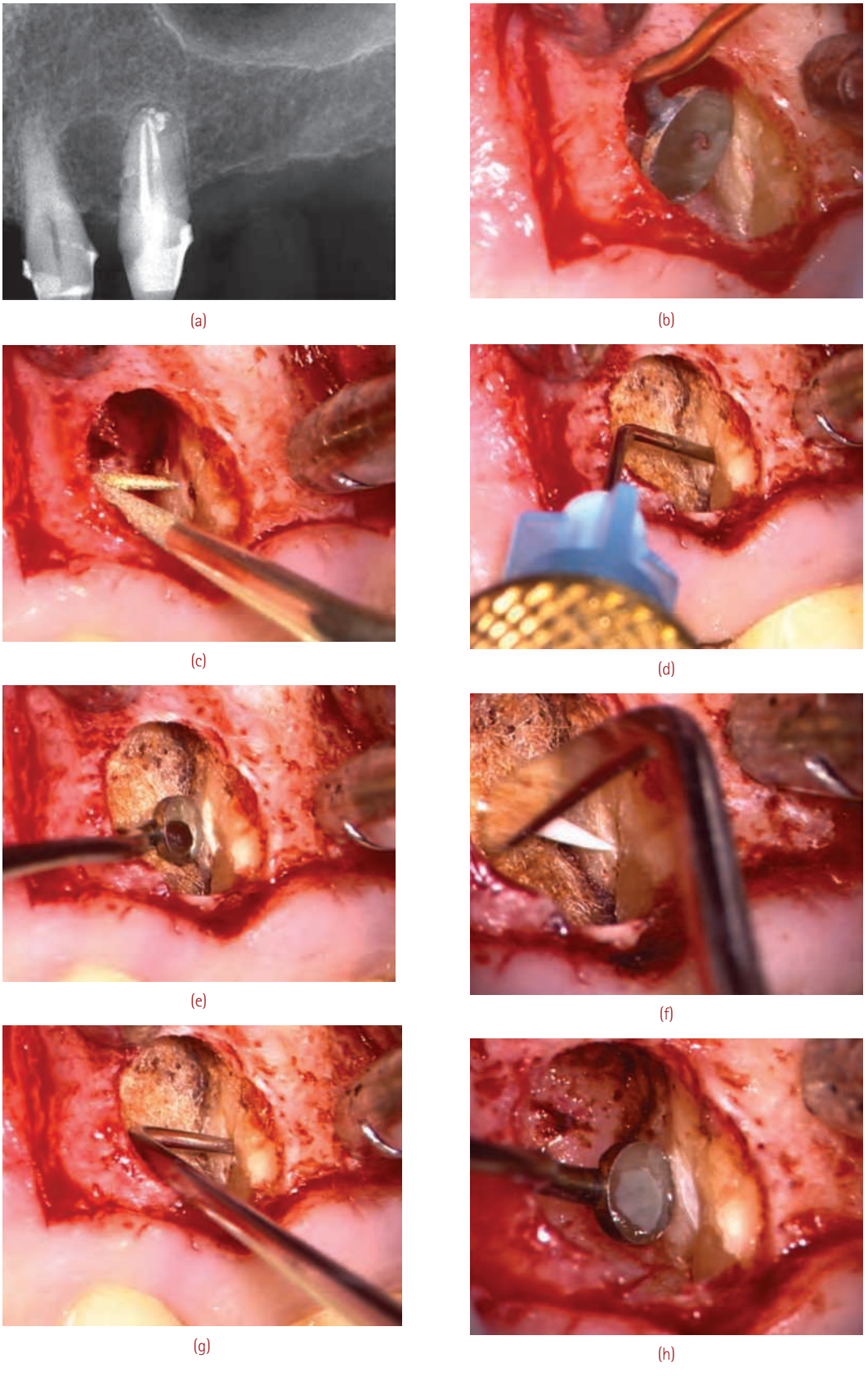
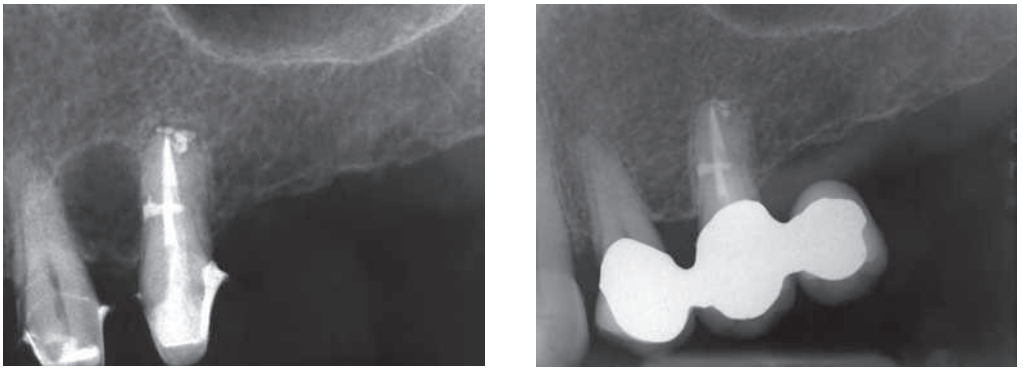


Figure 22.24 (a) Preoperative radiograph of a patient referred for surgical endodontics. Notice the lateral lesion of endodontic origin. (b) The micromirror shows the opening of the lateral canal. (c) The ultrasonic tip is preparing the lateral cavity for the retrofill. (d) The cavity is now dried with the Stropko irrigator. (e) The cavity is now ready to be obturated. (f) The retrofilling material is being carried in the cavity. (g) The microplugger is condensing the material. (h) The lateral retrofill has been completed and finished. *(continued)*



(i) (j)

Figure 22.24 *(continued)* (i) Postoperative radiograph. (j) Two-year recall. (*Courtesy: Arnaldo Castelluci, Italy.*)

HISTOPATHOLOGIC DIAGNOSIS

Grossman stated more than 60 years ago that anything that is removed from the periradicular area deserves histopathologic diagnosis. Before posting the patient for surgery, one has to think about histopathologic diagnosis, and biopsy bottle should be ready after the surgery. If the provisional clinical and radiographic diagnosis suggests a periapical cyst, the endodontist must attempt to take out the lesion in one piece with the cystic lining to help the pathologist arrive at a proper diagnosis.

CLOSURE OF SURGICAL AREA

Repositioning of Flap and Compression

As mentioned earlier, the flap has to be meticulously repositioned into the original position from where it was elevated. Reapproximation is accomplished based on the flap design. One has to also after repositioning the flap compress the tissues so that the flap does not resist suturing. The repositioned flap should always be kept moist with 2 × 2–inch moist gauze until suturing has begun. Compression results in a thin fibrin clot in the wound site. This will result in initial adhesion between the wound edges and intravascular clotting which reduces oozing from the severed microvessels. Without adequate compression, the wound edges are not properly co-opted, especially in the dissectioned wound edges between the flap and the bone, resulting in the formation of a thick clot or coagulum which causes delayed healing.

Needle Selection

Suture materials are manufactured with an assortment of needle shapes ranging from one-quarter circle to five-eighths of a circle as well as straight and half curve shaped. Gutmann recommends reverse cutting needles where the cutting edge is on the outer or convex surface and all are available with silk, gut, or polyglactin 910 suture material in sizes recommended for periradicular surgery. Commonly used needles include FS, P-3, PS-2 (three-eighths circle needles), and PS-4 (half circle needles). Selection of the needle shape and radius is based on a combination of factors and varies greatly from case to case. Hence, no single needle shape or radius is suitable for all situations.

Suture Materials

Medical grade adhesives such as cyanoacrylates have been suggested for closure of surgical wound in endodontics. However, sutures remain the ultimate for closure of periradicular surgical wounds.

Many different suture materials are available, and the options are as follows:

- Synthetic fibers—nylon, polyester, polyglactin (PG), and polyglycolic acid (PGA)
- Collagen, gut, and silk sutures

Sutures are also classified as follows:

- Absorbable and nonabsorbable sutures
- On the basis of size—minimum and maximum diameter
- On the basis of physical design—monofilament, multifilament, and twisted or braided filaments

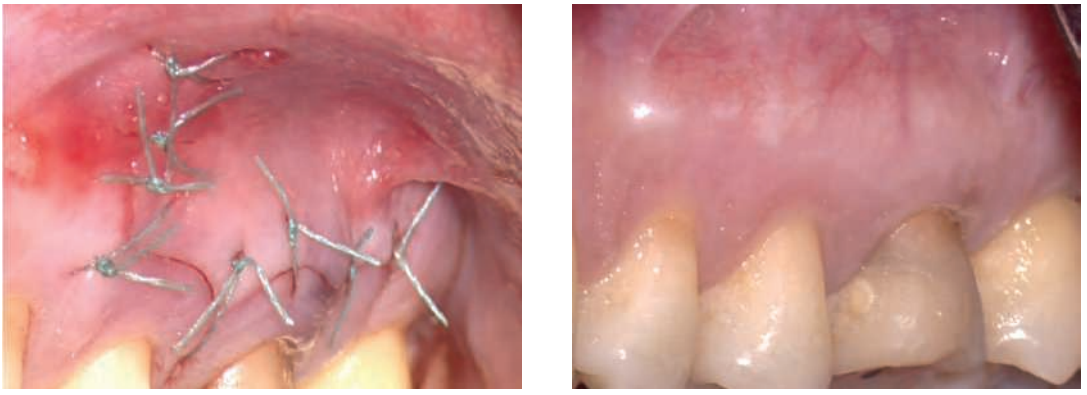
Silk sutures are protein fibers bound together with biological glue (sericin) similar to fibronectin. They are nonabsorbable, multifilamentous, and braided, and have the advantage of easy manipulation.

Suture Techniques

There are several suture techniques used by endodontists and others while carrying out periradicular surgery. The main aim of suturing is closure and stabilization of flaps involving oral mucoperiosteal tissues. Some amount of hemorrhage is required for a faster healing by primary intention. But one should also take care to see that the hemostasis is under control since excess hemorrhage will form a hematoma under the flap and cause unnecessary delay in healing (**Fig. 22.25**).

Single Interrupted

The first bite of the needle should be through the movable tissue. The buccal entry from the incision margin is suitable. Next, the needle should enter the undersurface of the mucoperiosteum of the dependent tissue. This type of suturing is basically for closure and stabilization of vertical releasing incisions.



(a) (b)

Figure 22.25 (a) View after suture placement. (b) Suture was removed after 24 hours and this view after 6 months shows complete healing without any scar formation. (*Courtesy: Arnaldo Castelluci, Italy.*)

Interrupted Looped Sutures

These sutures are primarily for securing and stabilizing the horizontal component of the mucoperiosteal flap. Other types of suturing techniques include vertical mattress suture and single sling sutures.

Clinical Note

- Most clinicians prefer interrupted sutures than continuous sutures due to better orientation and adaptation with interrupted sutures.
- Hemostasis is a requirement before sutures are placed but that does not mean totally drying out the surgical cavity.

POSTSURGICAL CARE

Once the sutures have been satisfactorily placed, the oral cavity is cleaned. A moist 2 × 2–inch gauze piece is kept over the surgical area and the patient is allowed to rest for few minutes. Check for bleeding points after the lapse of about half an hour. Instructions are given regarding postoperative medications before sending off the patient. Antibiotic prescriptions are not mandatory. However, anti-inflammatory analgesic drugs are prescribed routinely as described before.

Most endodontists who are carrying out periradicular surgeries have a set format printed and hand it over to the patient. However, these instructions have to be explained to the patient or his/her relative before discharging the patient. The patient has to be instructed to report for any postsurgical complications within 24 hours of surgery.

Clinical Note

- Most postendodontic surgical situations are uneventful, and hence if nonabsorbable sutures have been used, these sutures have to be removed within 96 hours (4 days) of placement.
- The postsurgical instructions are given in **Box 22.6**.

Box 22.6

Postsurgical Instructions

Following are few important instructions other than the instructions involving medications:

- At the end of the surgery, the patient is handed a readymade ice bag filled with ice cubes to be placed immediately over the external surface of the surgical area under pressure. This ice bag should not be in continuous contact with the tissues and there should be a gap after every 3 or 5 minutes. This ice pack should be continued for at least 1–2 hours after surgery and discontinued later on. These cold packs are very useful in substantially reducing the postoperative swelling and inflammation.
- The patient is instructed not to lift the upper lip or the lower lip depending on the site of surgery as this may result in tearing of the flap and dislodgement of the sutures.
- Presurgical rinsing for 48 hours prior to surgery with chlorhexidine gluconate proprietary preparations is mandatory. This antiseptic rinsing should be continued until 72 hours postoperatively three times a day or after each meal.
- Postsurgical brushing with chlorhexidine-incorporated toothbrushes has become a mandatory procedure until the sutures are removed.
- The day following the surgery, it may be useful for the patient to use warm saline mouth holds and mouthwashes. These warm saline holds will improve circulation in the surgical area and enhance healing capabilities of tissues.
- The patient is provided with the contact numbers of the endodontist and/or the assistant. The endodontist who has performed the endodontic surgery should be available postoperatively for 24 hours for any emergencies. If the endodontist is out of station, the information should be passed out to the patient as to whom the patient should contact in an emergency. The person referred by the endodontist should also be an endodontist to look into any complications. Otherwise this may lead to *abandoning* in medicolegal terminology.
- The patient has to be instructed to report for removal of sutures after 4 days.
- The dietary instructions are always in the printed format handed over to the patient.

REPAIR

The initial repair that follows a periradicular surgical procedure occurs across the margins of the line of incision. This healing by first intention usually occurs within 5 days, provided the sutures remain intact. Because healing takes place across the incisional margin, the length of the incision is not a factor in how quickly initial healing occurs. If the sutures tear or fail, then healing will occur through the formation of granulation tissue (second intention), a process lasting 4–6 weeks. At times, complete closure of such a wound can take over a year.

Repair of the periradicular tissue is usually complete within a year, and progressive repair should be noticeable on a radiograph 6 months after the operation (**Fig. 22.26**). In many cases, the root canal appears to be incompletely filled because the cut root end is at an obtuse angle to the direction of the X-rays. When the periosteum has been destroyed during the operation and when the lingual or palatal plate of bone has been either pathologically destroyed or accidentally perforated, a radiolucent area ("surgical defect") will persist even though repair around the root apex, including the lamina dura, is complete. In such cases, repair occurs by means of noninflamed fibrous tissue, rather than of bone. Such an area persists even if the tooth is extracted.

During the resection, necrotic bone, necrotic cementum, and granulomatous or cystic tissue, for example, are removed and are replaced by a blood clot. The formation and organization of the blood clot initiates the process of repair. This is followed by calcification. With a decreased need for vascularity and an increase in collagen, the capillaries disappear and ossification begins, leading to healing eventually.

TYPES OF REPAIR

According to Andreasen and Rud, three main types of repair occur following root resection:

1. Complete repair with restoration of the damaged periodontal ligament, with either mild or no inflammation

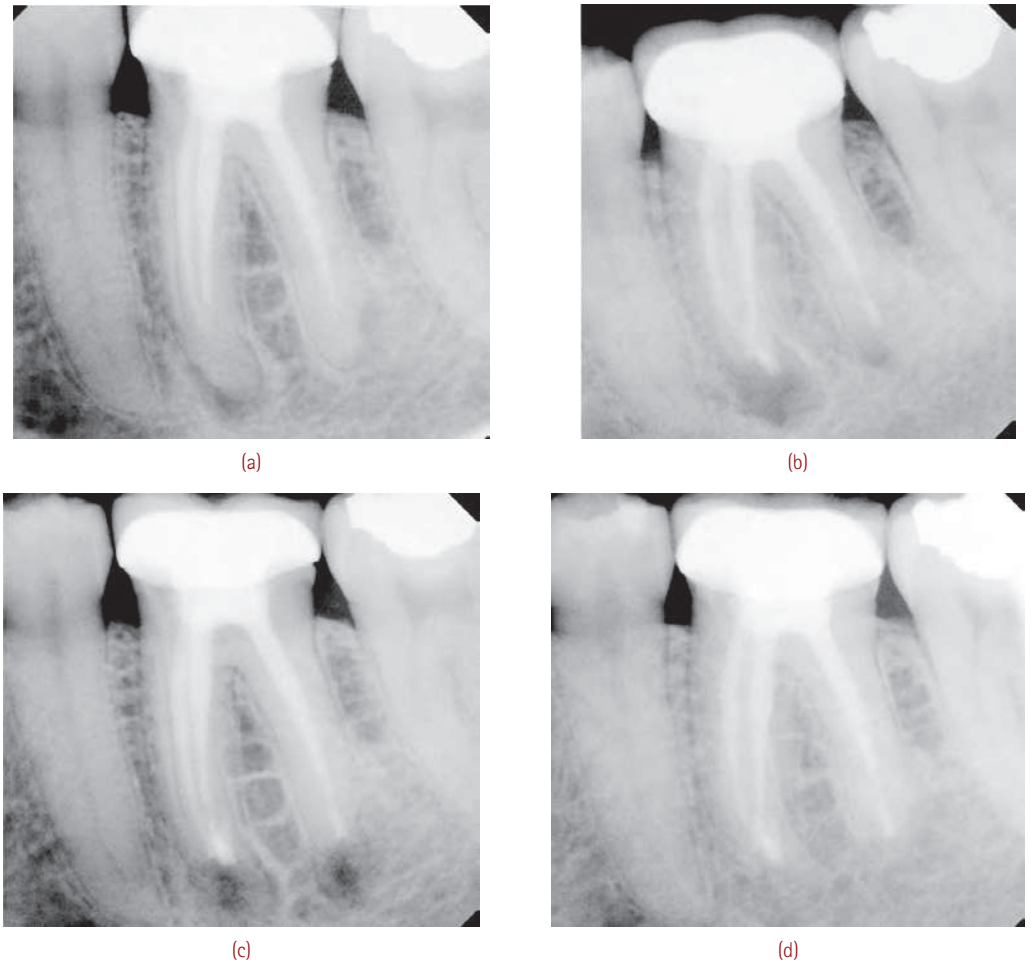


Figure 22.26 (a) Preoperative radiograph of an endodontically treated tooth indicated for surgical endodontic therapy. (b) Immediate postoperative view. (c) Six-month follow-up view showing signs of healing. (d) One-year follow-up radiograph showing resolution of the periradicular defect and good healing. (*Courtesy: Meetu Kohli and Syngcuk Kim, University of Pennsylvania, USA.*)

2. Repair with scar tissue adjacent to the periodontal ligament, with some degree of inflammation
3. Scar tissue, with moderate inflammation

Repair with new bone may occur 6 months to a year after root resection. This compares favorably with repair following extraction of a tooth, which may take much longer. In some cases, repair is slower, but repair following root resection usually occurs more rapidly than that following simple root canal treatment for an equivalent periradicular area.

ADDITIONAL SURGICAL PROCEDURES

At times, the endodontist is called on to perform other related surgical procedures. Using the surgical skills and knowledge needed for periradicular surgery, the operator can achieve these surgical objectives by modifying and applying the previously described techniques.

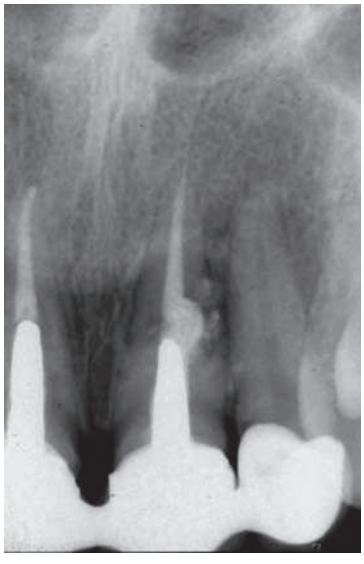
SURGICAL MANAGEMENT OF INTERNAL RESORPTION

The clinical features and nonsurgical management of internal resorption are discussed in Chapter 4. The various steps involved in the surgical management of internal resorption are explained in **Figure 22.27**.

RADISECTOMY AND HEMISECTION

Definition

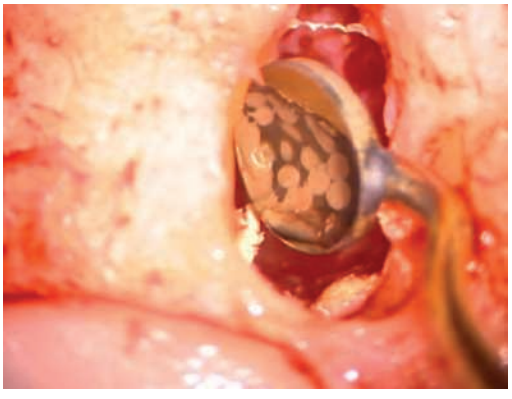
- *Radisectomy denotes the removal of one or more roots of a molar.*
- *Hemisection refers to sectioning of the crown of a molar tooth, with either the removal of half the crown and its supporting root structure or the retention of both halves, to be used after reshaping and splinting as two premolars.*



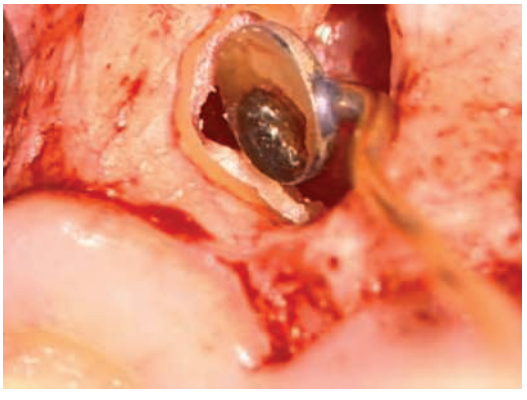
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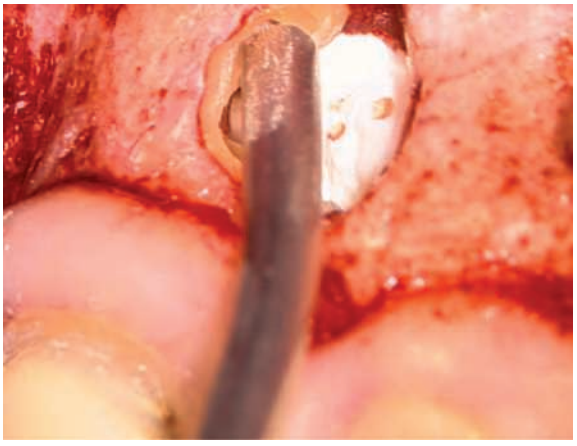


(c)

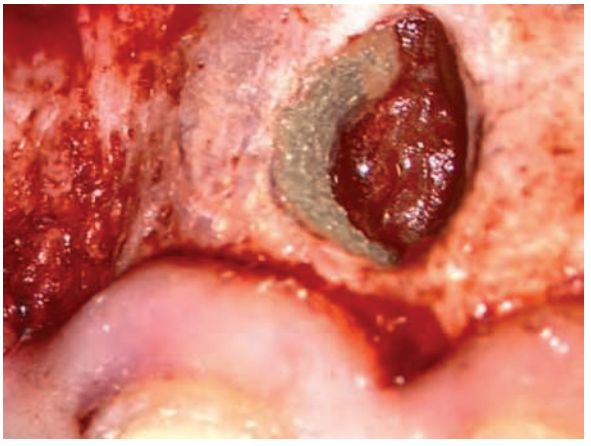


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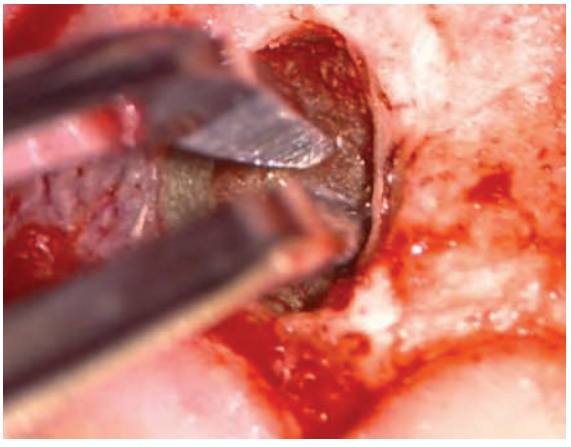
Figure 22.27 Internal resorption (progressive inflammatory secondary to infection) with intraosseous perforation of an upper left central incisor, already endodontically treated: (a) Preoperative radiograph. The defect was treated with lateral condensation. (b) An off-angle radiograph shows the gutta-percha cones laterally condensed. (c) A view of the gutta-percha cones through the micromirror during the surgical procedure. (d) The cast post. *(continued)*



(e)



(f)



(g)



(h)



(i)



(j)



(k)

Figure 22.27 *(continued)* (e) The Dovgan carrier is positioning gray MTA in the defect. A few pieces of CollaCote have been positioned on the bottom of the bony defect to collect the debris of MTA. (f) The resorption has been filled with gray MTA. (g) The cotton pliers are used to remove the CollaCote. (h) Postoperative sutures placed. (i) Removal of the suture after 24 hours. (j) Postoperative radiograph. (k) Two-year recall. Radiograph showing excellent healing. (*Courtesy: Arnaldo Castelluci, Italy.*)

Concept

Radisectomy and hemisection are often desirable for periodontal reasons. At times, a multirooted tooth has an untreatable periodontal lesion on one or more of its roots, but the remaining root or roots are well supported and treatable. For example, one root may have an extensive infrabony pocket with concomitant bone loss, and the other root may be surrounded by normal gingiva and supportive bone. To retain a portion of this strategic tooth and avoid extraction of the entire tooth, hemisection or radisectomy can be performed (**Fig. 22.28**).

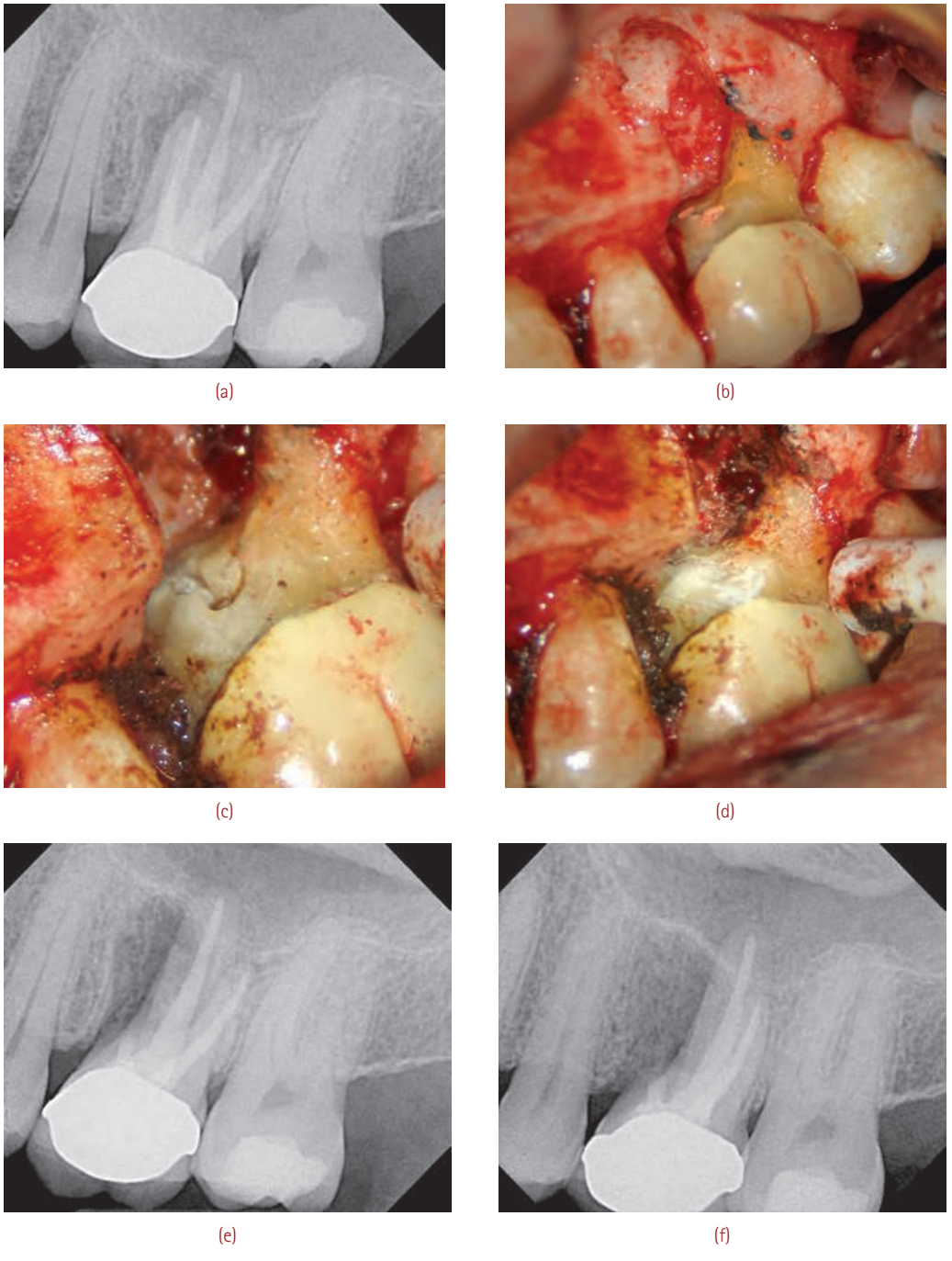


Figure 22.28 Radisectomy of the mesiobuccal root of a maxillary molar: (a) Lesion in relation to the mesiobuccal root. (b) Osteotomy and radisection of the mesiobuccal root completed. Note the exposed gutta-percha from both the mesiobuccal canals. (c) Ultrasonic retropreparation completed in both the canals. (d) MTA retrofilling done. (e) Immediate postoperative radiograph. (f) Three-month follow-up radiograph showing healing. (*Courtesy: Jason J. Hales, USA.*)

Indications and Contraindications for Radisectomy

The indications are as follows:

- Endodontic treatment of one root is technically impossible or when such treatment has failed
- Untreatable furcation involvement is present and removal of the root will facilitate oral hygiene in that area
- Extensive bone loss around one root of an upper molar
- Fractured root of an upper molar
- Root has been perforated and cannot be treated endodontically

The contraindications are as follows:

- When loss of bone involves more than one root, and the remaining roots would have inadequate support
- When the involved tooth is an abutment tooth for a long span bridge
- When the roots are fused

Indications and Contraindications of Hemisection

The indications for hemisection are as follows:

- When periodontal involvement of one root is severe
- When loss of bone is extensive in the furcation area
- When caries involves much of one of the roots

The contraindications are similar to those for radisectomy.



Clinical Note

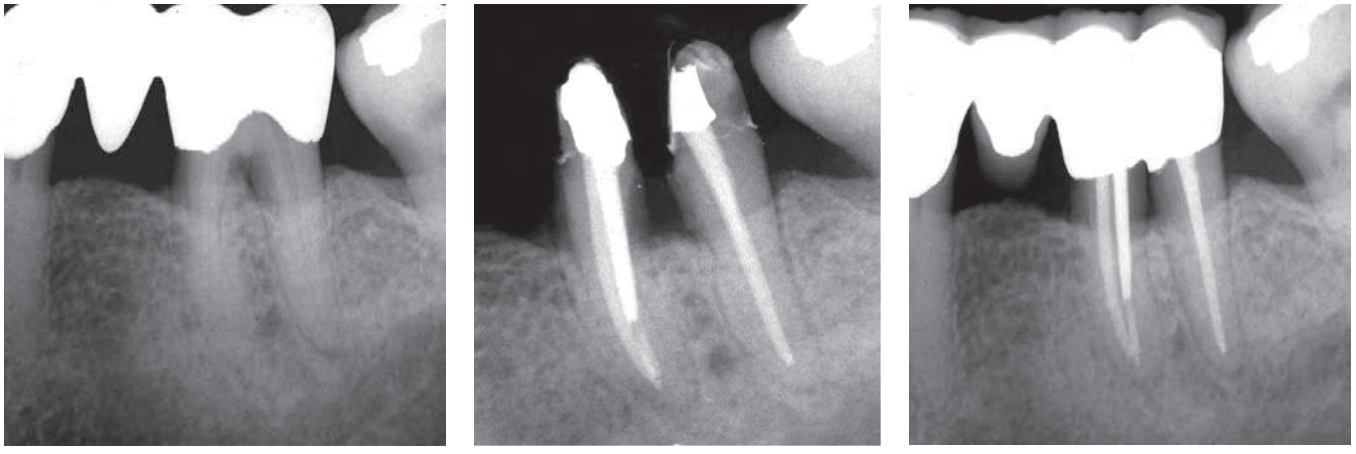
- Endodontic treatment should precede root removal. It is difficult to treat a tooth properly when it has been sectioned through the pulp chamber because asepsis is impossible, anatomical guidelines used in treatment are removed or destroyed, and a medicated dressing cannot be adequately sealed between visits.
- The coronal seal placed in the pulp chamber over the root to be removed should have set before hemisection or radisectomy to avoid "core material scatter" in the adjacent tissues.

Some clinicians prefer to use diamond disks when performing hemisection; however, the use of carbide burs and diamond points with water spray usually results in a controlled cut, with contoured sections having better margins and restorations. Frequently, a tissue flap is incised and retracted to allow unrestricted observation of the planned sectioning and extraction. Reluctance to create a flap when necessary could result in an improper section, a section through an adjacent root, incomplete root removal, and "spur" formation, all of which jeopardize proper restoration and repair. Moreover, exposure of the operative site enables one to avoid the disastrous error of separation and removal of fused roots that were not readily evident in the radiographs.

To remove a root or hemisect a tooth properly, the clinician should visualize the end result before initiating treatment (**Fig. 22.29**). When a full-coverage restoration is planned after hemisection or radisectomy, one would prepare this tooth for full coverage before removing the root. Once the crown has been prepared, it is easier to see and severe the root to be extracted from the remaining structures by hemisection and radisectomy; thus, maximum tooth structure is conserved, restorative problems are easier to solve, and periodontal healing is enhanced. Improper prosthodontic planning might lead to long-term clinical failure (**Fig. 22.30**).

INTENTIONAL REPLANTATION

Definition: According to Grossman, *intentional replantation is the purposeful removal of a tooth and its almost immediate replacement, with the objective of obturating the canals apically while the tooth is out of the socket.*



(a) (b) (c)

Figure 22.29 Hemisection of a mandibular molar: (a) Endodontic involvement in a mandibular molar serving as an abutment for a fixed partial denture. (b) Bridge removed, endodontic therapy completed, and hemisection done for improved periodontal health and maintenance. (c) Healing after prosthodontic rehabilitation. (*Courtesy: James L. Gutmann, USA.*)

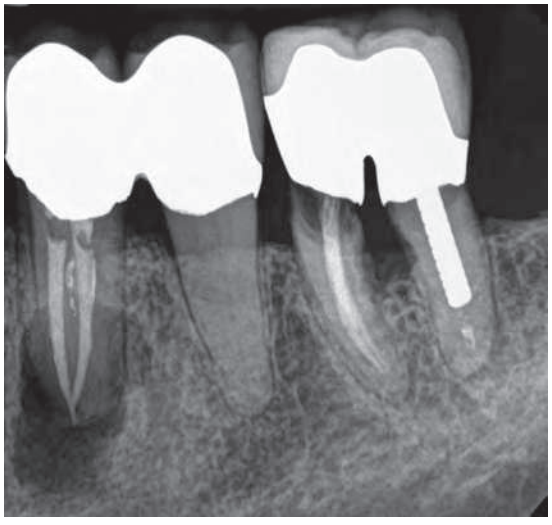


Figure 22.30 Prosthodontic failure in a hemisected mandibular molar of a 67-year-old male patient who had #36 hemisected 6 years previously. The two premolar crowns were splinted, which possibly created a difficult environment for the patient to maintain. Failure to maintain the furcation region between the roots has led to the recurrent decay and demise of the tooth. (*Courtesy: James L. Gutmann, USA.*)

Indications

- Difficulty of access for surgical endodontics especially in lower second and third molars
- When the apex of the involved tooth is in close proximity to key anatomical structures such as the mental nerve

The key prognostic variables for this procedure are that the tooth should be extracted in an atraumatic process and a minimal extraoral time should be taken to complete the process with care.

Technique

The procedure involves careful extraction of the tooth under adequate asepsis and anesthesia. Care should be exercised in ensuring that the periodontal ligament is not injured and is frequently washed with HBSS solution during the extraoral procedural time. The root resection and retrofilling is done with ultrasonic tips and MTA. The tooth is then reinserted into the socket and the buccal and lingual cortical plates are manually compressed. A semirigid temporary splint is then placed to stabilize the tooth. Regular follow-up of such cases is important to ascertain the status of such teeth (**Figs 22.31** and **22.32**).

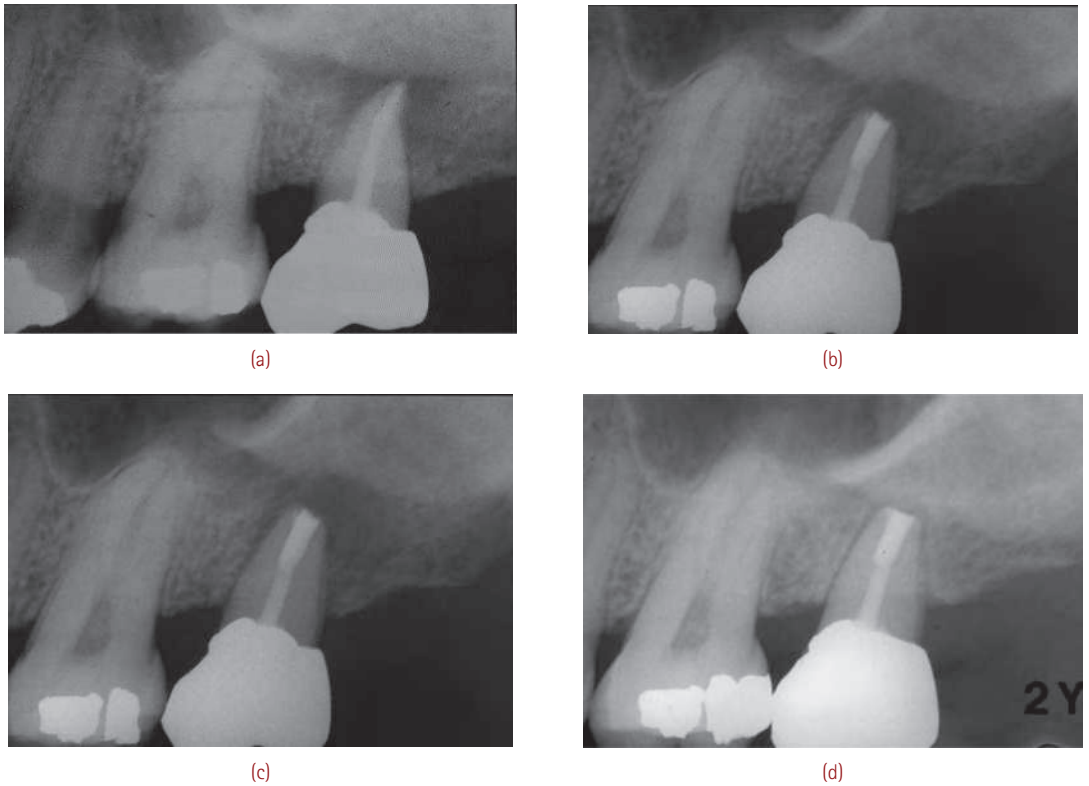


Figure 22.31 Intentional replantation in a maxillary second molar with 2-year follow-up: (a) Preoperative image. (b) Intentional replantation completed. (c) Six-month follow-up. (d) Two-year follow-up. (*Courtesy: S. Kratchman, USA.*)



(a) (b) (c)

Figure 22.32 Intentional replantation in a mandibular second molar with 6-year follow-up: (a) Preoperative image. (b) Postoperative view. (c) Six-year recall. (*Courtesy: Jason J. Hales, USA.*)

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23 Bleaching of Discolored Teeth

We live only to discover beauty. All else is a form of waiting.
—Kahlil Gibran

Esthetics is an important factor in a patient's decision to undergo endodontic treatment. A frequent question is, "Will my tooth turn black?" The usual response is a "qualified no," with the explanation that modern treatment and procedures are designed to avoid crown staining and tooth discoloration. Nevertheless, teeth can and do discolor, sometimes before endodontic treatment and sometimes afterward, in spite of all precautions taken to prevent color changes. When teeth discolor, bleaching should be considered as a means of restoring tooth esthetics.

The color of teeth is determined by the translucency and thickness of the enamel, the thickness and color of the underlying dentin, and the color of the pulp. Alterations in the color may be physiologic or pathologic and endogenous or exogenous in nature.

With age, the enamel becomes thinner because of abrasion and erosion, and the dentin becomes thicker because of the deposition of secondary and reparative dentin, which produce color changes in teeth during one's life.

Clinical Note

- The normal color of primary teeth is bluish white.
- The color of permanent teeth is grayish yellow, grayish white, or yellowish white.
- Teeth of elderly persons are usually more yellow or grayish yellow than those of younger persons.

CLASSIFICATION OF TOOTH DISCOLORATION

Tooth discoloration can be classified as either extrinsic or intrinsic.

I. EXTRINSIC DISCOLORATIONS

Extrinsic discolorations are found on the outer surface of teeth and are usually of local origin, such as tobacco stains. Some extrinsic discoloration, such as the green discoloration associated with the Nasmyth's membrane in children and tea and tobacco stains (**Fig. 23.1**), can be removed by scaling and polishing during tooth prophylaxis.

Extrinsic discolorations are stains that get bound to the tooth surface and for this reason can be easily removed. The



Figure 23.1 Extrinsic tobacco stains. (*Courtesy: Priya Ramani, India.*)

stains deposited on the tooth surface are a result of attractive forces which include both long-range interactions such as van der Waals and electrostatic forces and short-range interactions such as hydration forces, hydrophobic interactions, and hydrogen bonds. Other types of extrinsic discolorations, such as silver nitrate stains, are almost impossible to eliminate without grinding because the stains penetrate the surface of the crowns and are difficult to remove by chemical means alone.

In the past, extrinsic discoloration was classified as metallic or nonmetallic stains. The problem with this classification is that it does not explain the mechanism of staining and all metals do not stain the teeth. A newer classification based on chemistry of staining was put forth by Nathoo in 1997 (**Box 23.1**).

II. INTRINSIC DISCOLORATIONS

Intrinsic discolorations are due to the presence of chromogenic material within the enamel or dentin, incorporated either during odontogenesis or after tooth eruption. Intrinsic

Box 23.1

Nathoo's Classification of Extrinsic Discoloration

I. *N1 type or direct dental stain*: The colored materials (chromogens) bind to the tooth surface and cause discoloration. The color of the dental stain is same as the color of the chromogen.
II. *N2 type or direct dental stain*: The chromogen changes color after binding to the tooth.
III. *N3 type or indirect dental stain*: Colorless material or a prechromogen binds to the tooth and undergoes chemical reaction to cause a stain.



(a)



(b)

Figure 23.2 (a) Amelogenesis imperfecta. (b) Dentinogenesis imperfecta.

colors are determined by the optical properties of the enamel and dentin and their interaction with light. If incorporated into the dentin, they become visible because of the translucency of the enamel. They can be related to periods of tooth development, as in amelogenesis imperfecta (**Fig. 23.2a**) or dentinogenesis imperfecta (**Fig. 23.2b**), or they may be acquired after completion of tooth development, as in pulp necrosis.

Clinical Note

- The most common pre-eruptive staining is endemic fluorosis (**Fig. 23.3**), which is caused by excessive fluoride ingestion during tooth development.
- Staining due to tetracycline administration (**Fig. 23.4**) also occurs during odontogenesis and is due to the interaction of antibiotics with hydroxyapatite crystals during mineralization phase.
- Intrinsic discolorations such as those occurring with *amelogenesis imperfecta* or *dentinogenesis imperfecta* are impossible to eliminate because they originate from the developmental defects of the enamel and dentin.
- Hematologic disorders such as *erythroblastosis fetalis*, *thalassemia*, and *sickle cell anemia* might also be caused due to intrinsic discoloration. Stains that result from pulp necrosis, however, can usually be removed by bleaching procedures.

CAUSES OF INTRINSIC TOOTH DISCOLORATION (Table 23.1)

I. Decomposition of pulp tissue



Figure 23.3 Endemic fluorosis.



Figure 23.4 Tetracycline staining of teeth.

II. Trauma
III. Excessive hemorrhage following pulp extirpation
IV. Calcific metamorphosis
V. Filling materials
VI. Endodontic materials (root canal medicaments)
VII. Aging
VIII. Iatrogenic discolorations

I. DECOMPOSITION OF PULP TISSUE (Fig. 23.5)

Decomposition of pulp tissue is probably the most common cause of tooth discoloration, particularly if the pulp is necrotic. It often goes unnoticed for some time, perhaps several months after the death of the pulp or treatment of the tooth, because of the slow formation of color-producing compounds.

Intensity of discoloration is directly related to the duration of time the pulp has been necrotic.



Figure 23.5 Tooth discoloration following dental trauma and decomposition of pulp tissue.

Table 23.1 Tooth Discoloration: Causes and Colors (Abbott, 1997)

Cause of Tooth Discoloration	Color
Extrinsic discoloration	
Cigarettes, pipes, cigars, chewing tobacco, marijuana	Yellow-brown to black Dark brown to black rings
Coffee, tea, foods	Brown to black
Poor oral hygiene	Yellow or brown shades
Extrinsic and intrinsic discoloration	
Fluorosis	White, yellow, brown, gray, black
Aging	
Intrinsic discoloration	
Genetic conditions	
Amelogenesis imperfecta	Brown, black
Dentinogenesis imperfecta	Brown, blue
Systemic conditions	Blue-green, brown, purple-brown
Jaundice	
Porphyria	
Medications during tooth development	Brown, gray, black
Tetracycline	
Fluoride	
Body by-products	
Bilirubin	Blue-green, brown
Hemoglobin	Gray, black
Pulp changes	
Pulp canal obliteration	Yellow
Pulp necrosis	
With hemorrhage	Gray, black
Without hemorrhage	Yellow, gray-brown
Iatrogenic causes	
Trauma during pulp extirpation	Gray, black
Tissue remnants in pulp chamber	Brown, gray, black
Restorative dental materials	Brown, gray, black
Endodontic materials	Gray, black

II. TRAUMA

Traumatic injury of a tooth may cause the blood vessels in the pulp to rupture, with diffusion of blood into the dentinal tubules. Such teeth have a *dark pinkish hue* almost immediately after the accident (**Fig. 23.6**) and turn *pinkish brown* some days afterward. The discoloration persists even after the pulp is extirpated or if the pulp recovers. Particularly in young people, the pigment resulting from the breakdown of the erythrocytes in the dentinal tubules persists, causing discoloration of the crown. Usually, however, the pulp succumbs to trauma, and as a result, the hemoglobin breaks down, with the formation of various colored compounds such as hemin, hematin, hematoidin, hematoporphyrin, and hemosiderin. At times, hydrogen sulfide produced by bacteria combines with the hemoglobin to darken the tooth.



Figure 23.6 Pink discoloration following trauma.

III. PULPAL HEMORRHAGE DURING EXTIRPATION

Discoloration of the tooth may occur if hemorrhage is excessive during pulp extirpation. Staining of the crown of the tooth through the pulp chamber following profuse pulpal bleeding is common. When hemorrhage persists, it usually indicates that a vital pulp fragment is still present in the root canal. Hemorrhage ceases on removal of the pulp remnant. The pulp chamber and root canal should be thoroughly irrigated, to prevent discoloration, by removing blood elements from the dentinal tubules.

IV. CALCIFIC METAMORPHOSIS

Calcific metamorphosis is a condition characterized by rapid deposition of hard tissue within the root canal. This is usually seen in the anterior teeth following trauma. In certain traumatic injuries, there is transient disruption of blood supply causing destruction of odontoblasts. These are replaced by cells of the undifferentiated mesenchyme that lay down tertiary dentin. As a result, the tooth becomes more opaque due to the loss of translucency.

V. FILLING MATERIALS

Discoloration from filling materials depends on the kind of filling used. Silver amalgam produces a stain ranging from slate gray to dark gray; copper amalgam produces a bluish black to black stain; stains from amalgam are likely to occur when the dentinal wall is thin, and the filling material almost shimmers through the enamel. Microleakage of the old resin composite restorations might cause dark discoloration of the margins and may stain the dentin over time. Metal post can be seen through the translucent enamel or may release metallic ions causing discoloration. Fewer discolorations from amalgam fillings are seen nowadays because the dentinal walls are covered with liners and improvements

in the refining process of silver alloy and mercury have produced materials of greater purity.

Clinical Note

Fewer than 5% of treated pulpless teeth become noticeably discolored because of dehydration of the tooth substance with subsequent loss of translucency. Of these, most respond satisfactorily to bleaching. This concept is borne out by evaluation of bleached teeth observed over a 1- to 5-year period.

VI. ROOT CANAL MEDICAMENTS

Certain root canal medicaments may cause discoloration. Some stain the tooth directly, whereas others stain only on decomposing or combining with some other agents used in endodontic treatment; e.g., essential oils form resinous substances that discolor the tooth structure. Although some medicaments stain almost immediately, the effect of others may not be apparent for some time.

VII. AGING

During natural aging process, the physiological deposition of secondary dentin affects the light-transmitting properties of teeth, resulting in a more opaque hue of the tooth color (**Fig. 23.7**).

VIII. IATROGENIC DISCOLORATIONS

Tooth discolorations caused by certain dental materials or inappropriate operating techniques do occur; such dentist-related discolorations are usually preventable and efforts should be made to avoid them.

Clinical Note

- The prognosis for bleaching of a discolored pulpless tooth is good when the discoloration is due to the products of pulp decomposition, food debris, or chromogenic bacteria that gain access to the dentinal tubules.
- Dark blue–gray, tetracycline-stained teeth are considerably more difficult to treat than are the teeth with mild yellow–orange discolorations.
- Studies indicate that permanent teeth in adults also can experience a graying discoloration as a result of long-term exposure to minocycline, a tetracycline analogue.



Figure 23.7 Age-related yellowing of teeth.

BLEACHING

Definition: *Bleaching may be defined as the lightening of the color of the tooth through the application of a chemical agent to oxidize the organic pigmentation in the tooth.*

BLEACHING AGENTS

The goal of bleaching procedure is the restoration of normal color to a tooth by decolorizing the stain with a powerful oxidizing agent known as bleaching agent. The most commonly employed bleaching agents are as follows:

A. Hydrogen peroxide
B. Sodium perborate
C. Carbamide peroxide
D. Over-the-counter (OTC) agents

A. Hydrogen Peroxide

Hydrogen peroxide used in dentistry as a whitening agent ranges in concentration between 5 and 35%. Peroxides can be classified into organic and inorganic. They are strong oxidizers and can be considered as the products of hydrogen peroxide (H_2O_2) when hydrogen atoms are substituted with metals (inorganic peroxide) or with organic radicals (organic peroxide).

Mechanism of Action

H_2O_2 has a low molecular weight and hence can penetrate dentin and release oxygen that breaks down the double bond of inorganic and organic compounds inside the tubule.

Properties

- It is a clear, colorless, odorless liquid, stored in lightproof amber bottles.
- It is unstable and should be kept away from heat, which could cause it to explode.
- It should be stored in sealed refrigerated containers where it retains sufficient potency for approximately 3–4 months, but it decomposes readily in an open container and in the presence of organic debris.
- Care should be exercised when handling H_2O_2 because its ischemic effect on the skin and mucous membrane causes a chemical burn. It is especially painful if it comes in contact with the nail bed or the soft tissue under the fingernail.
- Because the amount needed for a bleaching operation is about 1–2 mL, the solution can be dispensed into a clean dappen dish.
- Once treatment has been completed, any remaining solution should be discarded.

Clinical Note

- H_2O_2 can be used alone or mixed with sodium perborate into a paste for use in the "walking bleach technique."
- H_2O_2 concentrations ranging from 3 to 7.5% are used for home bleach.

B. Sodium Perborate

Sodium perborate is a stable, white powder, normally supplied in a granular form that has to be ground into a powder before using.

Types

There are three forms of sodium perborate which vary in their oxygen content:

i. Sodium perborate monohydrate
ii. Sodium perborate trihydrate
iii. Sodium perborate tetrahydrate

Mechanism of Action

The powder is water-soluble. When mixed into a paste with Superoxol, this paste decomposes into sodium metaborate, water, and oxygen.

Sodium perborate → Sodium metaborate + hydrogen peroxide + O_2

Clinical Note

When sealed into the pulp chamber, sodium perborate oxidizes and discolors the stain slowly, continuing its activity over a longer period of time. This procedure is called the *walking bleach technique*.

C. Carbamide Peroxide

It is also known as urea hydrogen peroxide. Its concentration ranges from 3 to 45% depending on at-home and in-office bleach. The most popular commercial preparations have a concentration of *10% carbamide peroxide*.

Mechanism of Action

Carbamide peroxide → Urea + ammonia + carbon dioxide + 3.5% hydrogen peroxide

Additives in gel preparation include glycerine or propylene glycol, sodium stannate, phosphoric or citric acid, and flavoring agents. Some preparations contain Carbopol, a water-soluble polyacrylic acid polymer, which is added as a thickening agent. It prolongs the release of active peroxide and improves the shelf life.

D. Over-the-Counter Bleaching Agents (Fig. 23.8)

OTC bleaching agents that are being marketed include tray systems, trayless systems, chewing gums, tooth pastes, bleaching strips, and paint-on products. The scientific rationales behind such systems are not justified because the cause of tooth discoloration is diverse. These products primarily work by removing extrinsic surface stain only.

MECHANISM OF BLEACHING

The principle mechanism involved in bleaching is that the oxidizing agent reaches the sites within the enamel and dentin to allow a chemical reaction to occur between the discolored segment and the active ingredient.

Hydrogen peroxide has a low molecular weight that enables it to diffuse through the enamel matrix. The free



(a)



(b)



(c)

Figure 23.8 Over-the-counter bleaching agents: (a) Toothpaste, (b) chewing gum, and (c) bleaching pen.

radicals interact with organic molecules to attain stability. Bleaching agent opens the more highly pigmented carbon ring (yellow color) and converts it to carbon chains. When the carbon double bonds are converted to hydroxyl groups, the amount of light absorbed is reduced. Hence, the tooth appears lighter in color. If the bleaching process is allowed to continue beyond this point, then the organic matrix of the tooth is broken down, resulting in weakening of the tooth structure and postoperative sensitivity. Saturation point is that point at which only hydrophilic colorless tooth structure exists. Bleaching beyond this point results in the breakdown of the organic matrix resulting in weakening of the enamel and surface porosities.

The mechanism of carbamide peroxide used in home bleach is essentially similar to that of hydrogen peroxide excepting for the initial step. When carbamide peroxide is introduced in the mouth, it breaks down to urea and hydrogen peroxide. Urea is responsible for maintaining an alkaline environment (pH 8) which potentiates the action of hydrogen peroxide. Ten percent carbamide peroxide releases approximately 3.4% hydrogen peroxide and 6.5% urea. The mechanism of bleaching is given in **Box 23.2**.



Clinical Note

- Bleaching generally has an approximate life span of 1–3 years, although the change may be permanent in some situations.
- With all bleaching techniques, a transitory decrease occurs in the potential bond strength of the composite when it is applied to the bleached enamel and dentin. This reduction in the bond strength results from the residual oxygen or peroxide residue in the tooth that inhibits the setting of the bonding resin, precluding adequate resin tag formation in the etched enamel.
- No loss of bond strength is noted if the composite restorative treatment is delayed at least *1 week* after cessation of any bleaching.

Box 23.2

Mechanism of Bleaching

Redox reaction

Tooth (reducing agent takes up electrons) + Bleaching agent (oxidizing agent gives free electrons)

↓

Free reactive radicals react with the unsaturated bonds

↓

Larger stain molecules are converted into smaller ones

↓

Simpler molecules are formed

↓

Reflects less light or becomes colorless

FACTORS AFFECTING BLEACHING

- *Surface cleanliness:* Clean enamel surface is important to distinguish between intrinsic and extrinsic stains. Moreover, debris on the surface minimizes the contact of the bleaching agent with the tooth surface.
- *Concentration of peroxide:* The effect of bleaching is increased with the increase in the concentration of peroxide. In-office bleaching employs 35% hydrogen peroxide, which is more caustic in nature. The usual concentration of at-home bleaching is 10% carbamide peroxide, which is relatively safe in contact with the soft tissues. Due to the differences in the concentration, at-home bleaching would require more sessions of bleaching than the in-office technique.
- *Shelf life:* Carbamide peroxide is more stable than hydrogen peroxide and has a shelf life of 1–2 years, while hydrogen peroxide has a shelf life of few weeks.
- *Temperature:* This is of importance during in-office bleaching. Increase in temperature accelerates the release of oxygen free radicals. The reaction gets doubled with an increase of 10°C. However, an increase in the temperature to an uncomfortable level causes tooth sensitivity and irreversible pulpal damage. Local anesthesia should not be administered during bleaching.
- *pH:* Hydrogen peroxide is active in alkaline pH. The optimum pH for hydrogen peroxide ranges from 9.5 to 10.8.
- *Time:* Concentration of the bleaching agent and the time of contact with the tooth are the most important factors in effective bleaching. Increased contact time increases the bleaching efficacy. However, prolonged contact results in tooth sensitivity.
- *Sealed environment:* This is of relevance in nonvital tooth bleaching. Hydrogen peroxide sealed in the access cavity maintains the required concentration for active bleaching.
- *Additives:* In order to increase the viscosity of the bleaching material, additives such as glycerine, glycol, and toothpaste-like materials are added. These agents may reduce the efficacy of the bleaching material.
- *Other factors* such as age of the patient, initial color of the tooth, and gender may also play a role in the bleaching process.

CLASSIFICATION OF BLEACHING PROCEDURES (Table 23.2)

Table 23.2 Clinical Classification for Various Conventional Bleaching Procedures

I.	*Intracoronal bleaching (bleaching of endodontically treated tooth/nonvital bleaching)*
	1. Walking bleach technique
	2. In-office thermocatalytic bleach
II.	*Extracoronal bleaching (vital tooth bleaching)*
	1. In-office vital bleach
	2. At-home vital bleach

A. INTRACORONAL BLEACHING (BLEACHING OF AN ENDODONTICALLY TREATED TOOTH/ NONVITAL BLEACHING)

i. Walking Bleach Technique

Preparation

Prior to bleaching a tooth, one should examine and evaluate the condition of its crown and the status of its obturated root (**Table 23.3**). The crowns of teeth to be bleached should be relatively intact. Crowns weakened by an access preparation and with large or multiple restorations or large carious lesions are not recommendable for bleaching. These teeth should be restored with a post and core and a full-veneer porcelain crown for the best functional and esthetic result.

The root canal filling should be well condensed, radiopaque, with no voids, and well adapted to the root canal walls to prevent percolation of the bleaching solution into the periradicular tissues. The quality of obturation should be confirmed with a radiograph. If the canal is obturated with a silver cone, the cone should be replaced with a well-condensed gutta-percha filling, before bleaching is attempted.

Method

- Prepare the tooth for bleaching by polishing the enamel surface with a prophylaxis paste to remove any gross surface debris or discolorations (**Fig. 23.9**).
- Apply petroleum jelly to the gingival tissues around the tooth to be bleached for protection against tissue irritation. H_2O_2, in contact with the skin or mucous membrane, may cause severe discomfort.
- Adapt the rubber dam, invert it, ligate it with wax dental floss, and hold it securely in place with a clamp on the tooth to be bleached.
- Re-establish the access cavity.
- Remove any gutta-percha root canal filling that extends into the pulp chamber with a hot finger plugger or Gates-Glidden drill to the level of the crest of the alveolar bone. The remaining root canal filling should be vertically condensed with finger pluggers to *1 mm apical to the cementoenamel junction*. This can be confirmed with the help of a periodontal probe placed in the pulp cavity and reproducing the same probing depth in the gingival sulcus.

Table 23.3 Indications and Contraindications for Walking Bleach Technique

Indications	Contraindications
• Discoloration of pulp chamber	• Superficial enamel discoloration
• Dentin discoloration	• Defective enamel formation
• Discolorations not amenable to extracoronal bleaching	• Severe dentin loss • Presence of caries • Discolored composites

- Examine the pulp chamber and remove any residual debris or stains in the pulp horns and along the incisal edge of the pulp cavity with a small round bur in a slow-speed contra-angle.
- Seal the orifice of the root canal with at least *1 mm intracoronal barrier* over the gutta-percha to prevent percolation of the bleaching agent into the apical area. Glass ionomer cement, resin-modified glass ionomer (RMGI) cement, Cavit, or mineral trioxide aggregate (MTA)/ tricalcium silicate cements can be used as barrier materials; of these, *MTA*/tricalcium silicate cements *have been shown to be superior*. It is important to confine the bleaching agents to the crown of the tooth above the level of the bone. Since cervical root resorption has been reported following bleaching, it is proved that keeping the bleaching agents from the cervical area of the root canal may prevent cervical resorption.
- Protect the exposed areas of the patient's face by draping it and cover the patient's eyes with glasses. The patient's clothing should be covered with a plastic apron. The operator should wear gloves to protect his/her hands.
- Mix *sodium perborate powder with distilled water*. In case of severe stains, *3% hydrogen peroxide* can be used to form a thick paste in a clean dappen dish.
- Carry the thick paste into the pulp chamber with a plastic instrument or amalgam carrier. Make sure the entire facial surface of the pulp chamber is covered with the paste.
- Place a small cotton pellet, slightly moistened with H_2O_2, over the bleaching paste.
- Seal the access cavity to a *thickness of 3 mm* using an adhesive material. This ensures a tight seal around the margins and prevents the leaching of bleaching material. If materials like intermediate restorative materials are used, then apply pressure with the gloved finger against the tooth until the filling has set. This is to ensure that the temporary filling is not displaced with the liberation of oxygen.

The maximum bleaching effect is attained about 24 hours after the treatment. The patient should return in 3–7 days for evaluation of the result. If the shade is too dark, additional bleaching is necessary. If the shade is too light, the tooth should be permanently restored. Teeth that are bleached a shade too light seem to revert to their former color shortly after bleaching. This phenomenon may be associated with the ingress of pigmenting substances from the saliva into the dentin by way of the enamel, whose permeability may have been increased by the bleaching process. Generally, two treatments, performed about a week apart, are necessary to attain the desired shade, although in some cases a single treatment is sufficient (**Fig. 23.10**).

Through the years, other techniques have been used to bleach pulpless teeth. These techniques differ only in the method used to activate the H_2O_2 to liberate the bleaching agent, oxygen. Whereas the walking bleach uses the reaction of sodium perborate with H_2O_2 to liberate the bleaching agent, the other techniques use heat and light.

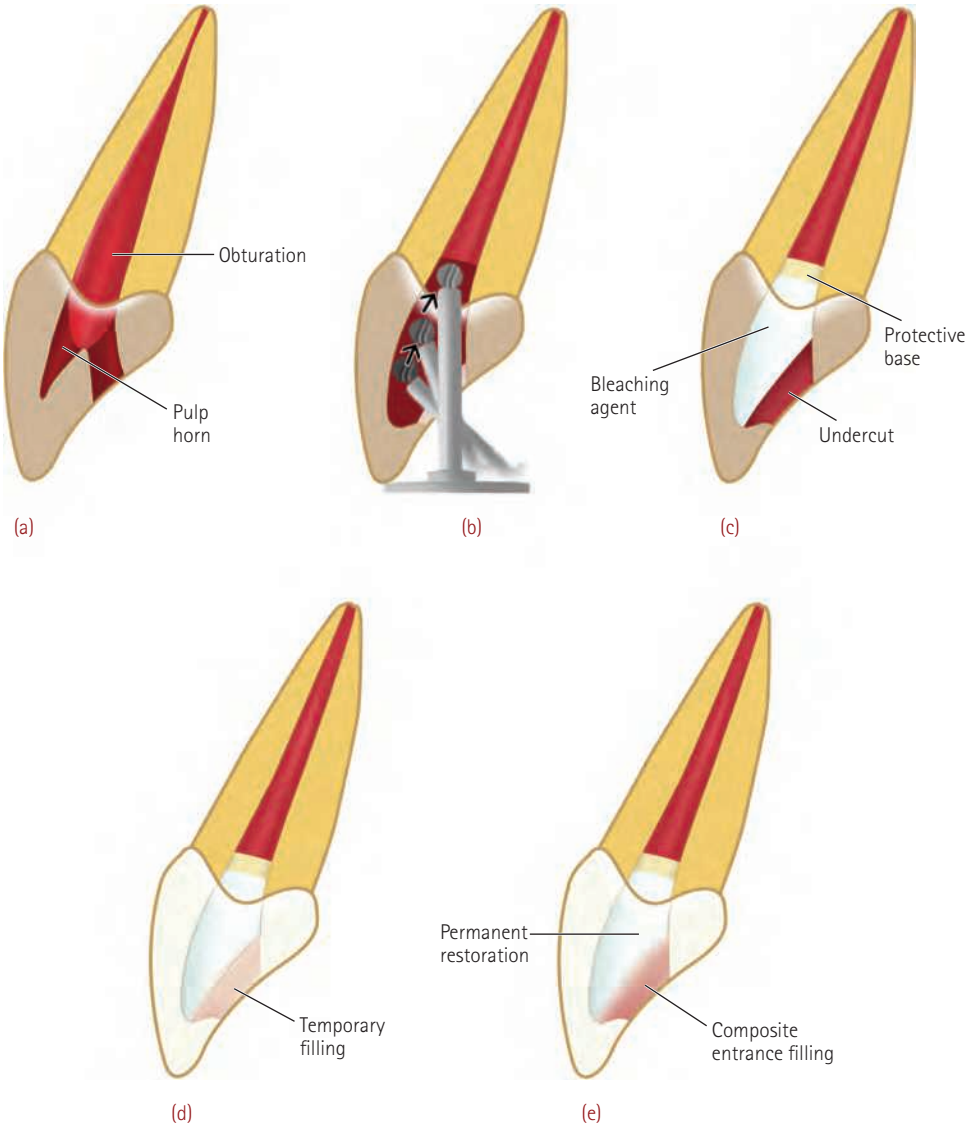


Figure 23.9 Walking bleach: (a) Internal staining of the dentin caused by the remnants of obturating materials in the pulp chamber, as well as by materials and tissue debris in the pulp horns. (b) Coronal restoration is removed completely, access preparation is improved, and gutta-percha is removed apically to just below the cervical margin. Next, the pulp horns are cleaned with a round bur. (Shaving a thin layer of dentin from the facial wall is optional and may be attempted at later appointments if discoloration persists.) (c) A protective cement base is placed over the gutta-percha, not extending above the cervical margin. After removal of sealer remnants and materials from the chamber with solvents, a paste composed of sodium perborate and water (mixed to the consistency of wet sand) is placed. The incisal area is undercut to retain the temporary restoration. (d) A temporary filling seals the access. (e) At a subsequent appointment, when the desired shade has been reached, a permanent restoration is placed. Acid-etched composite restores lingual access and extends into the pulp horns for retention and to support the incisal edge.



Figure 23.10 (a) Grayish-brown discoloration caused by trauma. (b) Results of walking bleach after 3 weeks.

Clinical Note

- Although nonvital bleaching is effective, a slight potential exists for a deleterious side effect termed *external cervical resorption*. Cervical resorption has been observed most when using a thermocatalytic technique with high heat.
- The walking bleach technique or an in-office technique that does not require the use of heat is preferred for nonvital bleaching.
- To reduce the possibility of resorption, immediately after bleaching, *a paste of calcium hydroxide* powder and sterile water is placed in the pulp chamber.
- Also, sodium perborate alone, rather than in conjunction with hydrogen peroxide, should be used as the primary bleaching agent. Although sodium perborate may bleach more slowly, it is safer for the tooth.
- Periodic radiographs should be obtained after bleaching to screen for cervical resorption, which generally has its onset in 1–7 years.

ii. Bleaching of Endodontically Treated Teeth in Office (Heat-and-Light/Thermocatalytic Bleaching)

- After preparation of the tooth as previously described, a loose mat of cotton is placed on the labial surface and another is placed in the pulp chamber of the tooth to be bleached.
- The loose cotton mats are saturated with *30% H_2O_2*.
- The solution is activated by exposing it to light and heat from a powerful light.
- The tooth is subjected to several, usually 5- to 6-minute exposures and the bleaching solution is replenished at frequent intervals.
- On completion of the bleaching process, a pellet of cotton moistened with H_2O_2, or H_2O_2 and sodium perborate, is sealed in the pulp chamber until the following appointment.

An alternative to activate the H_2O_2 is the application of a thermostatically controlled electric heating instrument or a stainless steel instrument heated over a flame. Heat and light from a photoflood light aimed directly on the tooth from a distance of 2 feet or more also activate H_2O_2. Wisps of cotton, moistened with H_2O_2, hold the bleaching agent inside the tooth chamber and on the labial and lingual surfaces of the crown. H_2O_2 is added to the cotton every 5 minutes during the bleaching process. The techniques can be used by themselves or in combination with the walking bleach.

Clinical Note

- An in vitro study comparing the bleaching of teeth with H_2O_2 and heat for 12 minutes in comparison with a paste of H_2O_2 and sodium perborate for 7 days, or a combination of the two techniques, showed no significant differences in bleaching efficacy.
- Since the clinical results of both these techniques do not appear to differ, the *walking bleach technique*, which is easy to perform, consumes the least time, and requires no special equipment, is the method of choice.
- It is imperative that *a sealing cement* (RMGI cement is recommended) be placed over the exposed root canal filling before application of the bleaching agent to prevent leakage and penetration of the bleaching material in an apical direction.
- It is also recommended that the bleaching agent be applied in *the coronal portion of the tooth* incisal to the level of the periodontal ligament (not down into the root canal space) to prevent unwanted leakage of the bleaching agent through the lateral canals or canaliculi to the periodontal ligament.

Adverse Effects of Intracoronal Bleaching

- *External root resorption:* There have been reports of external cervical root resorption following intracoronal bleaching procedures. This is probably caused due to the diffusion of hydrogen peroxide through unprotected dentinal tubules leading to resorptive changes in the periodontium. The caustic nature of hydrogen peroxide can cause the necrosis of the cementum and the periodontium, which in turn results in initiation of inflammation and subsequent resorption. Resorptive process may be worsened with the application of heat for bleaching agent activation. Hence, application of an appropriate intracoronal barrier is mandatory for intracoronal bleaching procedures.
- *Chemical burn:* Superoxol is highly caustic in nature and can result in chemical burns and sloughing of gingival tissue. Hence, the gingiva must be protected with petroleum jelly, Orabase, or cocoa butter.
- *Inhibition of resin polymerization:* The residual oxygen following bleaching procedure adversely affects the bonding and polymerization of composite resins. It is prudent to completely eliminate residual hydrogen peroxide before restoring the tooth with composite. *Sodium ascorbate* is a buffered form of vitamin C that consists of 90% ascorbic acid bound to 10% sodium—a powerful antioxidant useful in eliminating residual oxygen following bleaching.

B. EXTRACORONAL BLEACHING (VITAL TOOTH BLEACHING)

i. Bleaching of Vital Teeth in Office

This technique generally uses *35% hydrogen peroxide solution* that is directly placed on the teeth. The bleaching agent is commercially available in the form of gel that prevents running of the material on application (**Fig. 23.11**). This may involve the application of heat and/or light to activate the bleaching agent, hence called *thermocatalytic bleaching*. With this technique, patient compliance is not a major factor since effective results can be obtained in two to three visits.

Indications

- Discolored teeth as a result of mild fluorosis, and tetracycline stains



Figure 23.11 In-office bleaching system. (*Courtesy: Ultradent Products Inc.*)

- In severe discolorations, bleaching could be performed to lighten the tooth color before restoration with bonded resin or porcelain veneers or crowns
- In order to match the existing color of the crown that is lighter than the natural teeth

Contraindications

- Superficial stains that can be removed with rubber cup and prophylaxis paste
- Carious tooth structure or dark-colored resin restoration
- Hypersensitive teeth
- Children with large pulp chamber
- Pregnant and lactating women
- Exposed root surfaces

Procedure

- Take a radiograph to detect the presence of caries, defective restorations, and proximity to pulp horns. Well-sealed small restorations and minimal amounts of exposed incisal dentin are not usually a contraindication for bleaching.
- Evaluate the tooth color with a shade guide and take clinical photographs before and throughout the procedure (**Fig. 23.12a–23.12f**).
- Protect the gingival tissues with Orabase or Vaseline and isolate the teeth with a rubber dam.
- Do not inject a local anesthetic.
- Place protective sunglasses over the patient's and the operator's eyes.
- Clean the enamel surface with pumice and water.
- Apply 30–35% hydrogen peroxide liquid on the labial surface of the teeth using a small cotton pellet or a piece of gauze. A bleaching gel containing hydrogen peroxide may be used instead of the aqueous solution.
- Apply heat with a heating device or a light source. The temperature should be maintained between 125 and 140°F (52–60°C).
- The treatment time should not exceed 30 minutes even if the result is not satisfactory. Remove the heat source and allow the teeth to cool down for at least 5 minutes.
- Pumice is used on the teeth to remove the residual exposed gel from the enamel surface.
- Remove the bleaching agent and irrigate thoroughly.
- Dry the teeth and gently polish them with a composite resin polishing cup. Apply neutral sodium fluoride gel for 3–5 minutes.
- Instruct the patient to use a fluoride rinse daily for 2 weeks.
- Any bonded restoration on bleached surfaces must be postponed by 7–10 days.

Laser or Light-Assisted Power Bleaching

Dental lasers and other powerful light sources (**Fig. 23.13**) have been used to enhance the bleaching action. The light-curing systems generate heat to activate the bleaching agent. The heat causes *rapid dissociation* of *hydrogen peroxide* potentiating bleaching effect. Lasers principally work by activating the catalyst of the bleaching agent which in turn causes the release of *nascent oxygen*. These systems should be used with caution since they can induce severe postoperative sensitivity.

Clinical Note

- Polymethyl methacrylate restorations exhibit a yellow–orange discoloration on exposure to carbamide peroxide. For this reason, temporary crowns should be made from bis-acryl materials, rather than from polymethyl methacrylate crown and bridge resin, if exposure to carbamide peroxide is anticipated.
- As hydrogen peroxide has such a low molecular weight, it easily passes through the enamel and dentin. This characteristic is thought to account for the *mild tooth sensitivity* occasionally experienced during treatment. This effect is transient, however, and no long-term harm to the pulp has been reported.

ii. Bleaching of Vital Teeth at Home

At-home bleaching is the more commonly used technique because it is easy to perform and usually less expensive for the patient. It uses a custom-fit tray with 10% carbamide peroxide. Carbamide peroxide is more stable than hydrogen peroxide and can be active up to several hours.

This technique requires methodical documentation and execution of the following things:

- Dental and medical history (**Table 23.4**)
- Clinical examination
- Radiographs of the teeth to be treated
- Impression of the dental arches for the construction of bleaching tray
- Recall visits to assess progress and compliance



(a) (b) (c) (d) (e) (f)

Figure 23.12 (a) Documentation with photographs and shade tab. It is often difficult to ascertain tooth shade when hypoplastic bands are present. In these situations, the cervical tooth color is recorded. (b) Perform oral prophylaxis and clean the enamel surface using pumice slurry to remove surface debris. (c) Application of gingival liquid dam to prevent chemical burn. (d) Bleaching gel applied on the labial surfaces of teeth and activated using laser light to catalyze the bleaching reaction. (e) Immediate postbleaching appearance. (f) One week after in-office bleaching procedure and postbleaching care using CPP-ACP. Note the change of tooth color indicated by the shade tab. (*Courtesy: Krithika Datta, India.*)



Figure 23.13 Power bleaching lamp.

Table 23.4 Indications and Contraindications for Home-Administered Vital Teeth Bleaching

Indications	Contraindications
• Superficial enamel discolorations	• Severe enamel loss
• Mild yellow discolorations	• Hypersensitive teeth
• Brown fluorosis discolorations	• Bruxism
• Age-related discolorations	• Presence of caries • Defective coronal restorations • Allergy to bleaching gels

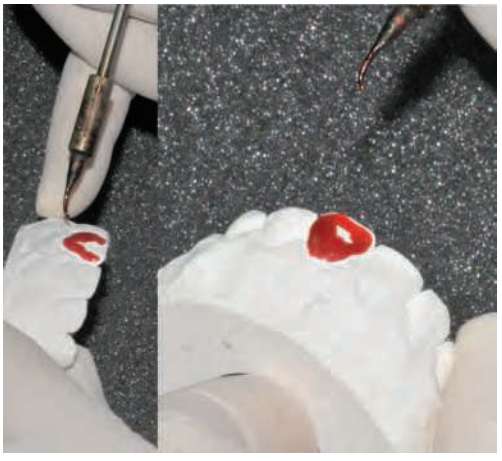
Tray Fabrication

This involves the fabrication of a vacuum pressed tray over the dental casts by the following steps (**Fig. 23.14a–23.14g**):

- Upper and lower alginate impressions are made in the first visit and casts are poured. The base of the cast should be trimmed to a thickness of 0.5 inch, leaving only the maxillary and mandibular teeth. The vestibular region, palatal surface, and tongue should be eliminated. This helps in better adaptation of the tray material.
- Reservoirs can be placed on the labial surface of the teeth to provide space for the bleaching agent. They are formed



(a)



(b)



(c)

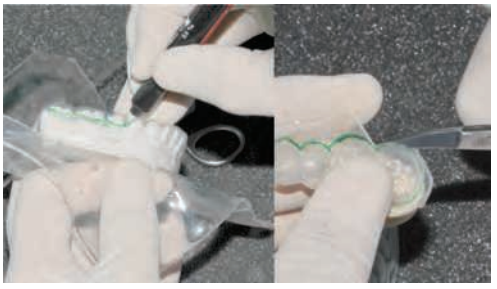


(d)

Figure 23.14 (a) Upper and lower casts trimmed to maintain a base height of 10–12 mm. (b) Reservoirs are formed on the labial surfaces of the teeth. (c) The margins of the reservoir should end 1 mm short of the free gingival margin. (d) The cast is duplicated using irreversible hydrocolloid impression material. *(continued)*



(e)



(f)



(g)

Figure 23.14 *(continued)* (e) The cast is placed on the vacuum-forming machine. Note that the plastic tray material is warmed from a coil above. The plastic tray material sags as it is softened. Vacuum is created at the base of the machine and adapts the tray material on the cast. (f) The free gingival margin is marked and trimmed accordingly. (g) Bleaching tray has to be tried in the patient's mouth and necessary adjustment should be made before delivering the tray. (*Courtesy: Tarek Frank Fessali, India.*)

using light-polymerized resin to a thickness of 0.5–1 mm. They can also be formed using pattern-forming wax. The reservoir should terminate 1 mm short of the free gingival margin. If wax is used to form the reservoirs, then the casts must be duplicated after the placement of reservoirs. This step is mandatory since wax reservoirs melt if placed directly in the vacuum-forming machine.

- The material used in the fabrication of the tray is a thick, semirigid plastic material. The tray is formed with the vacuum-forming machine that involves heat softening of the tray material and vacuum molding.
- The extent of the bleaching tray is dictated by the viscosity of the bleaching agent. For highly viscous material, the margins can be scalloped, terminating just incisal to the free gingival margin. If the bleaching agent is nonviscous, then the margins have to be nonscalloped and extending on to the gingival tissues.

Instructions to the Patient

- Preoperative photographs are important. Since the bleaching action occurs gradually over time, the patient might forget the original shade of the teeth.
- The fit of the bleaching tray should be checked during the delivery of the tray in the second visit. Any irritating margins should be marked and eliminated.
- The patient should be instructed to brush his/her teeth prior to the application of the tray. Any surface debris minimize the effective contact of the bleaching agent with the tooth surface.
- The patient should be instructed to place enough bleaching agent into the tray to cover the facial surfaces of the teeth. After seating of the tray, excess bleaching material extruding on to the gingival surface should be carefully wiped away.
- The tray should be worn for a time period of *4 hours for every session*. The patient should be cautioned to reduce the time period if sensitivity is experienced. Conversely, if sensitivity is not an issue, the patient can repeat the bleaching session for the second time on the same day.
- While removing the tray, the patient should be instructed to remove the tray from the second molar region in a peeling action. This avoids injury to the soft issues.
- After every bleaching session, the patient should be instructed to rinse off the bleaching agent from the surfaces of the teeth. The tray should be gently brushed to remove the bleaching agent and stored in cool or room temperature until the next use.
- The number of days required to achieve desired results is chiefly dependent on the original extent of tooth discoloration, the duration of bleaching in a day, and patient compliance. Results can be seen as early as 2–14 days or

may take as long as 6–12 months. The patient should be well informed about the treatment outcome.
- In case of uneven distribution of discoloration of teeth (e.g., fluorosis, where discoloration is not uniform), the tray can be loaded in areas corresponding to teeth that require further bleaching. Likewise, if the patient is wearing ceramic crown or crowns, then the tray is cut in that area and that particular tooth is eliminated from bleaching. Bleaching agents are known to cause etching and weakening of ceramic prosthesis.
- The patient should be instructed to maintain periodic visits to the dental clinic for assessment of the bleaching process, and this also improves patient compliance.

Clinical Note

- On the basis of numerous research studies, carbamide peroxide bleaching materials seem to be safe and effective when administered by or under the supervision of a dentist.
- The dentist may prescribe desensitizing agents to help alleviate sensitivity associated with bleaching.
- It is recommended that only one arch be bleached at a time, beginning with the maxillary arch. Bleaching the maxillary arch first allows the untreated mandibular arch to serve as a constant standard for comparison.
- Tetracycline-stained teeth typically are much more resistant to bleaching and may require several months before any results are observed. Some clinicians advocate intentional endodontic therapy along with the use of an intracoronal nonvital bleaching technique to overcome this problem.
- No single bleaching technique is effective in all cases. Often, with vital bleaching, a combination of the in-office technique and the dentist-prescribed, home-applied technique has better results than either technique used alone.

Adverse Effects of Extracoronal Bleaching

- *Tooth sensitivity:* This is a common side effect of bleaching. This occurs due to permeation of the bleaching agent into the tooth structure through the enamel microcracks, resulting in transient pulpal hyperemia. Sensitivity is directly related to the concentration of hydrogen peroxide. It is advisable not to perform bleaching in teeth exposed due to caries or defective restorative margins. Postoperative care using fluoridated mouth rinse or amorphous calcium phosphate in casein phosphopeptide (ACP-CPP) is used to promote remineralization of the enamel surface.
- *Enamel damage:* Bleaching action on the enamel may result in erosive areas and increased porosity. Caustic nature of hydrogen peroxide causes reduction in the enamel microhardness. Peroxides can cause changes in the organic–inorganic ratio rendering the enamel weak. Hence, it is advisable to follow up with the enamel remineralization protocol.
- *Gingival irritation:* This is most often seen following in-office bleaching technique due to the use of highly caustic bleaching agent coming in contact with the unprotected gingival tissue. When ill-fitted trays are used, the margins of the tray can cause gingival irritation. Such gingival lesions can be treated by copious rinsing with water. More severe chemical burns can be treated with topical application of anesthetic gels combined with good oral hygiene.
- *Mercury release from amalgam restoration:* This has been reported with extracoronal bleaching. It is not advisable to perform extracoronal bleaching for teeth with extensive amalgam restoration.

MANAGEMENT OF TETRACYCLINE-STAINED TEETH

The classification for tetracycline discoloration is given in **Box 23.3**.

The use of 30% hydrogen peroxide and a thermostatically controlled heat source for bleaching tetracycline-stained teeth has been described. Unfortunately, the discoloration is only superficial and does not affect the stained dentin. Another method of bleaching tetracycline stain has been described. In this method, the pulps of the teeth are intentionally extirpated, the root canals are cleaned, shaped, and obturated, and the teeth are internally bleached as previously described. The result in humans, as well as in dogs, has been successful. We believe that labial veneers with composite resins or even porcelain-veneer full-crown restorations are indicated instead of intentional devitalization of a tooth with a normal pulp.

Teeth discolored by tetracycline may also be bleached to some extent with hydrogen peroxide, but the bleaching effect leaves something to be desired, with regard to both discoloration and permanency, because the chemical cannot reach the real cause of the discoloration, which is the incorporation of tetracycline into the dentin. The degree of staining depends on the stage of tooth development at the time when medication is begun; the greater the amount of crown developed, the less severe the stain, and vice versa.

Clinical Note

- Minocycline has the ability to affect permanent dentition even in adults due to its ability to form complexes with the calcium in dentin. It is usually seen with long-term use for the treatment of acne.
- Destaining of the yellow color is most successful, whereas brownish teeth are least successfully bleached.

Box 23.3

Tetracycline Discoloration Classification (Jordon and Boskman, 1984)

I. *First degree:* Light yellow to light gray staining without banding
II. *Second degree:* Darker and more extensive yellow or gray staining without banding
III. *Third degree:* Severe staining characterized by dark gray or blue discoloration with banding

MICROABRASION

A number of microabrasion techniques to improve the appearance of fluorotic teeth have been described. McCloskey reported that Kane successfully removed fluorosis stains by applying acid and heat in 1916. In the 1960s, McInnes used a mixture of five parts of 36% hydrochloric acid (HCl), five parts of 30% hydrogen peroxide, and one part of ether as a topical treatment.

Croll and colleagues have described extensively the microabrasion technique using PREMA, which is an abrasive paste containing HCl, silicon gel, silicon carbide, and silica gel. The compound is polished on to the surface of the teeth using 10:1 gear reduction contra-angle on a standard slow-speed handpiece.

Box 23.4

McInnes Solution Versus Modified McInnes Solution

McInnes Solution

- *One part of anesthetic ether (0.2%):* Removes surface debris
- *Five parts of hydrochloric acid (36%):* Etch the enamel
- *Five parts of hydrogen peroxide (30%):* Bleach the enamel

Modified McInnes Solution

Comprises 20% sodium hydroxide instead of 36% hydrochloric acid. Since sodium hydroxide is highly alkaline in nature, it dissolves calcium of the enamel at a slower rate. Hence, the modified McInnes solution is considered to be a *slower but safer alternative* to the McInnes solution.

INDICATIONS

- Developmental intrinsic stains and discolorations
- Superficial surface enamel stains and opacities
- Yellow–brown stains
- Multicolored stains (brown, gray, or yellow)
- Superficial hypoplastic enamel
- Areas of enamel fluorosis
- White patches and white spot
- Decalcification lesions from stasis of plaque and from orthodontic bands
- Some irregular surface textures

CONTRAINDICATIONS

Microabrasion cannot be used for the following conditions:

- Age-related staining
- Tetracycline staining
- Deep enamel hypoplastic lesions
- Some concentric areas of hypocalcification that extend to the dentin
- Most amelogenesis imperfecta lesions
- Most dentinogenesis lesions
- Carious lesions underlying regions of decalcification
- Areas of deep enamel and dentin stains

TECHNIQUE

The technique of vital bleaching is as follows:

- A freshly prepared solution of anesthetic ether, sodium hydroxide, and hydrogen peroxide is used for bleaching. The modified McInnes solution is prepared in a clean dappen dish, as given in **Box 23.4**.
- Polish the crown with a prophylactic paste, protect the gingiva with petroleum jelly, and isolate the teeth to be bleached with a rubber dam that is carefully inverted and ligated.
- Apply the bleaching mixture on the tooth surface and gently abrade the surface using pumice in a rubber cup mounted on a slow-speed contra-angled handpiece.
- On completion of the bleaching, the solution is neutralized with a baking soda solution and copious irrigation with water.
- The bleached surface should be polished with graded abrasive disks and a prophylactic paste. This procedure may have to be repeated two or three times before the desired shade is obtained (**Fig. 23.15a–23.15c**).

MACROABRASION

This technique is indicated for the removal of localized surface stains. In macroabrasion, a *12- or 16-fluted composite finishing bur* or a *fine grit finishing diamond* in high speed is used to remove the surface defect. Light intermittent pressure is used to avoid unnecessary removal of the tooth structure. Air–water spray is recommended, not only as a coolant but also to maintain the teeth in a hydrated state. On removal of the defect, a *30-fluted composite finishing bur* is used to remove any striations on the surface. The surface is finally polished with abrasive rubber points. This technique works well when employed in conjunction with microabrasion where the former removes gross defect and the latter is used for final treatment.



Clinical Note

- Microabrasion has the advantage of ensuring better control of the removal of the tooth structure. It is considerably faster and easier than microabrasion and does not require the use of a rubber dam or special instrumentation.
- High-speed instrumentation used in macroabrasion is technique sensitive and can have catastrophic results if the clinician fails to use extreme caution. Microabrasion is recommended over macroabrasion for the treatment of superficial defects in children because of better operator control and superior patient acceptance.
- To accelerate the process, a combination of macroabrasion and microabrasion may also be considered.
- Gross removal of the defect is accomplished with macroabrasion, followed by final treatment with microabrasion.



(a) (b) (c)

Figure 23.15 (a) Enamel fluorosis. Isolated dark brown stains pose a problem for tooth-veneering procedures. (b) Appearance following first sitting of microabrasion using modified McInnes solution and fine grit abrasive disks. (c) Microabrasion was repeated after 2 weeks. Note the acceptable lightening of the stains. Final esthetic appearance can be achieved by composite resin veneering.

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24 Lasers in Endodontics

We can easily forgive a child who is afraid of the dark; the real tragedy of life is when men are afraid of the light.
—Plato

Numerous researchers have investigated laser applications in dentistry in the past five decades. Research and development has led to a multitude of lasers in both type and means of delivery systems. With a better understanding of biological tissue responses, the possibilities of a clinician using lasers in a range of endodontic procedures have increased, varying from pulpal diagnosis, pulpotomy, root canal disinfection, and retreatment to root resection.

CHRONOLOGY OF LASER DEVELOPMENT

- 1916—Albert Einstein: Theory of spontaneous emission of radiation
- 1953—Charles Townes: Microwave amplification by the stimulated emission of radiation (MASER)
- 1960—Theodore Maiman: Ruby laser
- 1964—Stern, Sognnaes, and Goldman: Lasers in dentistry
- 1971—Weichman and Johnson: Lasers in endodontics
- 1979—Adrian and Gross: Argon laser sterilization of dental instruments
- 1985—Shoji et al.: Laser-aided pulpotomy
- 1986—Zakariasen et al.: Sterilization of root canals
- 1988—Miserendino: Apicectomy with CO_2 laser
- 1990—Potts and Petrou: Laser-aided photopolymerization of camphoroquinone-activated resins
- 1993—Paghdiwala: Er:YAG lasers for root resection and retrograde cavity preparation
- 1994—Morita: Nd:YAG lasers in endodontics
- 1998—Mazeki et al.: Root canal shaping with Er:YAG laser

BASICS OF LASER PHYSICS

LASER is an acronym for *light amplification by the stimulated emission of radiation*. Light is a form of electromagnetic energy that travels at a constant velocity in the form of waves. The basic unit of light is termed *photon*, which means a particle of light. Ordinary light, as produced by the sun or a table lamp, is a sum of many types of photons or light waves that are diffused and not focused. Photons are released when an atom in its ground state absorbs energy, gets excited, and moves to a higher energy state. The release of photon is spontaneous in nature and hence termed *spontaneous emission*.

This is accompanied by neighboring atoms producing waves that are not in phase with one another, thereby having varying wavelengths and amplitude. The light waves produced are noncoherent and polychromatic.

Two photons are released if additional quantum of energy is absorbed by an already excited atom. The energy is emitted, or radiated, as identical photons, traveling as a coherent wave. These photons can energize more neighboring atoms, which would emit additional identical photons, resulting in an amplification of the light energy, producing a *laser beam*.

The generation of a laser beam requires an active medium containing a collection of atoms or molecules. The medium can be a solid, liquid, or gas, contained in a ceramic or glass tube. Applying an electric current or a flash lamp energizes this medium, thereby starting a stimulated emission of radiation. When the atoms in the energized state become more in number than those in the ground state, a *population inversion* occurs. These photons can be directed with the help of mirrors, and this coherent, collimated beam of laser light can be delivered to the target tissue. **Figure 24.1** illustrates the principal components of a LASER device.

CHARACTERISTICS OF A LASER BEAM

- *Monochromatic* (in other words, a single wavelength)*:* The laser light has one specific color
- *Collimated:* Having specific spatial boundaries and a very low divergence, ensuring a constant size and shape of the beam
- *Coherency:* Indicates that the light waves produced by a laser have a specific form of electromagnetic energy and are in phase with one another
- *Intense* in nature



Clinical Note

All available dental laser devices have emission wavelengths from approximately 0.5 µm (or 500 nm) to 10.6 µm (or 10,600 nm) (**Table 24.1**; **Fig. 24.2**).

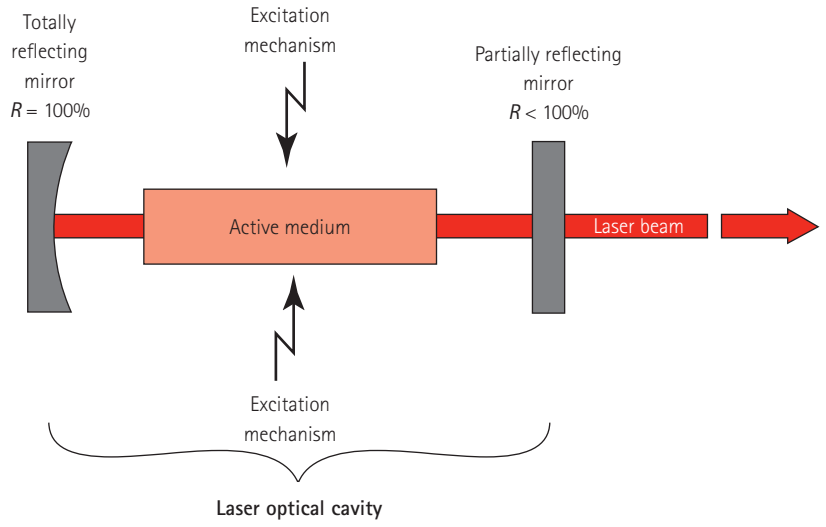


Figure 24.1 Principal components of a LASER device—laser optical cavity (also called optical resonator), an excitation mechanism that acts as an energy source, and an active medium.

Table 24.1 Classification of Dental Lasers in Accordance with Dental Use

	Wavelength
I. Soft-tissue lasers	
Argon	514 nm
KTP	532 nm
Diode	803, 810, 940, 980, 1064 nm
Nd:YAG	1064 nm
Nd:YAP	1340 nm
CO_2	10,600 nm
II. Hard- and soft-tissue lasers	
Er,Cr:YSGG	2780 nm
Er:YAG	2940 nm
III. Photopolymerization lasers	
Argon	488 nm
IV. Bleaching/tooth whitening lasers	
KTP	532 nm
Diode	803, 810–980 nm
V. Caries detection lasers	
Diode	655 nm
VI. Dentin desensitization	
Er:YAG	2940 nm
Er,Cr:YSGG	2780 nm
CO_2	10,600 nm

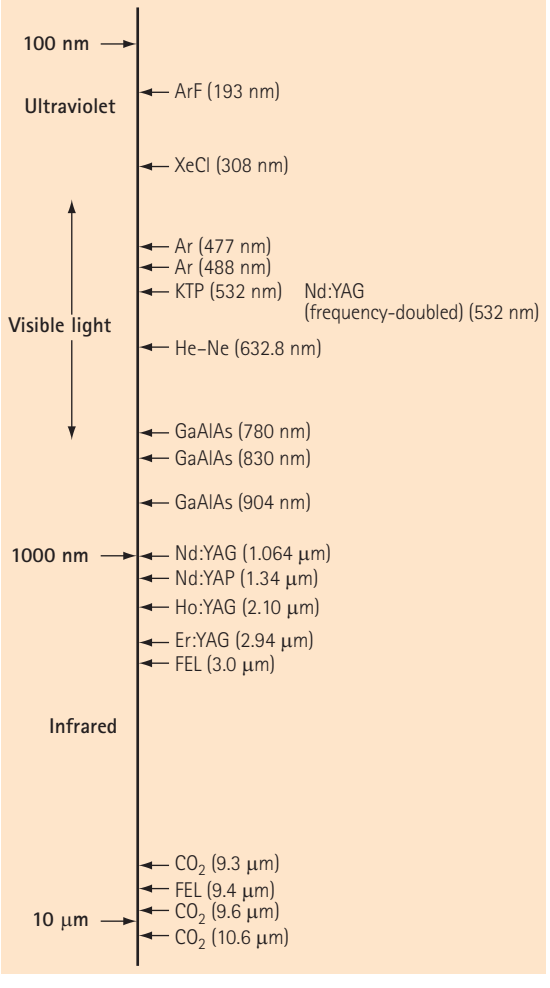


Figure 24.2 Laser wavelengths in dentistry.

DENTAL LASER DELIVERY SYSTEMS

There are two types of delivery systems that are used in dental lasers:

1. *Hollow tube delivery system:* A flexible hollow tube having an interior mirror finish (**Fig. 24.3**). The laser energy is reflected along the hollow tube and exits through a handpiece at the surgical end, with the beam striking the tissue in a *noncontact mode* (i.e., without directly touching the tissue).
2. *Glass fiberoptic delivery system:* A flexible glass fiberoptic cable (**Fig. 24.4**) in various diameters, with sizes ranging from 200 to 1000 µm. Although the glass fiber is encased in a resilient sheath, it cannot be bent into a sharp angle. This fiber fits into a handpiece with the bare end protruding. This system can be used in both *contact* and *noncontact modes*.

TISSUE RESPONSE TO LASERS

The light energy from a laser beam can have different interactions with the target tissue depending on two principal factors:

1. Wavelength of the laser used
2. Optical properties of the target tissue



Figure 24.3 Hollow tube delivery system.



Figure 24.4 Glass fiberoptic cable.

These two variables determine the following responses (**Fig. 24.5**):

- *Reflection:* The laser beam reflects or redirects itself away from the tissue surface and havs no effect on the target tissue.
- *Absorption:* This depends on tissue characteristics such as water content and level of pigmentation and on laser wavelength and emission mode.
- *Transmission:* There is no effect on the target tissue since it transmits the laser energy through itself. This depends on the wavelength of the laser employed.
- *Scattering:* This process weakens the energy of the beam and produces no useful biological effect. Scattering can cause heat transfer to the adjacent tissues and consequent thermal damage.

LASER WAVELENGTHS USED IN DENTISTRY

ND:YAG

- Solid active medium containing a crystal of yttrium–aluminum–garnet doped in neodymium
- Wavelength: **1064 nm** (invisible beam in the infrared range)
- First laser designed exclusively for dentistry
- Fiberoptically delivered in a pulsed mode and is most often used in contact with the tissue

Clinical Note

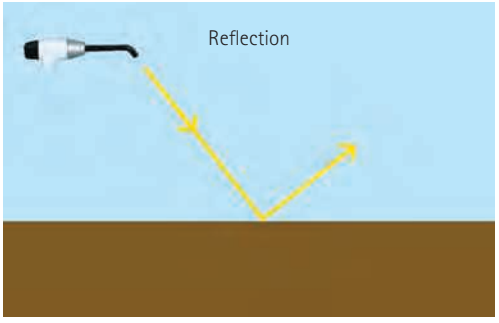
The pulsed Nd:YAG laser is ideal for soft-tissue procedures and root canal sterilization (**Fig. 24.6**).

DIODE

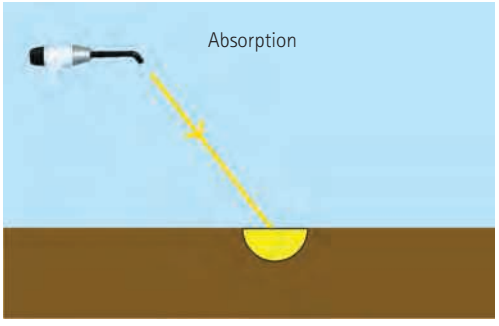
- Solid-state semiconductor laser that uses a combination of aluminum, gallium, and arsenide that converts electric energy into light energy
- Wavelength: **800–980 nm**
- Fiberoptically delivered in a continuous or pulsed mode and used commonly in contact with the tissue
- Poorly absorbed by tooth structure; hence, soft-tissue surgery can be safely performed in close proximity to dental hard tissues
- Advantage of being compact, portable, and economical (**Fig. 24.7**)

Clinical Note

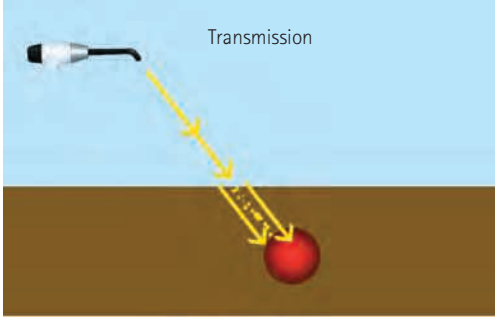
Diode laser light is well absorbed by pigmented tissues and is a good soft-tissue surgical laser indicated for precision cutting and coagulation of gingiva.



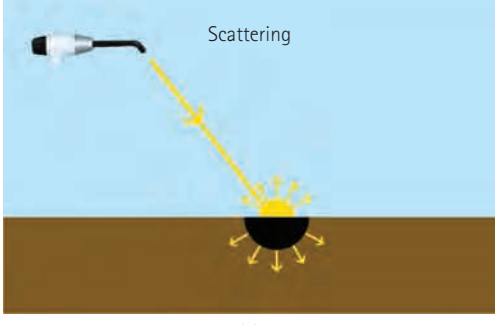
(a)



(b)



(c)



(d)

Figure 24.5 Tissue response to lasers. (a) Reflection. (b) Absorption. (c) Transmission. (d) Scattering.

CO_2 LASER

- Gas-active medium laser
- Wavelength: **10,600 nm**
- Delivered through a hollow tube system via a handpiece and cannot be delivered in a fiberoptic



Figure 24.6 Nd:YAG laser.



Figure 24.7 Diode laser.

- Highly absorbed by both hard and soft tissues and has a shallow depth of penetration
- Not suitable for hard tissues due to the deleterious thermal absorptive effect on the pulp

Clinical Note

The wavelength of a CO_2 laser is ideal for soft tissues and especially useful in cutting dense fibrous tissue.

ER:YAG AND ER,CR:YSGG

- Er:YAG is a solid active medium crystal containing yttrium–aluminum–garnet that is doped with erbium.

- Wavelength:
  - Er:YAG: **2940 nm**
  - Er,Cr:YSGG: **2790 nm**
- Delivered through a fiberoptic system in a pulsed mode. These wavelengths cannot be easily transmitted along the glass fiber, thus making this system less flexible and expensive.
- These wavelengths have the highest absorption in water and have a high affinity to hydroxyapatite. The vaporization of water from dental hard tissues causes the tissue to virtually explode away.

Clinical Note

They are ideal for hard-tissue cutting and drilling (**Fig. 24.8**).

ARGON

- Active gas medium containing argon
- Two emission wavelengths:
  - *488 nm:* Blue in color
  - *514 nm:* Blue-green in color
- Delivered through a fiberoptic system in a continuous as well as a pulsed mode
- The 488-nm emission is the exact wavelength needed to activate camphoroquinone. This laser is used to cure light-activated composites, light-activated impression materials, and light-activated bleaching gels
- The 514-nm wavelength has the highest absorption in hemoglobin and is used for its good hemostatic capabilities

APPLICATIONS OF LASERS IN ENDODONTICS

I. VASCULAR VITALITY ASSESSMENT OF PULP

Traditional vitality assessment methods such as heat, cold, and electric pulp testers assess neural vitality and often cause false-positive errors. As the histologic assessment of pulpal status is not feasible clinically, a tool to assess the vascular flow of the pulp would be very useful.

Laser Doppler flowmetry (LDF) is an accurate method to assess the blood flow in a microvascular system and is discussed in Chapter 6.

II. PULP CAPPING AND PULPOTOMY

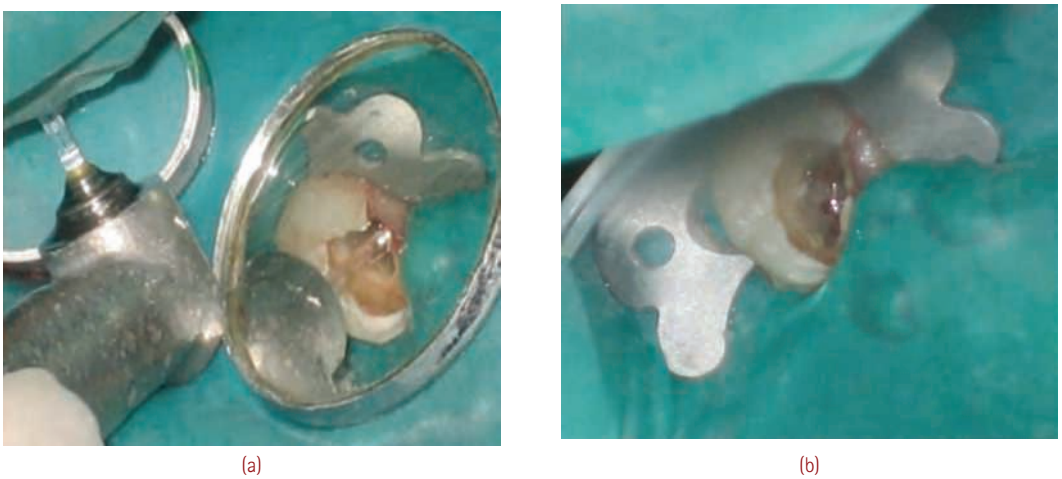
Pulp capping and pulpotomy constitute a more conservative form of pulp therapy in comparison to pulpectomy. Although the outcome of pulp capping procedures is variable ranging from 44 to 97%, the procedure is recommended when the exposure is 1.0 mm or less and especially when the patient is young. Pulpotomy is recommended in immature permanent teeth, where pulpectomy is not advised.

The most commonly used agents for both the procedures are calcium hydroxide and mineral trioxide aggregate (MTA). The use of a laser in these procedures leads to a potentially bloodless field as the laser has the ability to coagulate and seal small blood vessels. The laser–tissue interactions make the treated wound surface sterile and also improve the prognosis of the procedure.

Melcer et al. (1987) described the hemostatic effect of a CO_2 laser on exposed pulp tissues in dogs, while Ebihara et al. showed that Nd:YAG lasers facilitated pulpal healing after irradiation. In clinical trials, Moritz et al. showed significant superior success rates with a CO_2 laser–aided pulp capping procedure.

Various studies assessing the effect of CO_2 and Nd:YAG lasers on irradiated pulp found no damage in tissues underlying the laser-ablated tissues. There was the presence of secondary dentin and a regular odontoblast layer. Wound healing of irradiated pulps seemed to be better than that of controls.

Liu (2006) did a clinical trial of Nd:YAG laser pulpotomy on human primary molars and found 97% success rate



(a) (b)

Figure 24.8 (a) Hard-tissue removal with an Er:YAG laser. (b) Access cavity opened with an Er:YAG laser. (*Courtesy: Vivek Hegde, India.*)

clinically and 94.1% success rate radiographically. Yet more clinical trials are needed to ascertain the long-term clinical success rates.

III. DISINFECTION OF ROOT CANALS

The ability of bacterial pathogens to persist after shaping and cleaning is one of the main reasons for endodontic failures. This is attributed to the complex nature of the root canal system, the presence of a smear layer, and the fact that large areas (over 35%) of the canal surface area remain unchanged following instrumentation with various Ni–Ti techniques.

Studies have assessed the role of CO_2 and Nd:YAG lasers in root canals and found evidence of dentinal tubule disinfection. Other lasers such as XeCl laser, Er:YSGG, Er:YAG, diode, Nd:YAP, and argon have been used for this purpose. The laser is delivered into the root canal system with the help of thin fiberoptics (200 μm) as in the case of Nd:YAG, Er:YSGG, argon, and diode lasers (**Figs 24.9** and **24.10**). A hollow tube is employed for this purpose in CO_2 and Er:YAG lasers.

Goodis et al. concluded that there are several limitations with the intracanal use of lasers. The laser beam that is emitted from the tip of the fiberoptic is directed vertically downward into the root canal and not laterally into the dentinal tubules. This is further compromised by the inherent curvature present in the root canals. Thus, it is not possible to laser-irradiate all the dimensions of the canal system completely.



Figure 24.9 Root canal disinfection with an Nd:YAG laser.

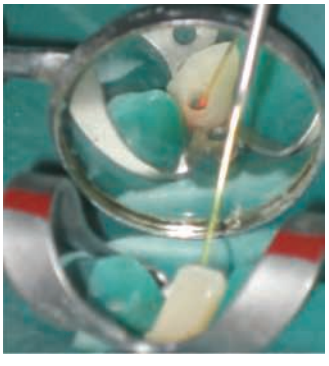


Figure 24.10 Diode laser disinfection of root canals.

The other concern raised was the inadvertent transmission of the laser into the periradicular region while irradiating the apical third of the root canal system. It is potentially dangerous in the areas around the apices of teeth close to the mental and mandibular foramen. The development of a side-firing spiral tip with an Er:YAG laser is an effort to overcome this hazard.

Most researchers conclude that laser irradiation is an effective method to kill microorganisms. It can act as an adjunct to the traditional means of shaping and cleaning.

Clinical Note

- *Photodynamic therapy (PDT):* For disinfection, laser energy can be used directly or in combination with a photosensitive chemical that, when bound to microorganisms, may be activated by low-energy laser light to essentially kill the microorganism.
- *Photon-induced photoacoustic streaming (PIPS):* Additional experiments suggest that the propagation of acoustic waves emanating from a pulsed low-energy laser may aid in distributing disinfecting solutions more effectively across the root canal system.

IV. OBTURATION

Thermoplasticized gutta-percha obturation systems are one of the most efficient methods in achieving a fluid-impervious seal. Softening of the gutta-percha has been attempted with various lasers. These include argon, CO_2, Nd:YAG, and Er:YAG.

Clinical Note

More clinical evidence is needed concerning the use of lasers during obturation.

V. APICAL SURGERY

Apical surgery including apical resection is indicated when the previously performed root canal therapy fails and nonsurgical means are inadequate to ensure the complete removal of the pathologic process.

The potential for using lasers is on the basis of the following observations:

- Ability of lasers to coagulate and seal small blood vessels, thereby enabling a bloodless surgical field
- Sterilization of the surgical site
- Potential of lasers (Er:YAG) to cut hard dental tissues without causing elaborate thermal damage to the adjoining tissues

Miserendino (1988) successfully treated an apical abscess using a CO_2 laser. When this laser was applied to patients having apicectomies, it did not improve the healing progress significantly.

Later, Ebihara proved the ability of Er:YAG lasers to prepare apical retrograde cavities similar to ultrasonic

preparations. Paghdiwala showed excellent results with smooth, clean resected surfaces, devoid of charring with an Er:YAG laser. Clinically, the use of this type of laser improved healing and patients reported reduced discomfort.

Although numerous studies have proved the efficacy of lasers in endodontic applications, acceptance of this technology by clinicians is limited. This could be attributed to the high cost of technology and the need for more than one laser frequency to cover all endodontic applications.

The future for lasers in endodontics is promising with the rapid development of thinner and more flexible fiberoptic delivery systems and with an improvement in our knowledge of optimal laser parameters.

Clinical Note

More research is required to develop laser energy for use in routine nonsurgical endodontics that is equal to, and perhaps one day superior to, current clinical treatment modalities.

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