Cohen's Pathways *of the* PULP

TENTH EDITION

Kenneth M. Hargreaves ▪ Stephen Cohen

Web Editor: Louis H. Berman

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Dr. Kenneth M. Hargreaves is professor and Chair of the Department of Endodontics at the University of Texas Health Science Center at San Antonio. He completed his endodontic residency at the University of Minnesota in 1993. Dr. Hargreaves is a Diplomate of the American Board of Endodontics and maintains a private practice limited to endodontics. He is an active researcher, lecturer, and teacher and serves as the Editor of the *Journal of Endodontics*. He is principal investigator on several nationally funded grants that combine his interests in pain, pharmacology, and regenerative endodontics. He has received several awards, including a National Institutes of Health MERIT Award for pain research, the AAE Louis I. Grossman Award for cumulative publication of research studies, and two IADR Distinguished Scientist Awards.

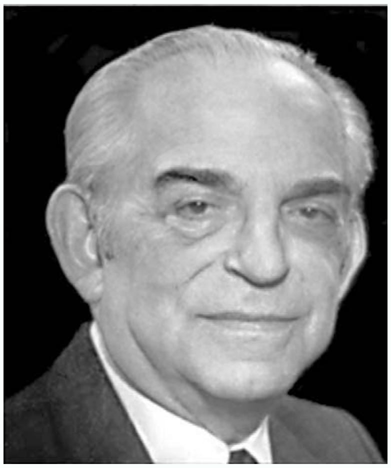
STEPHEN COHEN

Dr. Stephen Cohen is one of the foremost endodontic clinicians in the country and a worldwide lecturer on endodontics. Dr. Cohen completed his studies in the Endodontic Postgraduate Program at the University of Pennsylvania in 1969 and began his private practice. From 1970 until 1988, Dr. Cohen served as Chairman of the Department of Endodontics at The Arthur A. Dugoni School of Dentistry of the University of the Pacific, and he has continued his involvement with the university as an Adjunct Clinical Professor of Endodontics. He is also a Clinical Professor of Endodontics in the Department of Preventive and Restorative Dental Sciences at the University of California School of Dentistry, San Francisco. Dr. Cohen was senior editor of the first nine editions of *Pathways of the Pulp* and continues to serve as editor of the tenth edition. He is a Diplomate of the American Board of Endodontics, and has held leadership positions in many of the major professional and academic organizations in endodontics. He maintains a full-time endodontic practice in San Francisco, where he has practiced since 1969.

LOUIS H. BERMAN

Dr. Louis H. Berman has been in full-time private practice limited to endodontics in Annapolis, Maryland since 1983. Dr. Berman completed his endodontic residency at the Albert Einstein Medical Center in Philadelphia. He was formerly a Clinical Instructor and Assistant Professor of Endodontics at the University of Maryland School of Dentistry. An active lecturer and author, he is a past president of the Maryland State Association of Endodontics, and is a member of the *Journal of Endodontics* Scientific Advisory Panel. Dr. Berman is the senior editor of the textbook *Dental Traumatology* and is a Diplomate of the American Board of Endodontics and a Fellow of the American College of Dentistry.

Dr. I.B. Bender



For a man of short stature, I.B. Bender was a giant in shaping the field of endodontics. Dr. Bender started his remarkable career as an educator in 1942 at the Albert Einstein Medical Center in Philadelphia, and continued with his passionate pursuit of endodontic teaching for the next 61 years. He authored more than 130 articles in medicine and dentistry and was co-author of the classic textbook, *The Dental Pulp*. Recipient of the most prestigious awards given to endodontists, he also served as President of the American Association of Endodontists and as a Director of the American Board of Endodontics. In 1989, the endodontic residency program at the Albert Einstein Medical Center honored him by dedicating their program as the I.B. Bender Division of Endodontics and established the I.B. Bender Research Endowment Fund.

A true Renaissance man, I.B. was internationally known not just for his boundless knowledge of endodontic literature and extraordinary insight into the biological aspects of our specialty, but also for his quick wit, enjoyable sense of humor, and persistent quest to challenge "conventional" beliefs and let science lead us into the future. I.B. was a wise man who once stated, "The clinical practice of yesterday's endodontics becomes the heresy of today, and today's endodontic practice becomes the heresy of tomorrow. So don't be so rigid in your techniques or beliefs."

I.B. took much pride in inspiring and imbuing his students with a passion for endodontic excellence. During lectures he was well known to compliment their correct answers with his wide smile, a tilt of his head while pointing his finger, and a statement that they had been "Bender-ized." He always welcomed a challenge to the intellectual status quo, and took great pleasure in a duel of intellect. I.B. referred to himself as "the oldest living functional endodontist … who has helped to move the status of endodontics from the 'outhouse' to the 'penthouse'." He valued his close friendships and always finished his personal notes, in his uniquely recognizable penmanship, with "Azever, I.B."

At a 1995 lecture at the I.B. Bender Conference, "The Biological Basis and Clinical Practice of Endodontics," I.B. closed by stating: "The implementation of extended research and teaching is a means by which endodontics will be able to meet the future demands for its service. Service itself in a specialty cannot make progress. Other developments in our discipline will come from people who can touch tomorrow." And I.B. touched tomorrow by touching the lives of all of us.

I.B. was instrumental in shaping our past, directing our present, and providing the foundation and vision for our ever-changing future. His inspiring passion for knowledge and excellence set the standards for the legions of students who will always remain indebted to him for role-modeling what a healer and teacher does for others. To commemorate this iconic role model of our specialty, we are pleased to dedicate this tenth edition of *Pathways of the Pulp* to Dr. I.B. Bender.

Kenneth M. Hargreaves
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Preface

The co-editors and publisher are pleased to present the tenth edition of a textbook that has been continuously evolving since 1976. We are also proud to announce the renaming of this text to ***Cohen's Pathways of the Pulp*** to reflect the leadership, passion, and expertise of Dr. Stephen Cohen, who has guided the production of all 10 editions. This current edition has been completely updated and expanded to provide the latest clinically relevant, evidence-based knowledge, while also introducing exciting new chapters on subjects such as Regenerative Endodontics, Cone Beam Technologies, and Endodontic Practice Management. The companion Expert Consult version of the book has also been greatly enhanced with supplemental content available only online. With its exceptional capacity to provide continuous updates, the Expert Consult site is reflective of the dynamic nature of our specialty, empowering our readers with not only the most current clinical information available, but also with an invaluable feature that permits the downloading of any figure in the book as a PowerPoint or jpeg image for the reader's personal study or lectures. Moreover, the online Challenge section provides self-assessment of knowledge with a unique collection of hyperlinks that connects all of the multiple choice questions to relevant sections of the text. As editors, we feel privileged and honored to offer this thoroughly updated and expanded version of the first interactive textbook in dentistry that enables the reader to continuously stay on the "cutting edge" of endodontics.

We welcome your feedback at any time.

Kenneth M. Hargreaves
Stephen Cohen
Louis H. Berman

Acknowledgments

Working with such a talented, patient, and highly professional team at Elsevier has been an enriching experience. In the future, when we look back to the time that was devoted to developing this tenth edition, we'll always remember fondly the special people with whom we've forged a bond through hard work and how they helped us at every level. Some of the many people that we'd like to express our gratitude to include:

- *John Dolan, Executive Editor*
- *Courtney Sprehe, Senior Developmental Editor*
- *Karen Rehwinkel, Senior Project Manager*
- *Jill Norath, Multimedia Producer*
- *Jessica Williams, Designer*
- *Jaime Pendill, Freelance Editor*

And to the many people who helped those named above we extend a heartfelt "Thank You"!

About the Tenth Edition

With the publication of this milestone tenth edition, the staff at Elsevier would like to thank Dr. Stephen Cohen for his many years of dedication to *Pathways of the Pulp*. In recognition of Dr. Cohen's leadership in making this a world-renowned text and for his many contributions to the field of endodontics, the new edition has been renamed *Cohen's Pathways of the Pulp*.

Pathways of the Pulp has a longstanding reputation of providing high-level, comprehensive content that conveys the most current endodontic information, materials, and techniques to an international audience. The tenth edition builds on this solid reputation with a book that delivers more than ever! Renowned contributors from across the country and around the world offer expert perspectives and expand on observations made by previous contributors. Full-color photographs, illustrations, and a wide range of radiographs clearly demonstrate core concepts and reinforce the essential principles and techniques unique to the specialty of endodontics.

CHAPTERS NEW TO THIS EDITION

Chapter 14: Pathobiology of the Periapex by Louis M. Lin and George T-J Huang. This chapter looks at topics such as apical periodontitis, infection, asymptomatic apical periodontitis (apical granuloma), the relationship between apical periodontitis and systemic diseases, and wound healing of apical periodontitis.

Chapter 16: Regenerative Endodontics by Kenneth M. Hargreaves and Alan S. Law. This chapter describes the biological basis for regenerating the pulp-dentin complex of teeth with necrotic pulps and reviews the clinical procedures reported to date on this newly emerging procedure.

Chapter 22: Restoration of Endodontically Treated Teeth by Didier Dietschi and Serge Bouillaguet. Topics covered in this chapter include a description of the unique physical characteristics of endodontically treated teeth, restorative materials, pretreatment evaluation and treatment strategies, and a variety of clinical procedures, including direct composite restorations, veneers, selection of posts and core materials, and much more.

Chapter 29: Cone Beam Imaging for Endodontics (online) by Dale A. Miles and Thomas V. McClammy. With the recent advent of cone beam computerized tomography's use in the dental office, this chapter elaborates on the enhanced radiographic capabilities now available for endodontic diagnosis and treatment planning.

Chapter 30: Key Principles of Endodontic Practice Management (online) by Roger P. Levin. Providing insight on marketing, staff development, patient management, and referral relationships, this chapter describes endodontic management systems and the goals necessary for the development of a successful endodontic practice.

ORGANIZATION

As in the previous edition, the tenth edition is divided into three parts, Part I: The Core Science of Endodontics, Part II: The Advanced Science of Endodontics, and Part III: Related Clinical Topics.

Part I begins with chapters that focus on the process of developing an endodontic diagnosis, how to effectively diagnose and manage acute dental pain, and how to identify pain of nonodontogenic origin. The next chapter reviews the process of case selection and treatment planning, which is followed by chapters that prepare the clinician for endodontic treatment, including a thorough review of armamentarium, sterilization, and disinfection, where appropriate. The next chapter describes tooth morphology and how it relates to techniques crucial for achieving access to the entire root canal system. Following are three chapters that extensively describe the latest instruments, materials, techniques, and devices used for canal cleaning, shaping, and obturation. The concluding chapter in Part I reviews the legal responsibilities of the clinician and gives guidance for avoiding potential legal issues pertaining to patient care.

Part II starts with a chapter that brings together what is known about the development, structure, and function of the dentinal-pulpal complex and is followed by a chapter on how the pulp reacts to different stimuli, materials, and dental procedures. Following are chapters on the pathobiology of the periapex and the diverse aspects of endodontic microbiology, with special emphasis placed on the underlying principles for sound antimicrobial treatment of endodontic infections.

Part III begins with a new chapter on the rapidly developing field of regenerative endodontics and continues with a chapter that details the endodontic management necessary for optimizing favorable healing for the various types of traumatic dental injuries. The next chapter looks at the relationship between pulpal and periodontal tissues, and the following chapter presents insight into the medications used in endodontics, especially as it relates to the pharmacologic management of odontogenic pain. The chapter on periradicular surgery reviews how it has evolved into a precise, biologically-based adjunct to nonsurgical root canal therapy and is followed by a new chapter designed to help clinicians make informative decisions about the restorative options available to endodontically-treated teeth. Part III concludes with a chapter that looks at the special considerations that must be addressed when treating geriatric, pediatric, and medically compromised patients, followed by a chapter that provides the information necessary for proper treatment-planning considerations and management of nonsurgical endodontic retreatment.

In addition to the 25 chapters in the text there are also five new chapters included on *Expert Consult*, the book's online component. These chapters address topics such as management of the fearful dental patient, the law and dental technology, the role of digital technology in practice, cone beam computerized tomography, and endodontic practice management. *Expert Consult* also provides access to a wide range of essential educational and clinically-based topics, which are further described on the next page.

About Expert Consult

Elsevier's *Expert Consult* platform is an online collection of evidence-based reference titles that cross a wide range of specialties. Combining authoritative, world-class book content with full-search functionality and many additional online features, Expert Consult is one of the most efficient tools available to healthcare professionals today.

Access to the *Expert Consult* platform is part of the content package for the tenth edition of *Cohen's Pathways of the Pulp*. Simply activate your title at **expertconsult.com** to see a wide range of supplemental material. Activation instructions can be found on the inside front cover of the book.

When you register and activate your book on *Expert Consult*, you gain access to the complete, fully searchable contents of the book online, which enables you to:

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In addition, a wide range of premium content is offered, including the following:

- **Five chapters available only online:**
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  - Chapter 28: Digital Technology in Endodontic Practice
  - Chapter 29: Cone Beam Imaging for Endodontic Procedures
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- **Challenge:** Multiple-choice questions stemming from chapter-specific discussions or case scenarios, including answers and references to pages in the book.
- **Glossary and SORT:** Articles from *The Journal of Evidence-Based Dentistry—The Glossary of Evidence-Based Terms* and *JEBDP Improves Grading System and Adopts Strength of Recommendation Taxonomy Grading (SORT) for Guidelines and Systematic Reviews*—provided in their entirety.

Introduction

Welcome reader, to this tenth edition of *Pathways of the Pulp,* a reconceptualized textbook that blends form, content, print, and digital formats to describe and detail the transformative future of endodontics. The first edition of *Pathways of the Pulp* was published in 1976, with the aim of describing in a single print volume the basic and clinical science of what was then the emerging specialty of endodontics. Nine editions later, we have continued to refine and redefine the scope and organization of our textbook to mirror and represent the changing science of endodontics and the evolving landscape of learning and communication. Now offered in 14 different languages, *Pathways of the Pulp* is the most comprehensive and innovative evidence-based endodontic textbook available.

Beginning with the ninth edition, *Pathways of the Pulp* has been available anytime, anywhere to readers in an online version, enhanced with instructional images and graphics and periodic content updates. The new format of the tenth edition has expanded the use of digital resources to achieve a seamless blending of print and online content through the addition of narrated video clips and animations, and quarterly content updates drawn from the peer-reviewed literature.

Although the evolving form and format of *Pathways of the Pulp* defines its commitment to education, the steady and selfless dedication of the more than 150 contributors to the 10 editions honors and extends our tradition of collaborating with the most qualified and highly regarded authors, academicians, and researches in our field. Working with all of the dedicated teachers and scientists who author our chapters continues to be the signature honor and privilege for the editors. We are especially grateful to Dr. Lou Berman, who in his capacity as Webmaster has made our promise of online availability and digital features a reality. We are all indebted as well to Elsevier for its willingness to explore and support ever more dynamic and engaging ways of imparting knowledge and communicating with our readers.

The nine prior editions of *Pathways of the Pulp* have begun with a chapter on the history of endodontics and the inspiring story of the intense interplay between basic science and clinical care that established and certified our specialty. The vision and dedication of our founders who lived that history are now embedded in the field and practice of endodontics, and to call them out separately would seem to distance them rather than bring them closer to us. What now connects us more productively and most effectively with our storied past is our commitment to redefining that critical interplay between basic science and clinical care in terms of new technologies, new possibilities, and new expectations.

In this tenth edition, through evidence-based discussions in all of our 30 chapters, including five that are only available online, we have meticulously detailed that what was once regarded as science fiction in clinical care is now rapidly becoming clinical endodontic fact. The quality of care available to patients has never been higher, from the administrative efficiency and privacy protection afforded to patients through electronic medical records, to the greatly enhanced effectiveness of infection management through real-time PCR. A sampling of the innovative and paradigm shifting developments outlined in this edition include the following:

- More accurate devices to determine pulp vitality and inflammation
- Greater control of the duration of local anesthesia on a case-by-case basis
- Cleaning and shaping root canals in less than 5 minutes with a single device
- Regeneration of the pulp to replace canal obturation
- Nonsurgically accelerating the remineralization of periapical lesions through the apical foramen

As clinicians we must meet this rich convergence of discovery and invention with an equally rich commitment to continuous learning, exposing ourselves to all the science our field has to offer. This is our duty to our founders, this is our responsibility to our patients, and this is our gift to ourselves.

As I conclude this Introduction I also bring to a close my 35 years as editor of *Pathways of the Pulp*. It is with complete confidence and great excitement that I pass the editorship of our book to Dr. Kenneth Hargreaves, a uniquely qualified and accomplished scientist, educator, and clinician.

I am deeply grateful for the privilege of editing and contributing to *Pathways of the Pulp*. It has been a true labor of love, which has allowed me to indulge my passion for science and my love of teaching. Perhaps most importantly, however, my editorship has taught me what it means to practice endodontics, a true healing art.

Stephen Cohen

CHAPTER

1

Diagnosis

LOUIS H. BERMAN and GARY R. HARTWELL

CHAPTER OUTLINE

ART AND SCIENCE OF DIAGNOSIS

Almost a century ago, Dr. Hermann Prinz wrote: "The object of the practice of clinical dentistry … is to institute preventive measures, to relieve suffering, and to cure disease. These purposes are not achieved by the haphazard utilization of a few therapeutic formulas or of certain mechanical procedures, but they are based on a thorough knowledge of clinical pathology."[75] This statement has truly withstood the test of time and remains a cornerstone in diagnosis. But the gathering of scientific data is not enough to formulate an accurate clinical diagnosis. The data must be interpreted and processed in order to determine what information is significant, and what information might be questionable. The facts need to be collected with an active dialogue between the clinician and the patient, with the clinician asking the right questions and carefully interpreting the answers. In essence, the process of determining the existence of dental pathosis is the culmination of the art and science of making an accurate diagnosis.

The purpose of a diagnosis is to determine what problem the patient is having, and why the patient is having that problem. Ultimately, this will directly relate to what treatment, if any, will be necessary. No appropriate treatment recommendation can be made until all of the *whys* are answered. Therefore a planned, methodical, and systematic approach to this investigatory process is crucial.

The process of making a diagnosis can be divided into five stages:

1. The patient tells the clinician why the patient is seeking advice.
2. The clinician questions the patient about the symptoms and history that led to the visit.
3. The clinician performs objective clinical tests.
4. The clinician correlates the objective findings with the subjective details and creates a tentative differential diagnosis.
5. The clinician formulates a definitive diagnosis.

This information is accumulated by means of an organized and systematic approach that requires considerable clinical judgment. The clinician must be able to approach the problem by crafting what questions to ask the patient and how to ask these pertinent questions. Careful listening is paramount to begin painting the picture that details the patient's complaint. The diagnostic tests that are used become the science behind the creation of the diagnosis.

Neither the art nor the science is effective alone. Establishing a differential diagnosis in endodontics requires a unique blend of knowledge, skills, and ability to interpret and interact with a patient in real time. Questioning, listening, testing, interpreting, and finally answering the ultimate question of *why* will lead to an accurate diagnosis and in turn result in a more successful treatment plan.

Chief Complaint

On arrival for a dental consultation, the patient should complete a thorough registration that includes information pertaining to medical and dental history (Figs. 1-1 and 1-2). This should be signed and dated by the patient, as well as initialed by the clinician as verification that all of the submitted information has been reviewed (see Chapter 11 for more information).

The reasons patients give for consulting with a clinician are often as important as the diagnostic tests performed. These remarks serve as important clues for the clinician that will help in formulating a correct diagnosis. Without these direct and unbiased comments, objective findings may lead to an incorrect diagnosis. The clinician may find dental pathosis, but it

TELL US ABOUT YOUR SYMPTOMS

LAST NAME ______________________ FIRST NAME ______________________

1. Are you experiencing any pain at this time? If not, please go to question 6. Yes ______ No ______
2. If yes, can you locate the tooth that is causing the pain? Yes ______ No ______
3. When did you first notice the symptoms? ______________________
4. Did your symptoms occur suddenly or gradually? ______________________
5. Please check the frequency and quality of the discomfort, and the number that most closely reflects the intensity of your pain:

LEVEL OF INTENSITY (On a scale of 1 to 10) 1 = Mild 10 = Severe	FREQUENCY	QUALITY
1____2____3____4____5____6____7____8____9____10____	______ Constant	______ Sharp
	______ Intermittent	______ Dull
	______ Momentary	______ Throbbing
	______ Occasional	

Is there anything you can do to relieve the pain? Yes ______ No ______

If yes, what? ______________________

Is there anything you can do to cause the pain to increase? Yes ______ No ______

If yes, what? ______________________

When eating or drinking, is your tooth sensitive to: Heat ______ Cold ______ Sweets ______

Does your tooth hurt when you bite down or chew? Yes ______ No ______

Does it hurt if you press the gum tissue around this tooth? Yes ______ No ______

Does a change in posture (lying down or bending over) cause your tooth to hurt? Yes ______ No ______

6. Do you grind or clench your teeth? Yes ______ No ______
7. If yes, do you wear a night guard? Yes ______ No ______
8. Has a restoration (filling or crown) been placed on this tooth recently? Yes ______ No ______
9. Prior to this appointment, has root canal therapy been initiated on this tooth? Yes ______ No ______
10. Is there anything else we should know about your teeth, gums, or sinuses that would assist us in our diagnosis? ______________________

Signed: Patient or Parent ______________________ Date ______________________

FIG. 1-1 Dental history form that also allows the patient to record pain experience in an organized and descriptive manner.

TELL US ABOUT YOUR HEALTH

LAST NAME ______________________ **FIRST NAME** ______________________

How would you rate your health? Please circle one. Excellent Good Fair Poor

When did you have your last physical exam? ______________________

If you are under the care of a physician, please give reason(s) for treatment.

____

Physician's Name, Address, and Telephone Number:

Name ______________________ Address ______________________

City ____________ State ______ Zip ________ Telephone ______________

Have you ever had any kind of surgery? Yes _____ No _____

If yes, what kind? ______________________ Date ____________

______________________ Date ____________

Have you ever had any trouble with prolonged bleeding after surgery? Yes _____ No _____

Do you wear a pacemaker or any other kind of prosthetic device? Yes _____ No _____

Are you taking any kind of medication or drugs at this time? Yes _____ No _____

If yes, please give name(s) of the medicine(s) and reason(s) for taking them:

Name ______________________ Reason ______________________

______________________ ______________________

Have you ever had an unusual reaction to an anesthetic or drug (like penicillin)? Yes _____ No _____

If yes, please explain: ______________________

Please circle any past or present illness you have had:

Alcoholism	Blood pressure	Epilepsy	Hepatitis	Kidney or liver	Rheumatic fever
Allergies	Cancer	Glaucoma	Herpes	Mental	Sinusitis
Anemia	Diabetes	Head/Neck injuries	Immunodeficiency	Migraine	Ulcers
Asthma	Drug dependency	Heart disease	Infectious diseases	Respiratory	Venereal disease

Are you allergic to Latex or any other substances or materials? Yes _____ No _____

If so, please explain ______________________

If female, are you pregnant? Yes _____ No _____

Is there any other information that should be known about your health? ______________________

____

Signed: Patient or Parent ______________________ Date: ____________

FIG. 1-2 Succinct, comprehensive medical history form designed to provide insight into systemic conditions that could produce or affect the patient's symptoms, mandate alterations in the modality of treatment, or change the treatment plan.

may not be the pathologic condition that mediates the patient's chief complaint. Investigating these complaints may indicate that the patient's concerns are secondary to a medical condition or possibly a result of recent dental treatment. On occasion, the chief complaint is simply that another clinician correctly or incorrectly advised the patient that he or she had a dental problem, with the patient not necessarily having any symptoms. Therefore, the clinician must pay close attention to the actual expressed complaint, determine the chronology of events that led up to this complaint, and question the patient as to any other pertinent issues, including medical and dental history. For future reference and in order to ascertain a correct diagnosis, the patient's chief complaint should be properly documented, using *the patient's own words*.

Medical History

The clinician is responsible for taking a proper medical history from every patient who presents for treatment. Numerous examples of medical history forms are available from a variety of sources, or individual clinicians may choose to customize their own forms. After the form is completed by the patient, or by the parent or guardian in the case of a minor, the clinician should review the responses with the patient, parent, or guardian and indicate that this review has been done by initialing the medical history form. Any patient "of record" should be questioned at each treatment visit to determine any changes in the patient's medical history or medications. A more thorough and complete update of the patient's medical history should be completed if the patient has not been seen for over a year.[35,56]

Baseline blood pressure and pulse should be recorded for a patient at each treatment visit. Elevation in blood pressure or a rapid pulse rate may indicate an anxious patient who may require a reduced stress protocol, or it may indicate that the patient has hypertension or other cardiovascular health problems. It is imperative that vital signs be gathered at each treatment visit for any patient with a history of major medical problems. The temperature of patients presenting with subjective fever or any signs or symptoms of a dental infection should be taken.[42,56,78]

The clinician should evaluate a patient's response to the health questionnaire from two perspectives: (1) those medical conditions and current medications that will necessitate altering the manner in which dental care will be provided and (2) those medical conditions that may have oral manifestations or mimic dental pathosis.

Patients with serious medical conditions may require either a modification in the manner in which the dental care will be delivered or a modification in the dental treatment plan (Box 1-1).

In addition, the clinician should be aware if the patient has drug allergies or allergies to dental products, an artificial joint prosthesis, or organ transplants or is taking medications that may negatively interact with common local anesthetics, analgesics, and antibiotics.

The previous listing may seem overwhelming, but it emphasizes the importance of attaining a thorough and accurate medical history before any dental treatment is provided. A multitude of textbooks and journal articles are available to keep the dental community current on the appropriate ways to provide dental care for patients with medical problems (e.g., *The Merck Manual* at http://www.merck.com/mrkshared/mmanual/home.jsp). These sources provide the clinician with details about the various medical conditions and the dental treatment modifications that must be made in order to provide the appropriate care.

BOX 1-1

Medical Conditions That Warrant Modification of Dental Care or Treatment

Cardiovascular: High- and moderate-risk categories of endocarditis, pathologic heart murmurs, hypertension, unstable angina pectoris, recent myocardial infarction, cardiac arrhythmias, poorly managed congestive heart failure[42,56,78]

Pulmonary: Chronic obstructive pulmonary disease, asthma, tuberculosis[56,95]

Gastrointestinal and renal: End-stage renal disease; hemodialysis; viral hepatitis (types B, C, D, and E); alcoholic liver disease; peptic ulcer disease; inflammatory bowel disease; pseudomembranous colitis[17,21,22,33,56]

Hematologic: Sexually transmitted diseases, HIV and AIDS, diabetes mellitus, adrenal insufficiency, hyperthyroidism and hypothyroidism, pregnancy, bleeding disorders, cancer and leukemia, osteoarthritis and rheumatoid arthritis, systemic lupus erythematosus[22,28,53,59,64,73,99]

Neurologic: Cerebrovascular accident, seizure disorders, anxiety, depression and bipolar disorders, presence or history of drug or alcohol abuse, Alzheimer's disease, schizophrenia, eating disorders, neuralgias, multiple sclerosis, Parkinson's disease[23,29]

Several medical conditions have oral manifestations, which must be carefully considered when attempting to arrive at an accurate dental diagnosis. Many of the oral soft tissue changes that occur are more related to the medications used to treat the medical condition than the medical condition itself. More common examples of medication side effects are stomatitis, xerostomia, petechiae, ecchymoses, lichenoid mucosal lesions, and bleeding of the oral soft tissues.[56]

In arriving at an accurate dental diagnosis, a clinician must also be aware that some medical conditions can have clinical presentations that mimic oral pathologic lesions.[91] Tuberculosis involvement of the cervical and submandibular lymph nodes can lead to a misdiagnosis of lymph node enlargement as a result of an odontogenic infection. Lymphomas can also involve these same lymph nodes.[56] Immunocompromised patients and patients with uncontrolled diabetes mellitus respond poorly to dental treatment and may exhibit recurring abscesses in the oral cavity that must be differentiated from abscesses of dental origin.[28,53,56,59] Patients with iron deficiency anemia, pernicious anemia, and leukemia frequently exhibit paresthesia of the oral soft tissues. This finding may complicate making a diagnosis when other dental pathosis is also present in the same area of the oral cavity. Sickle cell anemia has the complicating factor of bone pain, which mimics odontogenic pain and loss of trabecular bone pattern on radiographs, which can be confused with radiographic lesions of endodontic origin. Multiple myeloma can result in unexplained mobility of teeth. Radiation therapy to the head and neck region can result in increased sensitivity of the teeth and osteoradionecrosis.[56] Trigeminal neuralgia, referred pain from cardiac angina, and multiple sclerosis can also mimic dental pain (see also Chapter 3). Acute maxillary sinusitis is a common condition that may create diagnostic confusion because it may mimic tooth pain in the maxillary posterior quadrant. In this situation the teeth in the quadrant will be extremely sensitive to cold and percussion, thus mimicking the signs and symptoms of pulpitis. This is certainly not a complete list of all the medical entities that can mimic dental disease, but it should alert the clinician that a medical problem could confuse and complicate the diagnosis of dental pathosis; this is discussed in more detail in subsequent chapters.

If at the completion of a thorough dental examination, the subjective, objective, clinical testing, and radiographic findings do not result in a diagnosis with an obvious dental etiology, then consideration must be given that an existing medical problem could be the true etiology. In such instances a consultation with the patient's physician is always appropriate. As noted previously, there are many current textbooks and journal articles that can serve as reference materials for clinicians who encounter some of these medical problems on an infrequent basis.

Dental History

The chronology of events that lead up to the chief complaint is recorded as the *dental history*. This information will help guide the clinician as to which diagnostic tests are to be performed. The history should include any past and present symptoms, as well as any procedures or trauma that might have evoked the chief complaint. Proper documentation is imperative. It may be helpful to use a premade form to record the pertinent information obtained during the dental history interview and diagnostic examination. Often an S.O.A.P. format is used, designating the *S*ubjective *O*bjective *A*ppraisal *P*lan for the diagnostic workup. There are also built-in features within some practice management software packages that allow digital entries into the patients' electronic file for the diagnostic workup (Figs. 1-3 and 1-4).

History of Present Dental Problem

The dialogue between the patient and the clinician should encompass all of the details pertinent to the events that led up to the chief complaint. The conversation should be directed by the clinician in order to produce a clear and concise narrative that chronologically depicts all of the necessary information about the patient's symptoms and the development of these symptoms. To help elucidate this information, the patient is first instructed to fill out a dental history form as a part of the patient's office registration. This information will help the clinician decide which approach to use when asking the patient questions. The interview first determines *what is going on* in an effort to determine *why is it going on* for the purpose of eventually determining *what is necessary for the resolution of the chief complaint*.

Dental History Interview

After starting the interview and determining the nature of the chief complaint, the clinician continues the conversation by documenting the sequence of events that promulgated the request for an evaluation. The dental history is divided into five basic directions of questioning: localization, commencement, intensity, provocation, and duration.

Localization: *"Can you point to the offending tooth?"* Often the patient can point to or "tap" the offending tooth. This is the most fortunate scenario for the clinician because it helps direct the interview toward the events that might have caused any particular pathosis in this tooth. In addition, localization allows subsequent diagnostic tests to focus more on this particular tooth. When the symptoms are not well localized, the diagnosis is a greater challenge.

Commencement: *"When did the symptoms first occur?"* A patient who is having symptoms may remember when these symptoms started. Sometimes, the patient will even remember the initiating event: It may be spontaneous in nature, it may have begun after a dental visit for a restoration, trauma may be the etiology, or biting on a hard object may have initially produced the symptoms. However, the clinician should resist the tendency to make a premature diagnosis based on these circumstances. The clinician should not simply assume "guilt by association" but instead should use this information to enhance the overall diagnostic process.

Intensity: *"How intense is the pain?"* It often helps to quantify how much pain the patient is actually having. The clinician might ask, "On a scale from 1 to 10, with 10 the most severe, how would you rate your symptoms?" Hypothetically, a patient could present with "an uncomfortable sensitivity to cold" or "an annoying pain when chewing" but might rate this "pain" only as a 2 or a 3. These symptoms certainly contrast with the type of symptoms that prevent a patient from sleeping at night. Often the intensity can be subjectively measured by what is necessary for the diminution of pain, for example, acetaminophen versus a narcotic pain reliever. This intensity level may affect the decision to treat or not to treat with endodontic therapy.

Provocation and Relief of Pain: *"What produces or reduces the symptoms?"* Mastication and locally applied temperature changes account for the majority of initiating factors that cause dental pain. The patient may relate that drinking something cold causes the pain or possibly that chewing or biting is the only stimulus that "makes it hurt." The patient might say that the pain is only reproduced on "release from biting." On occasion, a patient may present to the dental office with a cold drink in hand and state that the symptoms can only be *reduced* by bathing the tooth in cold water. Some symptoms may be relieved by nonprescription pain relievers, and others may require narcotic medication for the reduction of symptoms (see Chapter 19 for more information). Note that patients who are using narcotic pain relievers may respond differently to questions and diagnostic tests, which may alter the objectivity of the diagnostic results. These provoking and relieving factors may help to determine which diagnostic tests should be performed to establish a more objective diagnosis.

Duration: *"Do the symptoms subside shortly, or do they linger after they are provoked?"* The difference between a cold sensitivity that subsides in seconds and one that subsides in minutes may determine whether a clinician repairs a defective restoration or provides endodontic treatment. The duration of symptoms after a stimulating event should be recorded as to how long the sensation is felt by the patient, and documented in terms of seconds or minutes.

Name: (Last) ________________________________ (First) ________________________________ **Date:** ____________ **Tooth:** _____

S. (SUBJECTIVE)
Chief Complaint:
History of Present Illness:

Nature of Pain: None Mild Moderate Severe
Quality: Dull Sharp Throbbing Constant
Onset: Stim Required Intermittent Spontaneous
Location: Localized Diffuse Referred Radiating to:
Duration: Seconds Minutes Hours Constant
Initiated by: Cold Heat Sweet Spontaneous Palpation Mastication Supination Keeps awake at night
Relieved by: Cold Heat OTC-Meds Narc-Meds

O. (OBJECTIVE)

Extraoral:
Facial swelling: Yes No
L Nodes swollen: Yes No

Intraoral:
Soft tissues: WNL
Swelling: Yes No Mild Moderate Severe Location:
Sinus tract: Yes No Closed
Clinical crown: Restn Caries Exposure Fracture

#	Cold	Heat	EPT	Perc	Palp	Mob	Bite Stick	Dis-color	Periodontal Exam								
									MB	B	DB	DL	L	ML	Recessn	Furcation	Bleed-Probing

(Normal: N No Response: 0 Mild: + Moderate: ++ Severe: +++ Lingered: L Delayed: D)

Radiographic Findings:
Alveolar Bone: WNL Apical lucency Lateral lucency Ap / Lat opacity Crestal bone loss
Lamina Dura: WNL Obscure Broken Widened
Roots: WNL Curvature Resorption Perforation Dilaceration Fracture Long Sinus / IAN
Pulp Chamber: WNL Calcification Pulp Stone Exposure Resorption Perforation
Pulp Canal: WNL Calcification Bifurcated Resorption Prior RCT Furcation Involvement Perforation
Crown: WNL Caries Restoration Crown Dens in dente
Sinus Tract: Traces to:

A. (Assessment)
Diagnosis: Pulpal: WNL Rev Pulpitis Irrev Pulpitis Necrosis Prior RCT / Non-healing Pulpless
Periapical: WNL APP CPP APA CPA Cond Osteitis
Etiology: Caries Restoration Prior RCT Iatrogenic Coronal leakage Trauma Perio Elective Resorptn VRF
Prognosis: Good Fair Poor

P. (PLAN)
Endodontic: Caries control RCT ReTx I&D Apico Apexification/genesis Perf / Resorption Repair

Periodontal: S/RP Crown lengthen Root amp Hemisection Extraction

Restorative: Temp Post space B/U P&C Onlay / Crown Bleach

FIG. 1-3 When taking a dental history and performing a diagnostic examination, often a premade form can be helpful in facilitating complete and accurate documentation. *(Courtesy Dr. Ravi Koka, San Francisco, Calif.)*

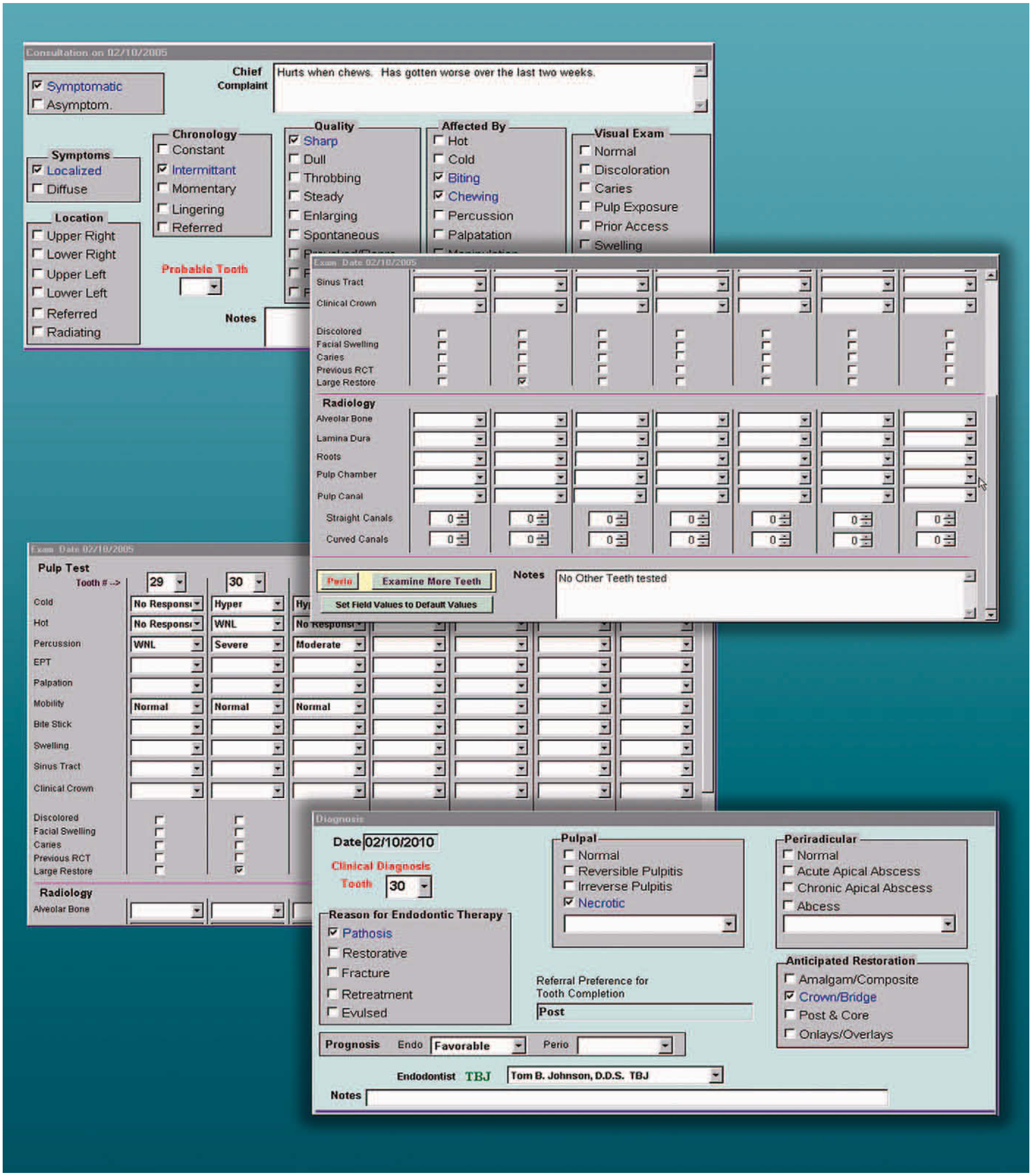

FIG. 1-4 Several practice management software packages have features for charting endodontic diagnosis using mouse-driven inputs, user-defined drop-down menus, and areas for specific notations. Note that for legal purposes, it is desirable that all recorded documentation have the ability to be locked, or if any modifications are made after 24 hours, the transaction should be recorded with an automated time/date stamp. This is necessary so that the data cannot be fraudulently manipulated. *(Courtesy PBS Endo, Cedar Park, Texas.)*

FIG. 1-5 A, Canine space swelling of the left side of the face extending into and involving the left eye. **B,** Swelling of the upper lip and the loss of definition of the nasolabial fold on the patient's left side, which is indicative of an early canine space infection.

With the dental history interview complete, the clinician has a better understanding of the patient's chief complaint and can concentrate on making an objective diagnostic evaluation, although the subjective (and artistic) phase of making a diagnosis is not yet complete and will continue after the more objective testing and scientific phase of the investigatory process.

EXAMINATION AND TESTING

Extraoral Examination

Basic diagnostic protocol suggests that a clinician observe patients as they enter the operatory. Signs of physical limitations may be present, as well as signs of facial asymmetry that result from facial swelling. Visual and palpation examinations of the face and neck are warranted to determine whether swelling is present. Many times a facial swelling can be determined only by palpation when a unilateral "lump or bump" is present. The presence of bilateral swellings may be indicative of a normal finding for any given patient; however, it may also be a sign of a systemic disease or the consequence of a developmental event. Palpation allows the clinician to determine whether the swelling is localized or diffuse, firm or fluctuant. These latter findings will play a significant role in determining the appropriate treatment.

Palpation of the cervical and submandibular lymph nodes is an integral part of the examination protocol. If the nodes are found to be firm and tender along with facial swelling and an elevated temperature, there is a high probability that an infection is present. The disease process has moved from a localized area immediately adjacent to the offending tooth to a more widespread systemic involvement.

Extraoral facial swelling of odontogenic origin typically is the result of endodontic etiology because diffuse facial swelling resulting from a periodontal abscess is rare. Swellings of non-odontogenic origin must always be considered in the differential diagnosis especially if an obvious dental etiology is not found.[54] This is discussed in subsequent chapters.

FIG. 1-6 Buccal space swelling associated with an acute periradicular abscess from the mandibular left second molar.

A subtle visual change such as loss of definition of the nasolabial fold on one side of the nose (Fig. 1-5) may be the earliest sign of a canine space infection.[55,94] Pulpal necrosis and periradicular disease associated with a maxillary canine should be suspected as the source of the problem. Extremely long maxillary central incisors may also be associated with a canine space infection, but most extraoral swellings associated with the maxillary centrals express themselves as a swelling of the upper lip and base of the nose. Further discussions of fascial space infections may be found in Chapter 15.

If the buccal space becomes involved, the swelling will be extraoral in the area of the posterior cheek (Fig. 1-6). These swellings are generally associated with infections originating from the buccal root apices of the maxillary premolar and molar teeth and the mandibular premolar (Fig. 1-7) and first molar teeth. The mandibular second and third molars may also be involved, but infections associated with these two teeth have as much likelihood to exit to the lingual where other spaces would be involved. For infections associated with these teeth, the root apices of the maxillary teeth must lie superior

FIG. 1-7 A, Buccal space swelling of the left side of the patient's face. Note the asymmetry of the left side of the face. **B,** Swelling in this case is also present in the left posterior mucobuccal fold. **C,** This buccal space infection was associated with periradicular disease from the mandibular left second premolar. Note on the radiograph the periradicular radiolucency and large restoration associated with this tooth.

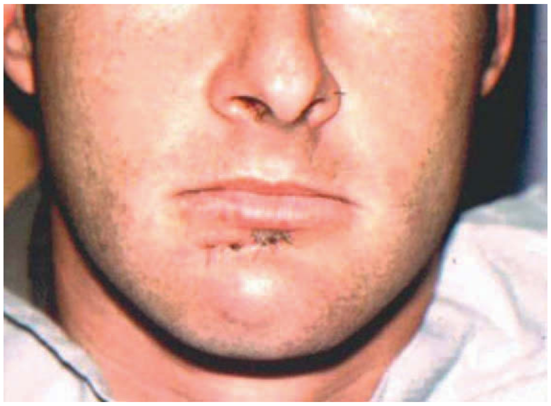

FIG. 1-8 Swelling of the submental space associated with periradicular disease from the mandibular incisors.

to the attachment of the buccinator muscle to the maxilla, and the apices of the mandibular teeth must be inferior to the buccinator muscle attachment to the mandible.[55,94]

Extraoral swelling associated with mandibular incisors will generally exhibit itself in the submental (Fig. 1-8) or submandibular space. Infections associated with any mandibular teeth, which exit the alveolar bone on the lingual and are inferior to the mylohyoid muscle attachment, will be noted as swelling in the submandibular space.[55,94] There is a complete review of fascial space infections in Chapter 15.

Sinus tracts of odontogenic origin may also open through the skin of the face (Figs. 1-9 and 1-10). These openings in the skin will generally close once the offending tooth is treated and healing occurs. A scar is more likely to be visible on the skin surface in the area of the sinus tract stoma than on the oral mucosal tissues (Fig. 1-11; see also Fig. 1-9). Many patients with extraoral sinus tracts will give a history of being treated by general physicians and dermatologists with systemic or topical antibiotics and/or surgical procedures in attempts to heal the extraoral stoma. In these particular cases, only after multiple treatment failures are the patients finally referred to a dental clinician to determine whether there is a dental etiology.[46]

Intraoral Examination

The extraoral examination may give the clinician insight as to which intraoral areas may need a more focused evaluation. Extraoral swelling, localized lymphadenopathy, or an extraoral sinus tract should provoke a more detailed assessment of related and proximal intraoral structures.

Soft Tissue Examination

As with any dental examination, there should be a routine evaluation of the intraoral soft tissues. The gingiva and

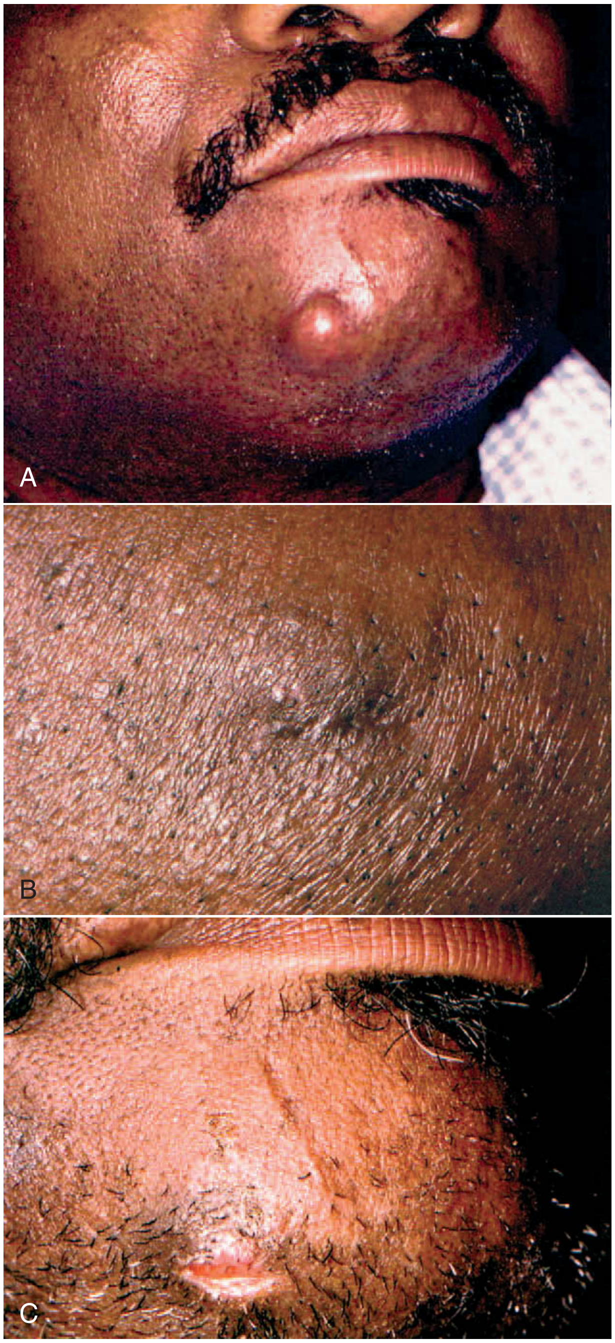

FIG. 1-9 A, Note the parulis on the right anterior side of the face. The extraoral drainage was found to be associated with periradicular disease from the mandibular right canine. **B,** Note the initial scar associated with the extraoral drainage incision after the parulis was drained and root canal therapy was performed on the canine. **C,** The healed incision area 3 months after drainage was achieved. Note the slight inversion of the scar area.

mucosa should be dried, either with an air syringe or a 2 × 2-in. gauze pad. By retracting the tongue and cheek, all of the soft tissue should be examined for any abnormalities in color or texture. Any raised lesions or ulcerations should be documented and, when necessary, evaluated with a biopsy or referral.[58]

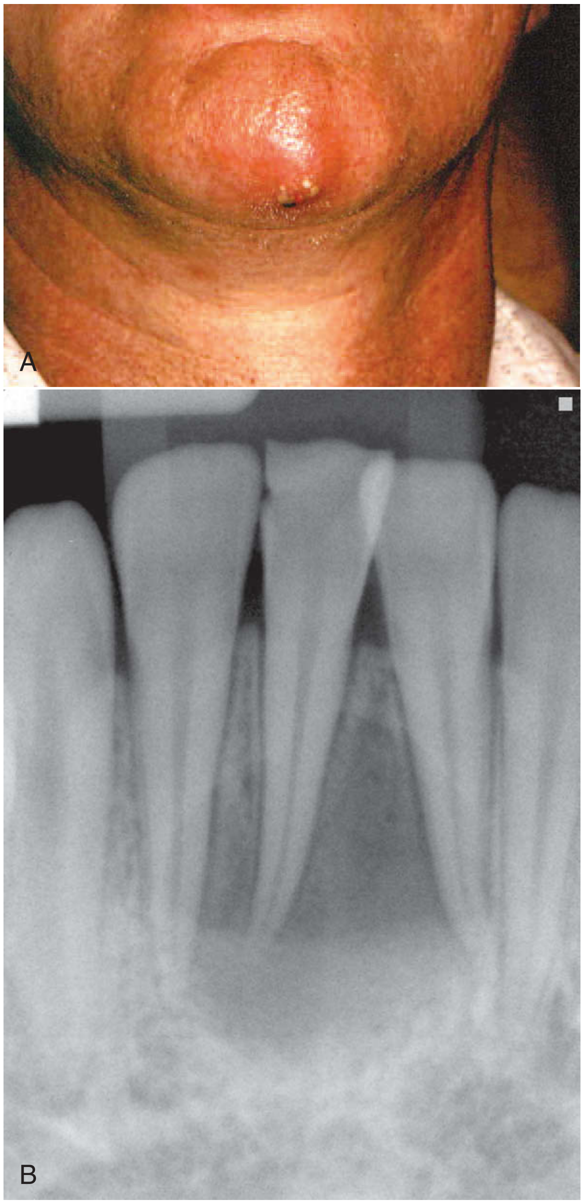

FIG. 1-10 A, Extraoral sinus tract opening on the skin in the central chin area. **B,** Radiograph of mandibular incisors and canine after root canal therapy.

Intraoral Swelling

Intraoral swellings should be visualized and palpated to determine whether they are diffuse or localized and whether they are firm or fluctuant. These swellings may be present in the attached gingiva, alveolar mucosa, mucobuccal fold, palate, or sublingual tissues. Other testing methods are required to determine whether the etiology is endodontic, periodontic, or a combination of these two or whether it is of nonodontogenic origin.

Swelling in the anterior part of the palate (Fig. 1-12) is most frequently associated with an infection present at the apex of the maxillary lateral incisor or the palatal root of the maxillary first premolar. More than 50% of the maxillary lateral incisor root apices deviate in the distal or palatal directions. A swelling

FIG. 1-11 A, A culture is obtained from the drainage from the extraoral sinus tract. **B,** The healed opening of the extraoral sinus tract 1 month after root canal therapy was completed. Note the slight concavity of the skin in the area of the healed extraoral opening.

FIG. 1-13 Fluctuant swelling in the posterior palate associated with periradicular disease from the lingual root of the maxillary first molar.

FIG. 1-12 Fluctuant swelling in the anterior palate associated with periradicular disease from the lingual root of the maxillary first premolar.

FIG. 1-14 Fluctuant swelling in mucobuccal fold associated with periradicular disease from the maxillary central incisor.

in the posterior palate (Fig. 1-13) is most likely associated with the palatal root of one of the maxillary molars.[55,94]

Intraoral swelling present in the mucobuccal fold (Fig. 1-14) can result from an infection associated with the apex of the root of any maxillary tooth that exits the alveolar bone on the facial aspect and is inferior to the muscle attachment present in that area of the maxilla (see also Chapter 15). The same is true with the mandibular teeth if the root apices are superior to the level of the muscle attachments and the infection exits the bone on the facial. Intraoral swelling can also occur in the sublingual space if the infection from the root apex spreads to the lingual and exits the alveolar bone superior to the attachment for the mylohyoid muscle. The tongue will be elevated and the swelling will be bilateral because the sublingual space is contiguous with no midline separation. If the infection exits the alveolar bone to the lingual with mandibular molars and is inferior to the attachment of the mylohyoid muscle, the swelling will be noted in the submandibular space. Severe infections involving the maxillary and mandibular molars can extend into the parapharyngeal space, resulting in intraoral swelling of the tonsillar and pharyngeal areas. This can be life-threatening if the patient's airway becomes obstructed.[55,94]

Intraoral Sinus Tracts

On occasion a chronic endodontic infection will drain through an intraoral communication to the gingival surface and is known as a *sinus tract*. This pathway,[7] which is sometimes lined with epithelium, extends directly from the source of the infection to a surface opening, or *stoma,* on the attached gingival surface. As previously described, it can also extend extraorally. The term *fistula* is often inappropriately used to describe this type of drainage. The fistula, by definition, is actually an abnormal communication between two internal organs or a pathway between two epithelium-lined surfaces.[1]

Histologic studies have found that most sinus tracts are not lined with epithelium throughout their entire length. Harrison and Larson[40] found only 1 of the 10 sinus tracts they studied were lined with epithelium. The other nine specimens were lined with granulation tissue. In a study with a larger sample size, Baumgartner and colleagues[7] found 20 of 30 specimens did not have epithelium that extended beyond the level of the surface mucosa rete ridges. The remaining 10 specimens had some epithelium that extended from the oral mucosa surface to the periradicular lesion. The presence or absence of an epithelial lining does not seem to prevent closure of the tract as long as the source of the problem is properly diagnosed and adequately treated and the endodontic lesion has healed. Failure of a sinus tract to heal will necessitate further diagnostic procedures to determine whether other etiologic factors are present or whether a misdiagnosis occurred.

In general, a periapical infection that has an associated sinus tract is not painful, although often there is a history of varying magnitude before the sinus tract development. Besides providing a conduit for the release of infectious exudate and the subsequent relief of pain, the sinus tract can also provide a useful aid in determining the source of a given infection. Sometimes objective evidence as to the origin of an odontogenic infection is lacking. The stoma of the sinus tract may be located directly adjacent to or at a distant site from the infection. Tracing the sinus tract will provide objectivity in diagnosing the location of the problematic tooth. To trace the sinus tract, a size #25 gutta-percha cone is threaded into the opening of the sinus tract. Although this may be slightly uncomfortable to the patient, the cone should be inserted until resistance is felt. After a periapical radiograph is exposed, the termination of the sinus tract is determined by following the path taken by the gutta-percha cone (Fig. 1-15). This will direct the clinician to which tooth is involved, and more specifically, which root of that tooth is the source of the pathosis. Once the causative factors related to the development of the sinus tract are removed, the stoma and the sinus tract will close within a few days.

The stomata of intraoral sinus tracts may open in the alveolar mucosa, in the attached gingiva, or through the furcation or gingival crevice. They may exit through either the facial or lingual tissues depending on the proximity of the root apices to the cortical bone. If the opening is in the gingival crevice, it is normally present as a narrow defect in one or two isolated areas along the root surface. When a narrow defect is present, the differential diagnosis must include the opening of a periradicular endodontic lesion, a vertical root fracture, or the presence of a developmental groove on the root surface. This

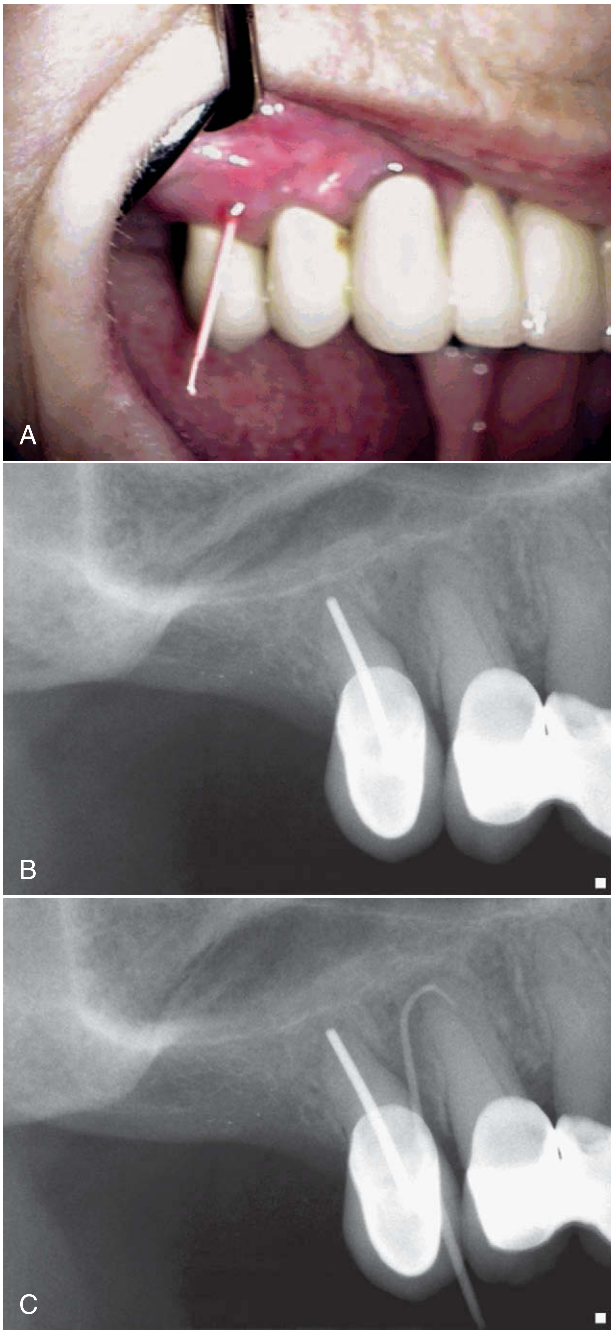

FIG. 1-15 A, To locate the source of an infection, the sinus tract can be traced by threading the stoma with a gutta-percha point. **B,** The radiograph of the area shows an old root canal in tooth #4, and a questionable radiolucent area associated with tooth #5, with no indication of the etiology of the sinus tract. **C,** After tracing the sinus tract, the gutta-percha is seen to be directed to the source of pathosis, the apex of tooth #5.

type of sinus tract can be differentiated from a primary periodontal lesion because the latter generally presents as a pocket with a broad coronal opening and more generalized alveolar bone loss around the root. Other pulp testing methods will assist in verifying the etiology.[39,90,93]

Palpation

In the course of the soft tissue examination, the alveolar hard tissues should also be palpated. Emphasis should be placed on detecting any soft tissue swelling or boney expansion, especially noting how it compares with and relates to the adjacent and contralateral tissues. In addition to objective findings, the clinician should question the patient about any areas that feel unusually sensitive during this palpation part of the examination.

Percussion

Referring back to the patient's chief complaint may indicate the importance of percussion testing for this particular case. If the patient is experiencing acute sensitivity or pain on mastication, this response can typically be duplicated by individually percussing the teeth, which often isolates the symptoms to a particular tooth. Pain to percussion does not indicate that the tooth is vital or nonvital, but is rather an indication of inflammation in the periodontal ligament (i.e., symptomatic apical periodontitis). This inflammation may be secondary to physical trauma, occlusal prematurities, periodontal disease, or the extension of pulpal disease into the periodontal ligament space. The indication of where the pain is coming from is interpreted by the mesencephalic nucleus, receiving its information from proprioceptive nerve receptors. Although subject to debate, the general belief is that there are few, if any, proprioceptors in the dental pulp; however, they are prevalent in the periodontal ligament spaces.[16] This is why it may be difficult for the patient to discriminate the location of dental pain in the earlier stages of pathosis, when only the C fibers are stimulated. Once the disease state extends into the periodontal ligament space, the pain may become more localized for the patient; therefore the affected tooth will be more identifiable with percussion and mastication testing.

Before percussing any teeth, the clinician should tell the patient what will transpire during this test. Because the presence of acute symptoms may create anxiety and possibly alter the patient's response, properly preparing the patient will give more accurate results. The contralateral tooth should first be tested as a control, as well as several adjacent teeth that are certain to respond normally. The clinician should advise the patient that the sensation from this tooth is normal and ask to be advised of any tenderness or pain from subsequent teeth. The testing should initially be done gently, with light pressure being applied digitally with a gloved finger-tapping. If the patient cannot detect any significant difference between any of the teeth, the test should be repeated using the blunt end of an instrument, like the back end of a mirror handle (Fig. 1-16). The teeth should first be percussed occlusally, and if the patient discerns no difference, the test should be repeated, percussing the buccal and lingual aspects of the teeth. For any heightened responses, the test should be repeated as necessary to determine that it is accurate and reproducible, and the information should be documented.

FIG. 1-16 Percussion testing of a tooth, using the back end of a mirror handle.

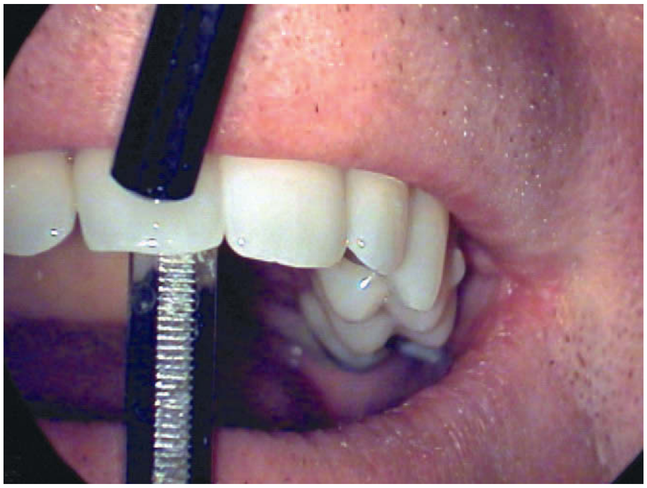

FIG. 1-17 Mobility testing of a tooth, using the back ends of two mirror handles.

Mobility

Like percussion testing, an increase in tooth mobility is not an indication of pulp vitality. It is merely an indication of a compromised periodontal attachment apparatus. This compromise could be the result of acute or chronic physical trauma, occlusal trauma, parafunctional habits, periodontal disease, root fractures, rapid orthodontic movement, or the extension of pulpal disease, specifically an infection, into the periodontal ligament space. Often the mobility reverses to normal after the initiating factors are repaired or eliminated. Because determining mobility by simple finger pressure can be visually subjective, the back ends of two mirror handles should be used, one on the buccal aspect of the tooth, and one on the lingual aspect of the tooth (Fig. 1-17). Any mobility over +1 mobility should be considered abnormal (Box 1-2). However, the teeth should be evaluated on the basis of how mobile they are relative to the adjacent and contralateral teeth.

BOX 1-2

Recording Tooth Mobility

+1 mobility: The first distinguishable sign of movement greater than normal
+2 mobility: Horizontal tooth movement no greater than 1 mm
+3 mobility: Horizontal tooth movement greater than 1 mm, with or without the visualization of rotation or vertical depressability

BOX 1-3

Recording Furcation Defects

Class I furcation defect: The furcation can be probed but not to a significant depth.
Class II furcation defect: The furcation can be entered into but cannot be probed completely through to the opposite side.
Class III furcation defect: The furcation can be probed completely through to the opposite side.

Periodontal Examination

Periodontal probing is an important part of any intraoral diagnosis. The measurement of periodontal pocket depth is an indication of the depth of the gingival sulcus, which corresponds to the distance between the height of the free gingival margin and the height of the attachment apparatus below. Using a calibrated periodontal probe, the clinician should record the periodontal pocket depths on the mesial, middle, and distal aspects of both the buccal and lingual sides of the tooth, noting the depths in millimeters. The periodontal probe is "stepped" around the long axis of the tooth, progressing in 1-mm increments. Periodontal bone loss that is wide, as determined by a wide span of deep periodontal probings, is generally considered to be of periodontal etiology and is typically more generalized in other areas of the mouth. However, isolated areas of vertical bone loss may be of an endodontic etiology, specifically from a nonvital tooth whose infection has extended from the periapex to the gingival sulcus. Again, proper pulp testing is imperative, not just for the determination of a diagnosis but also for the development of an accurate prognosis assessment. For example, a periodontal pocket of endodontic origin may resolve after endodontic treatment, but if the tooth was originally vital with an associated deep periodontal pocket, endodontic treatment will not improve the periodontal condition. In addition, as discussed elsewhere in this chapter, a vertical root fracture may often cause a localized narrow periodontal pocket that extends deep down the root surface. Characteristically, the adjacent periodontium is usually within normal limits.

Furcation bone loss can be secondary to periodontal or pulpal disease. The amount of furcation bone loss, as observed both clinically and radiographically, should be documented (Box 1-3).

Pulp Tests

Pulp testing involves attempting to make a determination of the responsiveness of pulpal sensory neurons. The tests involve thermal or electrical stimulation of a tooth in order to obtain a subjective response from the patient (i.e., to determine whether the pulpal nerves are functional), or the tests may involve a more objective approach using devices that objectively detect the integrity of the pulpal vasculature. Unfortunately, the quantitative evaluation of the status of pulp tissue can only be determined histologically, as it has been shown that there is not necessarily a good correlation between the objective clinical signs and symptoms and the pulpal histology.[91,92]

Thermal

Various methods and materials have been used to test the pulp's response to thermal stimuli. The baseline or normal response to either hot or cold is a patient's report that a sensation is felt but disappears immediately on removal of the thermal stimulus. Abnormal responses include a lack of response to the stimulus, the lingering or intensification of a painful sensation after the stimulus is removed, or an immediate, excruciatingly painful sensation as soon as the stimulus is placed on the tooth.

Heat testing is most useful when a patient's chief complaint is intense dental pain on contact with any hot liquid or food. When a patient is unable to identify which tooth is sensitive, a heat test is appropriate. Starting with the most posterior tooth in that area of the mouth, each tooth is individually isolated with a rubber dam. An irrigating syringe is filled with a liquid (most commonly plain water) that has a temperature similar to that which would cause the painful sensation. The liquid is then expressed from the syringe onto the isolated tooth to determine whether the response is normal or abnormal. The clinician moves forward in the quadrant, isolating each individual tooth until the offending tooth is located. That tooth will exhibit an immediate, intense painful response to the heat. With heat testing a delayed response may occur, so waiting 10 seconds between each heat test will allow sufficient time for any onset of symptoms.

Another method for heat testing is to apply heated gutta-percha or compound stick to the surface of the tooth. If this method is used, a light layer of lubricant should be placed onto the tooth surface before applying the heated material to prevent the hot gutta-percha or compound from adhering to the dry tooth surface. Heat can also be generated by the friction created when a dry rubber-polishing wheel is run at a high speed against the dry surface of a tooth. However, this latter method is seldom used today.

If the heat test confirms the results of other pulp testing procedures, emergency care can then be provided. Often a tooth that is sensitive to heat may also be responsible for some spontaneous pain. In these cases the patient may present with cold liquids in hand just to minimize the pain (Fig. 1-18). In these cases, the application of cold to a specific tooth may eliminate the pain and greatly assist in the diagnosis. Typically, a tooth that responds to heat and then is relieved by cold is found to be necrotic.

Cold is the primary pulp testing method for many clinicians today. To be most reliable, cold testing should be used in conjunction with an electric pulp tester so that the results

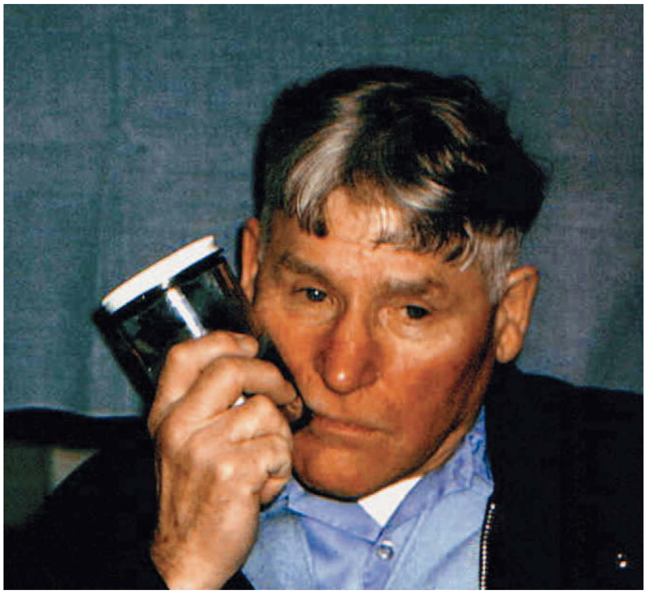

FIG. 1-18 Patient has irreversible pulpitis associated with the mandibular right second molar and has found that the only way to alleviate the pain is to place a jar filled with ice water against the right side of his face.

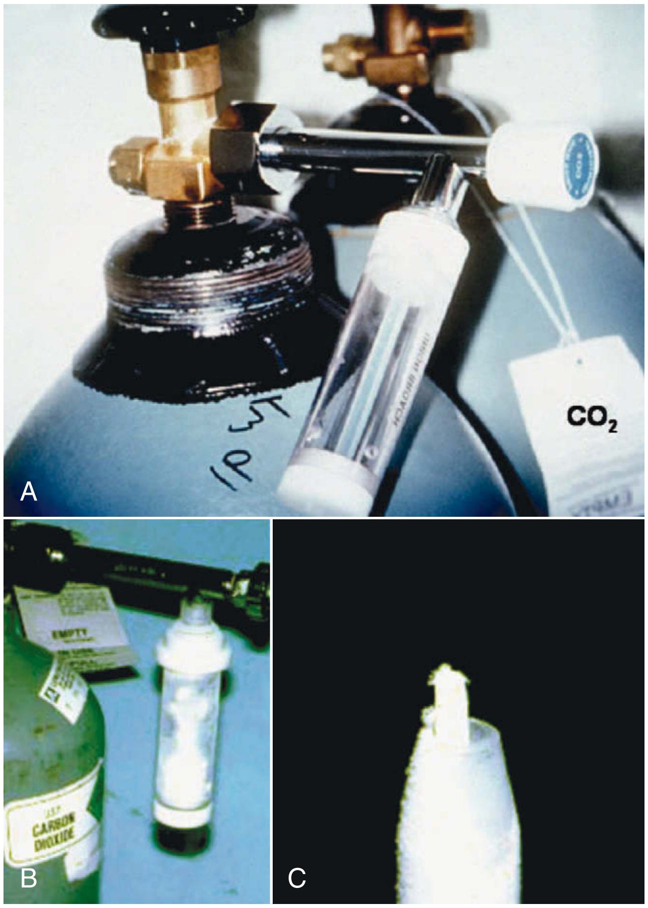

FIG. 1-19 A, Carbon dioxide tank with apparatus attached to form solid CO_2 stick/pencil. **B,** CO_2 gas being formed into a solid stick/pencil. **C,** CO_2 stick/pencil being extruded from the end of the plastic carrier.

from one test will verify the findings of the other test. If a mature, untraumatized tooth does not respond to both electric pulp test and cold test, then the pulp should be considered necrotic.[71] However, a multirooted tooth, with at least one root containing vital pulp tissue, may respond to a cold test even if one or more of the roots contain necrotic pulp tissue.[71] Cold testing can be accomplished similarly to heat testing, by individually isolating teeth with a rubber dam. This technique for cold testing is especially useful for patients presenting with porcelain jacket crowns or porcelain-fused-to-metal crowns where there is no natural tooth surface (or much metal) accessible. Another benefit of this technique for cold testing is that it requires no armamentarium except for a rubber dam. If a clinician chooses to perform this test with sticks of ice, then the use of the rubber dam is recommended because melting ice will run onto adjacent teeth and gingiva, yielding potentially false-positive responses.

Frozen carbon dioxide (CO_2), also known as *dry ice* or *carbon dioxide snow,* has been found to be reliable in eliciting a positive response if vital pulp tissue is present in the tooth.[32,71,72] One study found that vital teeth would respond to both CO_2 and skin refrigerant, with skin refrigerant producing a slightly quicker response.[48] Carbon dioxide has also been found to be effective in evaluating the pulpal response in teeth with full coverage crowns for which electric pulp testing is not possible.[6] For testing purposes a solid stick of CO_2 is prepared by delivering CO_2 gas into a specially designed plastic cylinder (Fig. 1-19). The resulting CO_2 stick is applied to the facial surface of either the natural tooth structure or crown. Several teeth can be tested with a single CO_2 stick. The teeth should be isolated and the oral soft tissues should be protected with a 2 × 2-in. gauze or cotton roll so the CO_2 will not come into contact with these structures. Because of the extremely cold temperature of the CO_2 (–69° F to –119° F; –56° C to –98° C) burns of the soft tissues can occur. Investigators[6] have demonstrated on extracted teeth that CO_2 application resulted in a significantly greater intrapulpal temperature decrease than either skin refrigerant or ice. Studies[45,77] have also shown that the application of CO_2 to teeth does not result in any irreversible damage to the pulp tissues or cause any significant enamel crazing.

The most popular method of performing cold testing is with a refrigerant spray. It is readily available, easy to use, and provides test results that are reproducible, reliable, and equivalent to that of CO_2.[32,48] One of the current product contains 1,1,1,2-tetrafluoroethane, which has zero ozone depletion potential and is environmentally safe. It has a temperature of –26.2° C.[48] The spray is most effective for testing purposes when it is applied to the tooth on a large #2 cotton pellet (Fig. 1-20). In one study[47] a significantly lower intrapulpal temperature was achieved when a #2 cotton pellet was dipped or sprayed with the refrigerant compared with the result when a small #4 cotton pellet or cotton applicator was used. The sprayed cotton pellet should be applied to the midfacial area of the tooth or crown. As with any other pulp testing method, adjacent or contralateral "normal" teeth should be tested to establish a baseline response. It appears that CO_2 and refrigerant spray are superior to other cold testing methods and equivalent or superior to the electric pulp tester for assessing pulp vitality.[6,32]

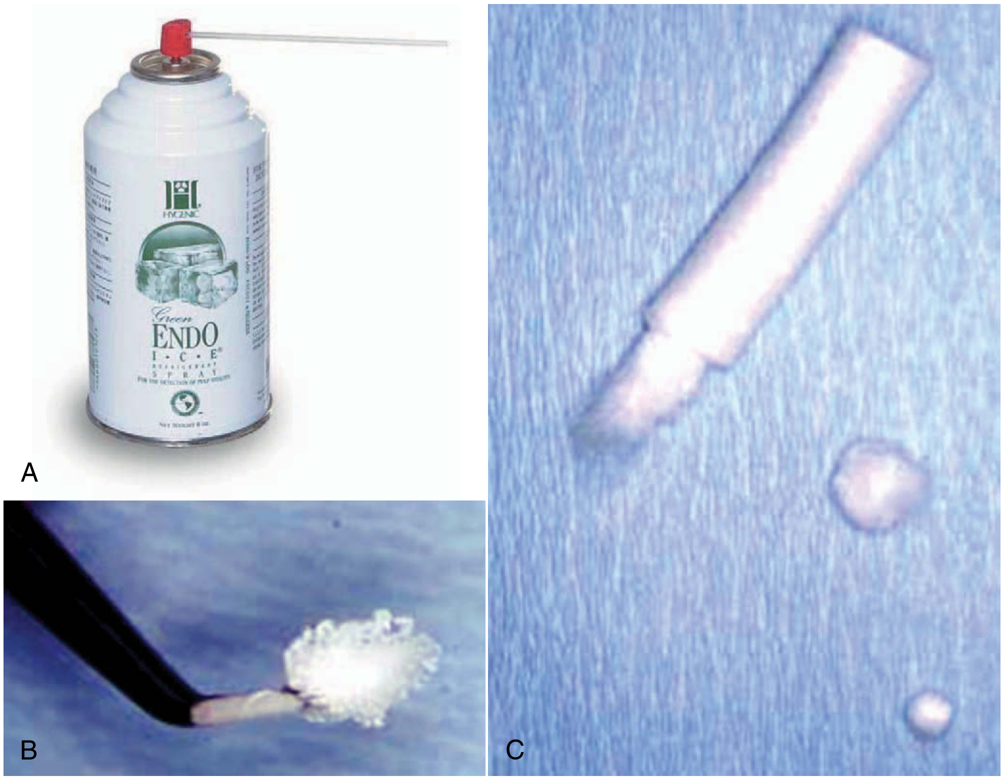

FIG. 1-20 A, Refrigerant spray container. **B,** A cotton roll can be used to form a large cotton pellet, or a size #2 (large) cotton pellet can be used to apply the refrigerant spray to the tooth surface. The small #4 cotton pellet does not provide as much surface area as the #2 cotton pellet, and therefore it should not be used to deliver the refrigerant to the tooth surface. **C,** A large cotton pellet that has been sprayed with the refrigerant and is ready to be applied to the tooth surface. (*A, Courtesy Coltène/Whaledent, Cuyahoga Falls, Ohio.*)

One study[72] compared the ability of thermal and electric pulp testing methods to register the presence of vital pulp tissue. The *sensitivity,* which is the ability of a test to identify teeth that are diseased, was 0.83 for the cold test, 0.86 for heat test, and 0.72 for the electric test. This means the cold test correctly identified 83% of the teeth that had a necrotic pulp, whereas heat tests were correct 86% of the time and electric pulp tests were correct only 72% of the time. This same study evaluated the *specificity* of these three tests. Specificity relates to the ability of a test to identify teeth without disease. Ninety-three percent of teeth with healthy pulps were correctly identified by both the cold and electric pulp tests, whereas only 41% of the teeth with healthy pulps were identified correctly by the heat test. From the results of the testing it was found that the cold test had an accuracy of 86%, the electric pulp test 81%, and the heat test 71%.

Electric

Assessment of pulp vitality is most frequently accomplished by electric pulp testing and/or cold testing. The vitality of the pulp is determined by the intactness and health of the vascular supply, not the status of the pulpal nerve fibers. Even though advances are being made with regard to determining the vitality of the pulp on the basis of the blood supply, this technology is not accurate enough at this time to be used on a routine basis in a clinical setting.

The electric pulp tester has limitations in providing information about the vitality of the pulp. The response of the pulp to electric testing does not reflect the histologic health or disease status of the pulp.[91,92] A response by the pulp to the electric current only denotes that some viable nerve fibers are present in the pulp and are capable of responding. Numerical readings on the pulp tester have significance only if the number differs significantly from the readings obtained from a control tooth tested on the same patient with the electrode positioned at a similar area on both teeth. However, in most cases, the response is scored as either present or absent. Studies[91,92] have shown that electric pulp test results are most accurate when no response is obtained to any amount of electric current. This lack of response has been found most frequently when a necrotic pulp is present. The electric pulp tester will not work unless the probe can be placed in contact with or be bridged[69] to the natural tooth structure. With the advent of universal precautions for infection control, the patient may be required to place a finger or fingers on the tester probe to complete the electric circuit for some models; however, lip clips are an alternative to having patients hold the tester. The use of rubber gloves prevents the clinician from completing the circuit.[3] Proper use of the electric pulp tester requires that the teeth to be evaluated be isolated and dried. A control tooth of similar tooth type and location in the arch should be tested first in order to establish a baseline response and to inform the patient what a "normal" sensation is. The suspected tooth should be tested at least twice to confirm the results. The tip of the testing probe that will be placed in contact with the tooth structure must be coated with a water- or petroleum-based medium.[62] The most commonly used medium is toothpaste. The coated probe tip is placed in the incisal third of the facial or buccal area of the tooth to be tested.[10] Once the probe is in contact with the tooth, the patient is asked to touch or grasp the tester probe (Fig. 1-21, *A*).[3] This completes the circuit and initiates the delivery of electric current to the tooth. The patient is instructed to remove his or her finger(s) from the probe when a "tingling" or "warming" sensation is felt in the tooth. The

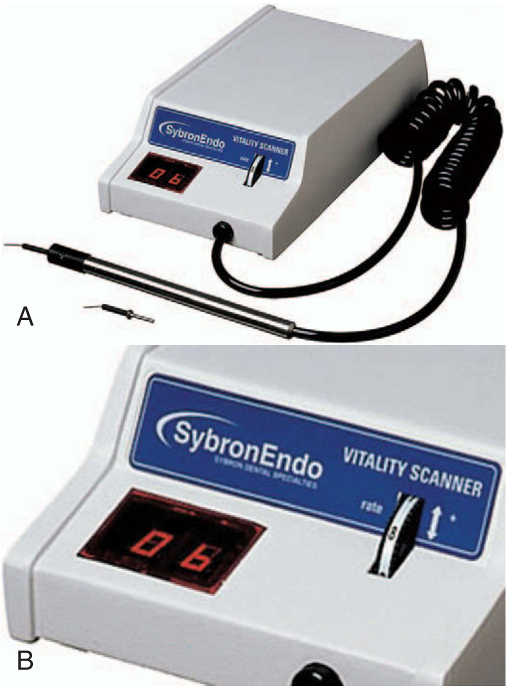

FIG. 1-21 A, View of an electric pulp tester with probe. The probe tip will be coated with a medium such as toothpaste and placed in contact with the tooth surface. The patient will activate the unit by placing a finger on the metal shaft of the probe. **B,** View of the electric pulp tester control panel: The knob on the right front of the unit controls the rate at which the electric current is delivered to the tooth. The plastic panel on the left front displays the digital numerical reading obtained from the pulp test. The digital scale runs from 0 to 80. *(Courtesy SybronEndo, Orange, Calif.)*

readings from the pulp tester are recorded (Fig. 1-21, B) and will be evaluated once all the appropriate teeth have been tested and the results obtained from other pulp testing methods.

If a complete coverage crown or extensive restoration is present, a bridging technique can be attempted to deliver the electric current to any exposed natural tooth structure.[69] The tip of an endodontic explorer is coated with toothpaste or other appropriate medium and placed in contact with the natural tooth structure. The tip of the electric pulp tester probe is coated with a small amount of toothpaste and placed in contact with the side of the explorer. The patient completes the circuit and the testing proceeds as described previously. If no natural tooth structure is available then an alternative pulp testing method, such as cold, should be used.

As noted previously, studies[32,71,72] have shown that there does not appear to be any significant difference between the pulp testing results obtained with the electric pulp tester and those obtained by the thermal methods, although cold tests have been shown to be more reliable than electric pulp tests in younger patients with less developed root apices.[71] However, unlike electric pulp testing, cold testing can reveal the health and integrity of pulp tissue (i.e., no response, a momentary response, or a prolonged, painful response after the thermal stimulus is removed). This is why it is a good rationale to verify the results obtained by one testing method by comparing them with the results obtained by the other method. Until such time that the testing methods used to assess the vascular supply of the pulp become less time-consuming and technique-sensitive, thermal and electric pulp testing will continue to be the primary methods for determining pulp vitality.

FIG. 1-22 Nellcor OxiMax N-600× pulse oximeter. *(Courtesy Nellcor Puritan Bennett [Boulder, Colo]; part of Covidien.)*

Laser Doppler Flowmetry

Laser Doppler flowmetry (LDF) is a method used to assess blood flow in microvascular systems. Attempts are being made to adapt this technology to assess pulpal blood flow. A diode is used to project an infrared light beam through the crown and pulp chamber of a tooth. The infrared light beam is scattered as it passes through the pulp tissue. The Doppler principle states that the light beam will be frequency-shifted by moving red blood cells but will remain unshifted as it passes through static tissue. The average Doppler frequency shift will measure the velocity at which the red blood cells are moving.[81]

Several studies[25,44,61,81-83] have found LDF to be an accurate, reliable, and reproducible method of assessing pulpal blood flow. Even with these positive findings, the technology is not advanced enough for this method to be used on a routine basis in a dental practice. In one clinical trial[25] fabricating the individualized stabilization jig, making the LDF recordings took approximately 1 hour, a finding not unique to this study. If technology can be developed whereby testing by LDF can be accomplished in minutes, it will likely replace the thermal and electric pulp testing methods.

As is discussed in Chapter 16, certain luxation injuries will cause inaccuracies in the results of electric and thermal pulp testing. LDF has been shown to be a great indicator for pulpal vitality in these cases.[96]

Pulse Oximetry

One of the great advantages of pulp testing with devices such as the laser Doppler flowmeter is that the collected data are based on objective findings rather than subjective patient responses. The pulse oximeter is another such noninvasive device (Fig. 1-22). Widely used in medicine, it is designed to measure the oxygen concentration in the blood and the pulse rate. A pulse oximeter works by transmitting two wavelengths of light, red and infrared, through a translucent portion of a patient's body (e.g., a finger, earlobe, or tooth). Some of the light is absorbed as it passes through the tissue; how much is absorbed depends on the ratio of oxygenated to deoxygenated hemoglobin in the blood. On the opposite side of the targeted tissue, a sensor detects the absorbed light, and on the basis of the difference between the light emitted and the light received, a microprocessor calculates the pulse rate and oxygen concentration in the blood.[84] The transmission of light to the sensor requires that there be no obstruction from restorations, which can sometimes limit the usefulness of pulse oximetry to test pulp vitality.

Attempts to use the pulse oximeter to diagnosis pulp vitality have met with mixed results. Some studies[84,103] have reported that pulse oximetry is a reliable method for assessing pulp vitality. Others[103] have stated that in its present form the pulse oximeter is not of predictive diagnostic value for diagnosing pulp vitality. Most of the problems appear to be related to the currently available technology. Some investigators have concluded that these devices used for pulp testing are too cumbersome and complicated to be used on a routine basis in a dental practice.[50,84,103] However, Gopikrishna and colleagues[37] developed a sensor that can be directly applied to a tooth for assessing human pulp vitality and found it more accurate than electric and thermal pulp tests. This device has been especially useful in evaluating teeth that have been subjected to traumatic injuries,[38] because these teeth tend to present, especially in the short term, with questionable vitality using conventional pulp testing methods.[4]

Special Tests

Bite Test

Percussion and bite tests are indicated when a patient presents with pain while biting. On occasion, the patient may not know which tooth is sensitive to biting pressure, and percussion and bite tests may help to localize the tooth involved. The tooth may be sensitive to biting when the pulpal pathosis has extended into the periodontal ligament space, creating a *periradicular periodontitis,* or the sensitivity may be present secondary to a crack in the tooth. The clinician can often differentiate between periradicular periodontitis and a cracked tooth or fractured cusp. If periradicular periodontitis is present, the tooth will respond with pain to percussion and biting tests regardless of where the pressure is applied to the coronal part of the tooth. A cracked tooth or fractured cusp will elicit pain only when the percussion or bite test is applied in a certain direction to one cusp or section of the tooth.[15,80]

For the bite test to be meaningful a device should be used that will allow the clinician to apply pressure to individual cusps or areas of the tooth. A variety of devices have been used for bite tests, including cotton applicators, toothpicks, orangewood sticks, and rubber polishing wheels. Today several devices are specifically designed to perform this test. The Tooth Slooth (Professional Results, Laguna Niguel, CA) (Fig. 1-23) and FracFinder (Hu-Friedy, Oakbrook, IL) are just two of the commercially available devices used for the bite test. As with all pulp tests, adjacent teeth should be used as controls so that the patient is aware of the "normal" response to these tests. The small cupped-out area on these instruments is placed in contact with the cusp to be tested. The patient is then asked to apply biting pressure with the opposing teeth to the flat surface on the opposite side of the device. The biting pressure should be applied slowly until full closure is achieved. The firm pressure should be applied for a few seconds; the patient is then asked to release the pressure quickly. Each individual cusp on a tooth can be tested in a like manner. The clinician should note whether the pain is elicited during the pressure phase or on quick release of the pressure. A common finding with a fractured cusp or cracked tooth is the frequent presence of pain on release of biting pressure.

FIG. 1-23 To determine which tooth is sensitive to mastication and which part of that tooth is sensitive, having the patient bite on a specially designed bite stick is often helpful.

Test Cavity

The test cavity method for assessing pulp vitality is seldom used today. This method is used only when all other test methods are deemed impossible or the results of the other tests are inconclusive. An example of a situation in which this method might be used is when the tooth suspected of having pulpal disease has a full coverage crown. If no sound tooth structure is available to use a bridging technique with the electric pulp tester and cold test results are inconclusive, a small class I cavity preparation is made through the occlusal surface of the crown. This is accomplished with a high-speed #1 or #2 round bur with proper air and water coolant. The patient is not anesthetized while this procedure is performed, and the patient is asked to respond if any painful sensation is felt during the drilling procedure. If the patient feels pain once the bur contacts sound dentin, the procedure is terminated and the class I cavity preparation is restored. This sensation signifies only that there is some viable nerve tissue remaining in the pulp, not that the pulp is totally healthy. If the patient fails to feel any sensation when the bur reaches the dentin, it is a good indication that the pulp is necrotic and root canal therapy is indicated.

Staining and Transillumination

To determine the presence of a crack in the surface of the tooth, the application of a stain to the area is often of great assistance. Applying a bright fiberoptic light probe to the surface of the tooth is also helpful. This will be elaborated on later in this chapter in the discussion of the detection of cracks and fractures.

Selective Anesthesia

When symptoms are not localized or referred, the diagnosis may be challenging. Sometimes the patient may not even be able to specify whether the symptoms are emanating from the maxillary or mandibular arch. In these instances, when pulp testing is inconclusive, *selective anesthesia* may be helpful.

If the patient cannot determine which arch the pain is coming from, then the clinician should first selectively anesthetize the maxillary arch. This should be accomplished by using a periodontal ligament (intraligamentary) injection. The injection is administered to the most posterior tooth in the quadrant of the arch that may be suspected, starting from the distal sulcus. The anesthesia is subsequently administered in an anterior direction, one tooth at a time, until the pain is eliminated. If, after an appropriate period of time, the pain is not eliminated, the clinician should similarly repeat this technique on the mandibular teeth below. It should be understood that periodontal ligament injections may inadvertently anesthetize an adjacent tooth, and thus are more useful for identifying the arch rather than the specific tooth.

Radiographic Examination and Interpretation

Intraoral Radiographs

Few diagnostic tests provide as much useful information as dental radiography. For this reason, the clinician is sometimes tempted to prematurely make a definitive diagnosis based solely on radiographic interpretation. However, the image should be used only as one sign, providing important clues in the diagnostic investigation. When not coupled with a proper history and clinical examination and testing, the radiograph alone can lead to a misinterpretation of normality and pathosis (Fig. 1-24). Because treatment planning will ultimately be based on this diagnosis, the potential for inappropriate treatment may be great if the radiograph alone is used for making this diagnosis. The clinician should not subject the patient to unnecessary multiple radiation exposures; often two pretreatment images from different angulations are sufficient. But in extenuating circumstances, especially when the diagnosis is difficult, multiple exposures may be necessary in order to determine the presence of multiple roots, multiple canals, resorptive defects, caries, restoration defects, root fractures, and the extent of root maturation and apical development.

The radiographic appearance of endodontic pathosis can sometimes be highly subjective. In a study by Goldman and colleagues,[34] there was agreement for the presence of pathosis in only 50% of the radiographically evaluated cases, as interpreted by two endodontists, three second-year residents, and an associate professor in radiology. In addition, when the cases were evaluated several months later, the evaluators agreed with their own original diagnosis only 75% to 83% of the time. Again, this emphasizes the necessity for other objective diagnostic tests, as well as the importance of obtaining and comparing older radiographs.

For standard two-dimensional radiography, clinicians basically project x-radiation through an object and capture the image on a recording medium—either x-ray film or a digital sensor. Much like casting a shadow from a light source, the image appearance may vary greatly depending on how the radiographic source is directed. Therefore, the three-dimensional interpretation of the resulting two-dimensional image requires not only knowledge of normality and pathosis but also advanced knowledge of how the radiograph was exposed. By virtue of "casting a shadow," the anatomic features

FIG. 1-24 Radiograph of what appears to be a periapical lesion associated with a nonvital tooth; however, the tooth is vital. The appearance of apical bone loss is actually secondary to a cementoma.

that are closest to the film (or sensor) will move the least when there is a change in the horizontal or vertical angulation of the radiation source (Fig. 1-25). This may be helpful in determining the existence of additional roots, the location of pathosis, and the unmasking of anatomic structures. Changes in the horizontal or vertical angulation may help elucidate valuable anatomic and pathologic information; it also has the potential to hide important information. An incorrect vertical angulation may cause the buccal roots of a maxillary molar to be masked by the zygomatic arch. An incorrect horizontal angulation may cause roots to overlap with the roots of adjacent teeth, or it may incorrectly create the appearance of a one-rooted tooth, when two roots are actually present.

In general, when endodontic pathosis appears radiographically, it appears as bone loss in the area of the periapex. The infection in the pulpal space transgresses through the pulp canal space and into the adjacent alveolar bone. The pathosis may present merely as a widening or break in the lamina dura—the most consistent radiographic finding when a tooth is nonvital[49]—or it may present as a radiolucent area at the apex of the root or in the alveolar bone adjacent to the exit of a lateral or furcation canal. On occasion there may be no radiographic change at all, even in the presence of an acute periradicular abscess.

Variability in the radiographic expression of an osseous pathosis has much to do with the relative location of the root of the tooth and how it is oriented with respect to the cortical and cancellous bone. Radiographic changes from bone loss will

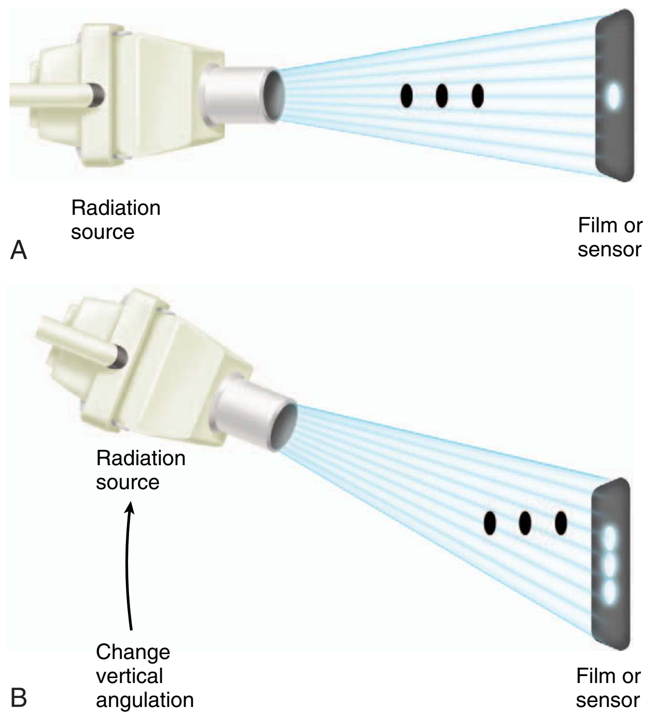

FIG. 1-25 Radiographic images are only two-dimensional, and often it is difficult to discriminate the relative location of overlapping objects. **A,** When the source of the radiation is directly perpendicular to overlapping objects, the image is captured without much separation of the objects. However, when the radiation source is at an angle to offset the overlapping objects, the image is captured with the objects being viewed as separated. **B,** The object that is closest to the film (or sensor) will move the least, with the object closest to the radiation source appearing farthest away.

not be detected if the bone loss is only in cancellous bone. However, radiographic evidence of pathosis will be observed once this bone loss extends to the junction of the cortical and cancellous bone, as was illustrated by Bender and Seltzer,[11] who created artificial lesions in cadaver bone and evaluated them radiographically. As a follow-up to this study, the authors reported why certain teeth are more prone to exhibit radiographic changes than others, depending on their anatomic location.[12] Their findings revealed that the radiographic appearance of endodontic pathosis is correlated with the relationship of the periapex of the tooth and its juxtaposition to the cortical–cancellous bone junction. Most anterior and premolar teeth are located close to the cortical–cancellous bone junction. For this reason, periapical pathosis from these teeth is exhibited sooner. By comparison, the distal roots of mandibular first molars and both roots of mandibular second molars are generally positioned more centrally within the cancellous bone, as are maxillary molars, especially the palatal roots. Periapical lesions from these roots must expand more before they reach the cortical–cancellous bone junction and are recognized as radiographic pathosis. For these reasons, it is important not to exclude the possibility of pulpal pathosis in situations in which there are no radiographic changes.

Many factors can influence the quality of the radiographic interpretation, including the ability of the person exposing the radiograph, the quality of the radiographic film, the quality of the exposure source, the quality of the film processing, and the skill with which the film is viewed. Controlling all of these variables can be a difficult challenge but is paramount for obtaining an accurate radiographic interpretation.

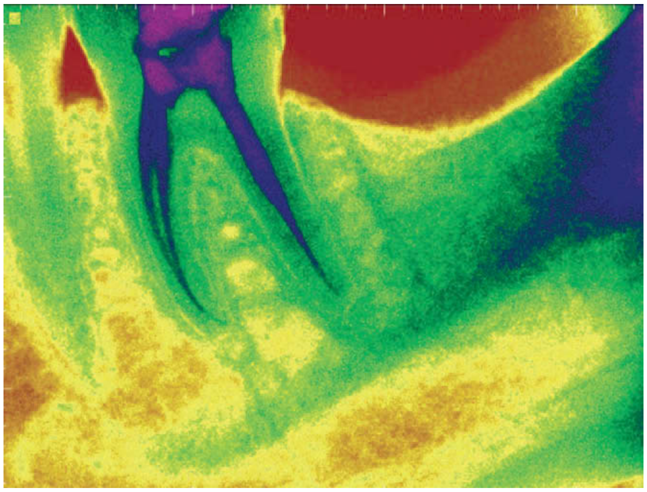

FIG. 1-26 Digital radiography has an advantage over conventional film in that the image can be enhanced and colorized, a useful tool for patient education.

Digital Radiography

One technique for controlling many of the variables in the diagnostic quality of conventional radiography has been the advent of *digital radiography*. This technology has been available for approximately 20 years but has more recently been refined with better hardware and more user-friendly software. Digital radiography has the ability to capture, view, magnify, enhance, and store radiographic images in an easily reproducible format that does not degrade over time.

Digital radiography uses no x-ray film and requires no chemical processing. Instead, a *sensor* is used to capture the image created by the radiation source. This sensor is either directly or remotely attached to a local computer, which interprets this signal and, using specialized software, translates the signal into a two-dimensional digital image that can be displayed and enhanced. The image is stored in the patient's file, typically in a dedicated network server, and can be recalled as needed. Further information about digital radiography may be found in Chapter 5 and online Chapters 28 and 29.

The viewing of a digital radiographic image on a high-resolution monitor allows for rapid and easy interpretation for both the clinician and the patient. The image appears almost instantly, with no potential for image distortion from improper chemical processing, because there is none. The clinician can zoom in to different areas on the x-ray image, digitally enhance the image in order to better visualize certain anatomic structures, and in some cases the image can even be colorized, a useful tool for patient education (Fig. 1-26).

Until recently, x-ray film has had a slightly better resolution than most digital radiography images, at about 16 line pairs per millimeter (lp/mm).[63] However, some sensor manufacturers are now claiming to have resolutions beyond that of film and up to 22 lp/mm. Under the best of circumstances, the human eye can see only about 10 lp/mm, which is the lowest resolution for most dental digital radiography systems. The digital sensors are much more sensitive to radiation than conventional x-ray film and thus require 50% to 90% less radiation in order to acquire an image, an important feature for generating greater patient acceptability of dental radiographs.

The diagnostic quality of this expensive technology has been shown to be comparable to, but not necessarily superior to, perfectly exposed and perfectly processed conventional film-based radiography.[24,52,70] However, digital radiography has the advantage over conventional film in that there is no diminution in diagnostic quality caused by developing and processing errors, and it has the ability to enhance, magnify, store, and electronically send the images, as well the ability to duplicate the original radiograph as a perfect copy. In 1998, the American Association of Endodontists (Chicago, IL) predicted that "digital radiography will rapidly replace conventional dental X-rays."[2] The reader is referred to Chapters 28 and 29 for more information about digital radiography.

Cone-Beam Volumetric Tomography

The radiographic interpretation of a potential endodontic pathosis is an integral part of endodontic diagnosis and prognosis assessment. Until about 10 years ago, routine dental radiography consisted of only two-dimensional imaging. But limitations in conventional radiography promulgated a need for three-dimensional imaging, known as *cone-beam volumetric tomography* (CBVT) (also known as *cone-beam volumetric imaging* [CBVI] or cone-beam computerized tomography [CBCT]). Although a form of this technology has existed since the early 1980s,[79] these devices first appeared specifically for use in dentistry in 1998.[65] Most of these machines are similar to a dental panoramic radiographic device, whereby the patient stands or sits as a cone-shaped radiographic beam is directed to the target area with a reciprocating capturing sensor on the opposite side (Fig. 1-27). The resulting information is digitally reconstructed and interpreted to create an interface whereby the clinician can three-dimensionally interpret "slices" of the patient's tissues in a multitude of planes (Figs. 1-28 and 1-29). The survey of the scans can be directly interpreted immediately after the scan. Various software applications have been used to enable the images to be sent to other clinicians. This is accomplished either in printed format or with portable and transferable software that can be interactively used by another clinician.

FIG. 1-27 Cone-beam volumetric tomography, using the 3D Accuitomo 80. *(Courtesy J. Morita USA, Irvine, Calif.)*

In general, the dental clinician will desire a limited field of vision, confining the study to the maxilla and mandible. However, many devices have the ability to provide a full field of vision for viewing more regional structures. Clinicians should thoroughly understand the ethical and medical–legal ramifications of doing scans with full fields of view. Incidental nondental findings have been seen from these scans, such as

FIG. 1-28 Cone-beam volumetric tomography has the ability to capture, store, and present radiographic images in various horizontal and vertical planes. *(Courtesy J. Morita USA, Irvine, Calif.)*

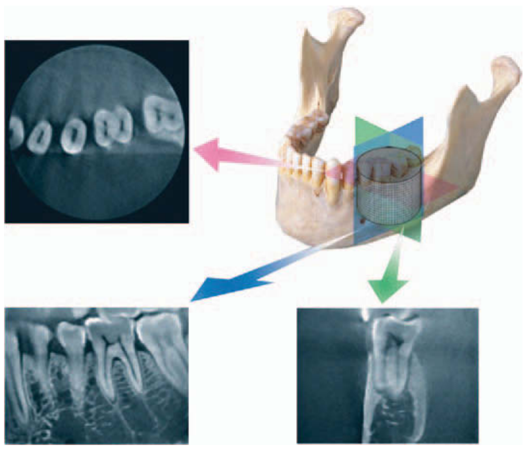

FIG. 1-29 Cone-beam volumetric tomography has the advantage of being able to detect pathosis in the bone or associated with the teeth without the obstruction of anatomic structures. The planes of vision may be axial, sagittal, or coronal. *(Courtesy J. Morita USA, Irvine, Calif.)*

intracranial aneurysms, that when undetected could be life-threatening.[66] The radiation source of CBVT is different from that of conventional two-dimensional dental imaging in that the radiation beam created is conical in shape. Also, conventional digital dental radiography is captured and interpreted as "pixels," a series of "dots" that collectively produces an image of the scanned structure. For CBVT, the image is instead captured as a series of three-dimensional pixels, known as *voxels*. Combining these voxels gives a three-dimensional image that can be "sliced" into various planes, allowing for specific evaluations never before possible without a necropsy (Fig. 1-30). One of the advantages of using a device that has a limited field of vision is that the voxel size can be less than half that of a device using a full field of vision, thereby increasing the resolution of the resulting image, providing for a more accurate interpretation of anatomic structures. The development of limited field of vision devices has also contributed to decreasing the costs of these relatively expensive machines, making them more practical for dental office use.[27]

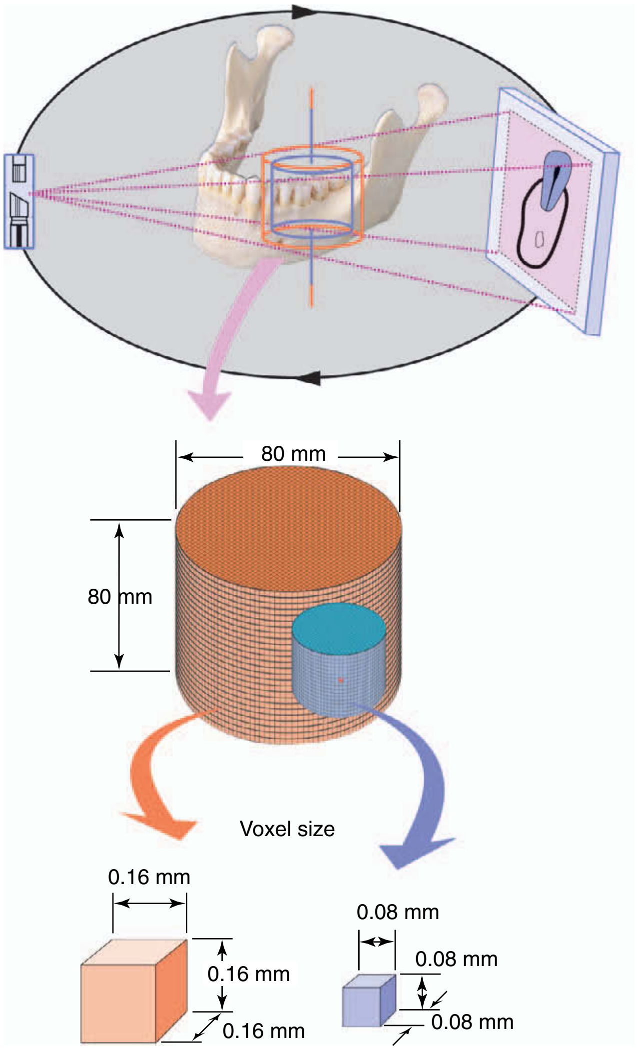

FIG. 1-30 The radiation source in cone-beam volumetric tomography is conical. The receiving sensor captures the image as "voxels," or three-dimensional pixels of information, allowing digital interpretation.

Two-dimensional dental radiography has two basic shortcomings: the lack of early detection of pathosis in the cancellous bone because of the density of the cortical plates, and the influence of the superimposition of anatomic structures. In 1961, Bender and Seltzer[11,12] showed that artificially created "lesions" in cancellous bone were radiographically undetected unless the bone loss extended to the junction between the cancellous and cortical bone. Therefore, an infection that is present only in the cancellous bone will typically not be radiographically visible. Consistent with this finding, if the root of a nonvital infected tooth is closer to the cortical bone (e.g., the *mesial* root of a mandibular first molar), the pathosis will be detected sooner than if the infected root is more centered within the cancellous bone (e.g., the *distal* root of a mandibular first molar). Because CBVT can clearly visualize the interior of the cancellous bone without the superimposition of the cortical bone, these boney defects may be more easily detected. In 2007, Lofthag-Hansen and colleagues[57] studied 48 teeth with "endodontic problems," using both standard periapical radiographs and CBVT. Three different oral radiologists reviewed the scans. They found demonstrable lesions associated with 32 of these teeth, using standard periapical radiographs, but found pathosis associated with 42 teeth when using CBVT. In addition, 53 roots from these teeth were found to have pathosis associated with them, using standard periapical radiographs, whereas when using CBVT, 86 roots were found to have associated pathosis. Nakata and colleagues[67] showed how periapical bone loss associated with a palatal root was detected by CBVT when it was not visible in conventional periapical radiographs. The superimposition of anatomic structures can also mask the interpretation of alveolar defects. Specifically, the maxillary sinus, zygoma, incisive canal and foramen, nasal bone, orbit, mandibular oblique ridge, mental foramen, mandibular mentalis, sublingual salivary glands, tori, and the overlap of adjacent roots may either obscure bone loss or mimic bone loss, making an accurate radiographic interpretation sometimes difficult or impossible. Cotton and colleagues[19] presented seven case reports in which CBVT was invaluable in ascertaining information essential for making a diagnosis related to alveolar pathoses. These scans revealed an incomplete root canal, a large incisive foramen suspicious of being a lesion of endodontic origin, a root fracture, internal resorption, cervical resorption, root canal cement extruded with symptoms associated with the mental nerve, and a lesion associated with a failed implant that was originally thought to have been of endodontic origin from an adjacent tooth. In 2001, Velvart and colleagues[102] found 100% accuracy with CBVT scans predicting 78 periapical lesions that were then confirmed by surgical biopsy. However, when applying conventional radiographic imaging to these same cases, they found that only 78% of these lesions could be detected.

Cone-beam volumetric tomography should not be seen as a replacement for conventional dental radiography, but rather as a diagnostic adjunct. The advantage of conventional dental radiography is that it can visualize most of the structures in one image. CBVT, although it can show great detail in many planes of vision, can also leave out important details if the "slice" is not in the area of existing pathosis (Fig. 1-31). There is a promising future for the use of CBVT for endodontic diagnosis. It has already proven invaluable in the detection of dental and nondental pathoses (Fig. 1-32).