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KENNETH M. HARGREAVES | LOUIS H. BERMAN

COHEN'S PATHWAYS *of the* PULP

ELEVENTH EDITION

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He has served in leadership roles for various dental organizations, including chair of the International Federation of Endodontic Associations' Research Committee, member on committees of the American Association of Endodontists, European Society of Endodontology, and as scientific reviewer for international endodontic and dental journals. He has also served as president of the Southern California Academy of Endodontists, Israel Endodontic Society, International Association for Dental Research—Israel Division, and chair of the Israel National Board of Diplomates in Endodontics.

Dr. Rotstein has published more than 150 scientific papers and research abstracts in the dental literature as well as chapters in international endodontic textbooks, including *Pathways of the Pulp*, *Ingle's Endodontics*, *Endodontics: Principles and Practice*, *Seltzer and Bender's Dental Pulp*, and *Harty's Endodontics in Clinical Practice*. He has lectured extensively in more than 25 countries throughout 5 continents.

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Stephen Cohen
MA, DDS, FICD, FACD

The field of endodontics would be difficult to imagine without *Pathways of the Pulp*. In speaking with colleagues across North America and around the world, it becomes clear that *Pathways* has had an immense, ubiquitous, and persistent impact on endodontics. This enduring contribution to our specialty is due to the genius of Stephen Cohen, who, together with Richard Burns, developed the most distinguished and perpetually updated evidenced-based textbook in our specialty. Their insight was to form a collaboration of the most renowned experts in our field, with expansion of the authorships for each new edition, and with an unwavering emphasis on the art and science of contemporary endodontic therapy. The result was a textbook that is both comprehensive and nuanced, which has transcended 11 editions and 14 languages since 1976. As each edition of *Pathways* evolved, it changed with the times, updating from unquestionable dogma into what was later considered the novel state of the art. Each edition progressed through the decades of endodontics and was inclusive of the next generation of technologies, philosophies, materials, devices, and instruments. As a result, with Steve as the lead editor since its inception, *Pathways of the Pulp* is considered the most comprehensive and innovative endodontic textbook available, literally defining the field of endodontics.

Stephen is an active educator, having lectured for decades around the world and serving as a Clinical Professor of Endodontics at the Arthur A. Dugoni School of Dentistry of the University of the Pacific. His passion for teaching, coupled with his distinctive authoritative voice and his vast scientific and clinical expertise, generates a highly effective combination for educating students on every facet of the endodontic specialty. His steadfast commitment in his authoring and editing of *Pathways of the Pulp* has propelled this textbook into what it is today.

In short, Dr. Stephen Cohen is a renaissance man, being both a practitioner and a teacher, whose breadth of expertise is leveraged by a passionate focus on detail and clarity. Defined by his unquestionable ethics and pursuit of perfection, Stephen's philosophy of learning, teaching, and practicing endodontics can best be summed up in his own words, as he penned in the Introduction of his last edition of *Pathways*:

"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."

Steve is a pioneer who has transformed the field of endodontics. For the tenth edition of this textbook, we recognized his legacy by renaming this textbook *Cohen's Pathways of the Pulp*. We reinforce our esteem appreciation of him by dedicating this eleventh edition to our mentor and friend, Dr. Stephen Cohen.

Kenneth M. Hargreaves and
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New to This Edition

EIGHT NEW CHAPTERS

Chapter 2: Radiographic Interpretation covers imaging modalities, diagnostic tasks in endodontics, three-dimensional imaging, cone beam computed tomography, intraoperative or postoperative assessment of endodontic treatment complications, and more!

Chapter 4: Pain Control looks at two overarching topics: local anesthesia for restorative dentistry and endodontics and analgesics and therapeutic recommendations.

Chapter 11: Evaluation of Outcomes covers the reasons for evaluating treatment outcomes, outcome measurements for endodontic treatment, the outcomes of vital pulp therapy procedures, nonsurgical root canal treatment, nonsurgical retreatment, and surgical retreatment.

Chapter 16: Root Resorption looks at the histological features of root resorption, external inflammatory resorption, external cervical resorption, and internal resorption.

Chapter 19: Managing Iatrogenic Endodontic Events looks at treatment scenarios for eight different iatrogenic events: cervicofacial subcutaneous emphysema, sodium hypochlorite accidents, perforations (nonsurgical), inferior alveolar nerve injury (surgical), sinus perforation, instrument separation, apical extrusion of obturation materials, and ledge formation.

Chapter 21: Cracks and Fractures looks at three categories of cracks and fractures: cracked and fractured cusps, cracked and split teeth, and vertical root fractures, emphasizing the early diagnosis of these conditions.

Chapter 23: Vital Pulp Therapy addresses the living pulp, pulpal response to caries, procedures for generating reparative dentin, indications and materials for vital pulp therapy, MTA applications, treatment recommendations, and more!

Chapter 27: Bleaching Procedures provides a review of internal and external bleaching procedures, their impact on pulpal health/endodontic treatment, with presentations of cases and clinical protocols.

NEW CHAPTER ORGANIZATION

Chapters have been reorganized and grouped into three parts: Part I: *The Core Science of Endodontics*, Part II: *The Advanced Science of Endodontics*, and Part III: *Expanded Clinical Topics*. The seven chapters in Part 1 focus on the core clinical concepts for dental students; the chapters in Parts II and III provide the information that advanced students and endodontic residents and clinicians need to know. In addition, seven additional chapters are included in the online version.

The new organization better reflects the chronology of endodontic treatment.

EXPERT CONSULT

New features included on the Expert Consult site include:

- Seven chapters exclusively online:
  - *Chapter 24: Pediatric Endodontics: Endodontic Treatment for the Primary and Young Dentition*
  - *Chapter 25: Endodontic and Periodontic Interrelationships*
  - *Chapter 26: Effects of Age and Systemic Health on Endodontics*
  - *Chapter 27: Bleaching Procedures*
  - *Chapter 28: Understanding and Managing the Fearful Dental Patient*
  - *Chapter 29: Endodontic Records and Legal Responsibilities*
  - *Chapter 30: Key Principles of Endodontic Practice Management*

- Twelve lecture modules consisting of assigned readings, PowerPoint slides, written objectives for each lecture, and suggested examination questions. Topics covered include:
  - Diagnosis
  - Treatment planning
  - Pain control
  - Isolation
  - Cleaning and shaping
  - Obturation
  - Surgery
  - Assessment of outcomes
  - Pulp biology
  - Pathobiology
  - Emergencies
  - Restoration

- New videos and animations

Introduction

ENDODONTICS: A VIEW OF THE FUTURE

The Editors have had the privilege of "standing on the shoulders" of our generous contributors, enabling us to "look over the horizon" to gain a glimpse at our endodontic future. As we advance into the years ahead, we will incorporate even more refined and accurate improvements in pulpal diagnosis, canal cleaning and disinfection, canal obturation, and surgical enhancements.

In looking more clearly toward our impending endeavors, it becomes important to scrutinize the deficiencies of our past and present. Over the past several decades we have gone from arsenic to sodium hypochlorite, from bird droppings to gutta percha, from hand files to motor-driven files, from culturing to one-visit appointments, from two-dimensional to three-dimensional radiography, and from pulp removal to pulpal regeneration. And still, the clinical and academic controversies are pervasive. So, where will the future of our specialty take us?

With patients living longer and with the inescapable comparison of endodontics to endosseous implants, the demand for endodontic excellence has greatly increased. To that end, we suspect that future evidence-based approaches will continue to question the longevity of successful implant retention, intensifying the need for more predictable endodontic outcomes.

Surprisingly, we still base our diagnosis on a presumed and almost subjective pulpal status. Imagine a future in which endodontic diagnosis could be more objective by non-invasively scanning the pulp tissue. Imagine algorithms built into all digital radiography for interpreting and extrapolating disease processes. CBCT has made a huge impact on endodontic diagnosis, but can we enhance these digital captures with a resolution that would approach micro-computed tomography, and with less radiation? Will non-radiation imaging methods such as MRI (magnetic resonance imaging) leave the dental research clinic to provide a novel solution to address these issues? Will it be CT technology or some other form of detection for dramatically enhancing our guidance during surgical and nonsurgical treatment in order to both maximize our precision and minimize tooth structure and associated tissue removal? Considering the differences in color and consistency of the tissues within the pulp chamber, future technology may permit us to better discriminate these differences and enhance our ability for more precision when negotiating the openings to these canals. And as for clinical visualization: will there be digital or electronic enhancements of conventional loupes? Will 3-D visualization and monitor-based observation change the way we visualize and implement our procedures? During our canal cleaning and shaping, we are lucky if we can debride half of the pulpal tissues within all of the canal ramifications; however, we still use an irrigant that is so toxic by a non-selective mechanism, such that when inadvertently extruded beyond the canal system it can cause severe tissue damage. Our future technology should guide us to obtain the complete removal of organic debris within the pulpal spaces while obtaining complete canal disinfection—and without the potential morbidity from toxic non-selective chemicals. We still use files that can inadvertently separate. The resolution may be in a complete transformation in metallurgy or even the implementation of other non-metal cutting materials. Our obturation material is one of the worst filling materials in dentistry. Hopefully, the future evolution of obturation will lead us to a totally leakage-free, non-neurotoxic, and biocompatible substance that will three-dimensionally expand into *all* microscopic canal ramifications and stop when there is no more space to expand to, being limited to when it reaches the periodontal ligament. Will this obturating material be newly regenerated vital pulp?

Clearly, it is evident that our endodontic future lies in out-of-the-box thinking with the next generation of transformations coming with collaborations not just from within the biological sciences, but rather in conjunction with physicists, chemists, engineers, and a multitude of other great innovative minds. The predictability of endodontics must be incontestable, not just with better technology to guide us toward greater success, but also to better elucidate exactly when endodontics *cannot* be successful. Our future needs to focus on predictability, which will only be achieved by reinventing the wheel with disruptive technologies, rather than persisting with variations and modifications of our current convictions.

As a specialty, we have advanced by leaps and bounds since our inception, but we are still in our infancy with a brilliant future ahead of us. Since 1976 and with 11 editions, *Pathways of the Pulp* has always been about the art and science of endodontics. The dedicated contributing authors have generously given their time to meticulously describe what is considered the state of the art of our specialty. We are hopeful that future editions will guide us toward enhanced endodontic outcomes, with the never-ending pursuit of endodontic excellence.

Contents

COHEN'S PATHWAYS *of the* PULP

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PART I

The Core Science of Endodontics

CHAPTER 1

Diagnosis

LOUIS H. BERMAN | ILAN ROTSTEIN

CHAPTER OUTLINE

ART AND SCIENCE OF DIAGNOSIS

Diagnosis is the art and science of detecting and distinguishing deviations from health and the cause and nature thereof.[6] 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, careful data gathering as well as a planned, methodical, and systematic approach to this investigatory process is crucial.

Gathering objective data and obtaining subjective findings are not enough to formulate an accurate clinical diagnosis. The data must be interpreted and processed 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 an oral pathosis is the culmination of the art and science of making an accurate diagnosis.

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

1. The patient tells the clinician the reasons for 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 list of differential diagnoses.
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. These subjective findings combined with results of diagnostic tests provide the critical information needed to establish 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 29 for more information).

The reasons patients give for consulting with a clinician are often as important as the diagnostic tests performed. Their remarks serve as initial important clues that will help the clinician to formulate a correct diagnosis. Without these direct and unbiased comments, objective findings may lead to an incorrect diagnosis. The clinician may find a dental pathosis, but it may not contribute to the pathologic condition that mediates the patient's chief complaint. Investigating these complaints may indicate that the patient's concerns are related to a medical condition or to recent dental treatment. Certain patients may

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 treatment modality, or change the treatment plan.

even receive initial emergency treatment for pulpal or periapical symptoms in a general hospital.[93] 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 or any objective pathosis. Therefore, the clinician must pay close attention to the actual expressed complaint, determine the chronology of events that led to this complaint, and question the patient about 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 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 then initial the medical history form to indicate that this review has been done. The patient "of record" should be questioned at each treatment visit to determine whether there have been any changes in the patient's medical history or medications. A more thorough and complete update of the patient's medical history should be taken if the patient has not been seen for over a year.[51,52]

Baseline blood pressure and pulse should be recorded for the patient at each treatment visit. Elevation in blood pressure or a rapid pulse rate may indicate an anxious patient who may require a stress reduction protocol, or it may indicate that the patient has hypertension or other cardiovascular health problems. Referral to a physician or medical facility may be indicated. 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.[57,80,105]

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 any drug allergies or interactions, allergies to dental products, an artificial joint prosthesis, organ transplants, or is taking medications that may negatively interact with common local anesthetics, analgesics, sedatives, and antibiotics.[80] This may seem overwhelming, but it emphasizes the importance of obtaining a thorough and accurate medical history while considering the various medical conditions and dental treatment modifications that may be necessary before dental treatment is provided.

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 rather than to the condition itself. More common examples of medication side effects are stomatitis, xerostomia, petechiae, ecchymoses, lichenoid mucosal lesions, and bleeding of the oral soft tissues.[80]

When developing a dental diagnosis, a clinician must also be aware that some medical conditions can have clinical presentations that mimic oral pathologic lesions.[13,28,32,74,80,102,107,133] For example, tuberculosis involvement of the cervical and submandibular lymph nodes can lead to a misdiagnosis of lymph node enlargement secondary to an odontogenic infection. Lymphomas can involve these same lymph nodes.[80] 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.[43,76,80,83] 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 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.[80] Trigeminal neuralgia, referred pain from cardiac angina, and multiple sclerosis can also mimic dental pain (see also Chapter 17). 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 may 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

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[57,80,105]

Pulmonary: Chronic obstructive pulmonary disease, asthma, tuberculosis[80,129]

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[25,34,48,80]

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[35,43,76,80,83,88,100,135]

Neurologic: Cerebrovascular accident, seizure disorders, anxiety, depression and bipolar disorders, presence or history of drug or alcohol abuse, Alzheimer disease, schizophrenia, eating disorders, neuralgias, multiple sclerosis, Parkinson disease[36,44,80] the diagnosis of dental pathosis; this issue 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 origin, then the clinician must consider that an existing medical problem could be the true source of the pathosis. In such instances, a consultation with the patient's physician is always appropriate.

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 a SOAP format is used, with the history and findings documented under the categories of *S*ubjective, *O*bjective, *A*ppraisal, and *P*lan. There are also built-in features within some practice management software packages that allow digital entries into the patient's 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 to the chief complaint. The clinician should direct the conversation in a manner that produces 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 to resolve 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 initiated the request for an evaluation. The dental history is divided into five basic directions of questioning: localization, commencement, intensity, provocation and attenuation, 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 often remembers when these symptoms started. Sometimes the patient will even remember the initiating event: it may have been spontaneous in nature; it may have begun after a dental visit for a restoration; trauma may be the etiology, biting on a hard object may have initially produced the symptoms, or the initiating event may have occurred concurrently with other symptoms (sinusitis, headache, chest pain, etc.). 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. Pain is now considered a standard vital sign, and documenting pain intensity (scale of 0 to 10) provides a baseline for comparison after treatment.

Provocation and attenuation. "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. Nonprescription pain relievers may relieve some symptoms, whereas narcotic medication may be required to reduce others (see Chapter 4 for more information). Note that patients who are using narcotic as well as non-narcotic (e.g., ibuprofen) analgesics may respond differently to questions and diagnostic tests, thereby altering the validity of diagnostic results. Thus, it is important to know what drugs patients have taken in the previous 4 to 6 hours. These provoking and relieving factors may help the clinician 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 a few 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 to establish how long the patient felt the sensation in terms of seconds or minutes. Clinicians often first test control teeth (possibly including a contralateral "normal" tooth) to define a "normal" response for the patient; thus, "lingering" pain is apparent when comparing the duration between the control teeth and the suspected tooth.

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,

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 facilitate complete and accurate documentation. (Courtesy Dr. Ravi Koka, San Francisco, CA.)

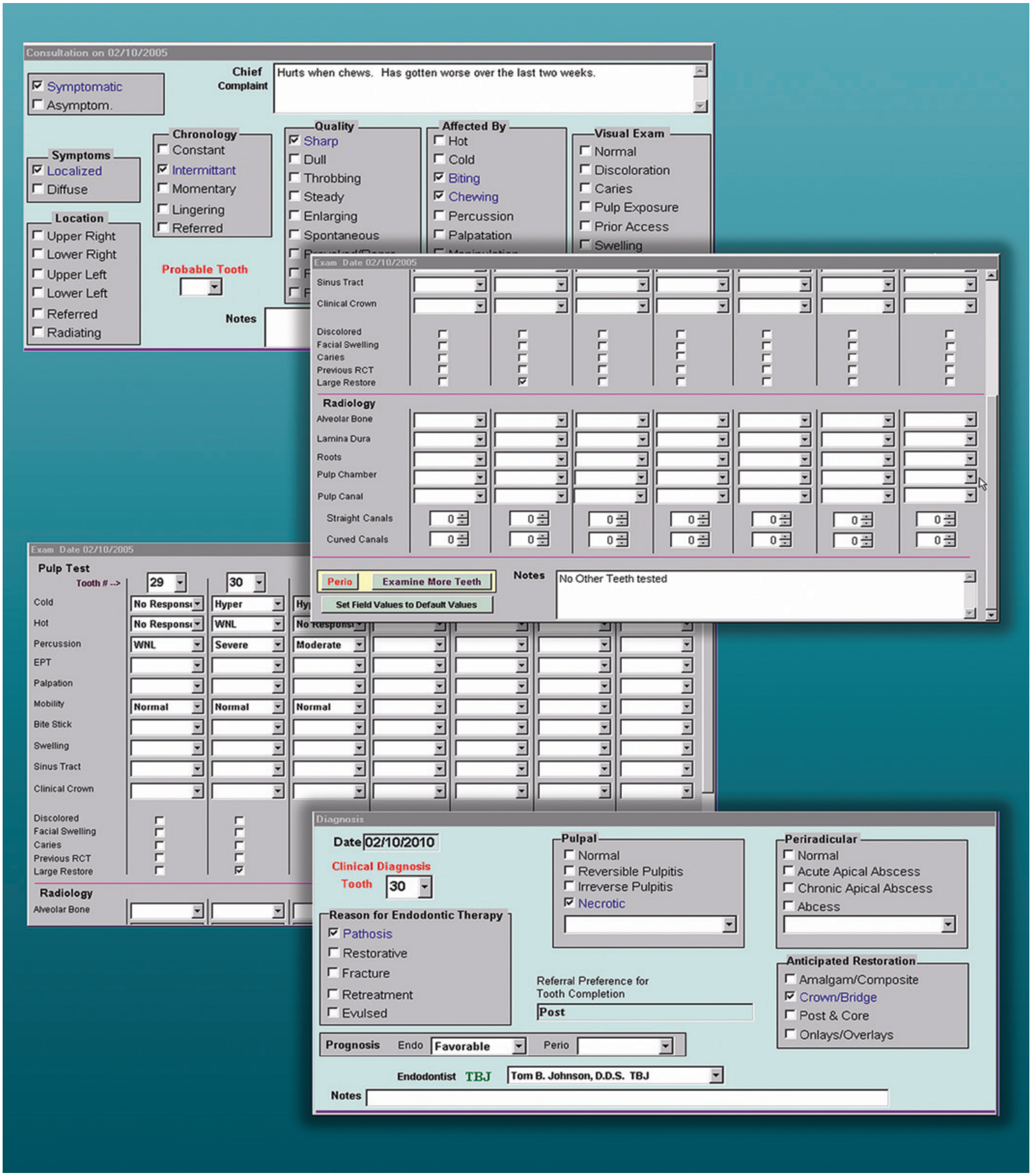

FIG. 1-4 Several practice management software packages have features for charting endodontic diagnoses using user-defined drop-down menus and areas for specific notations. Note that for legal purposes, it is desirable that all recorded documentation have the ability to be locked, or if any modifications 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, TX.)

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 indicates an early canine space infection.

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 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 nonodontogenic origin must always be considered in the differential diagnosis, especially if an obvious dental pathosis is not found.[77] This situation 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 may be the earliest sign of a canine space infection (Fig. 1-5). 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.

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 are just as likely to exit to the lingual where other spaces

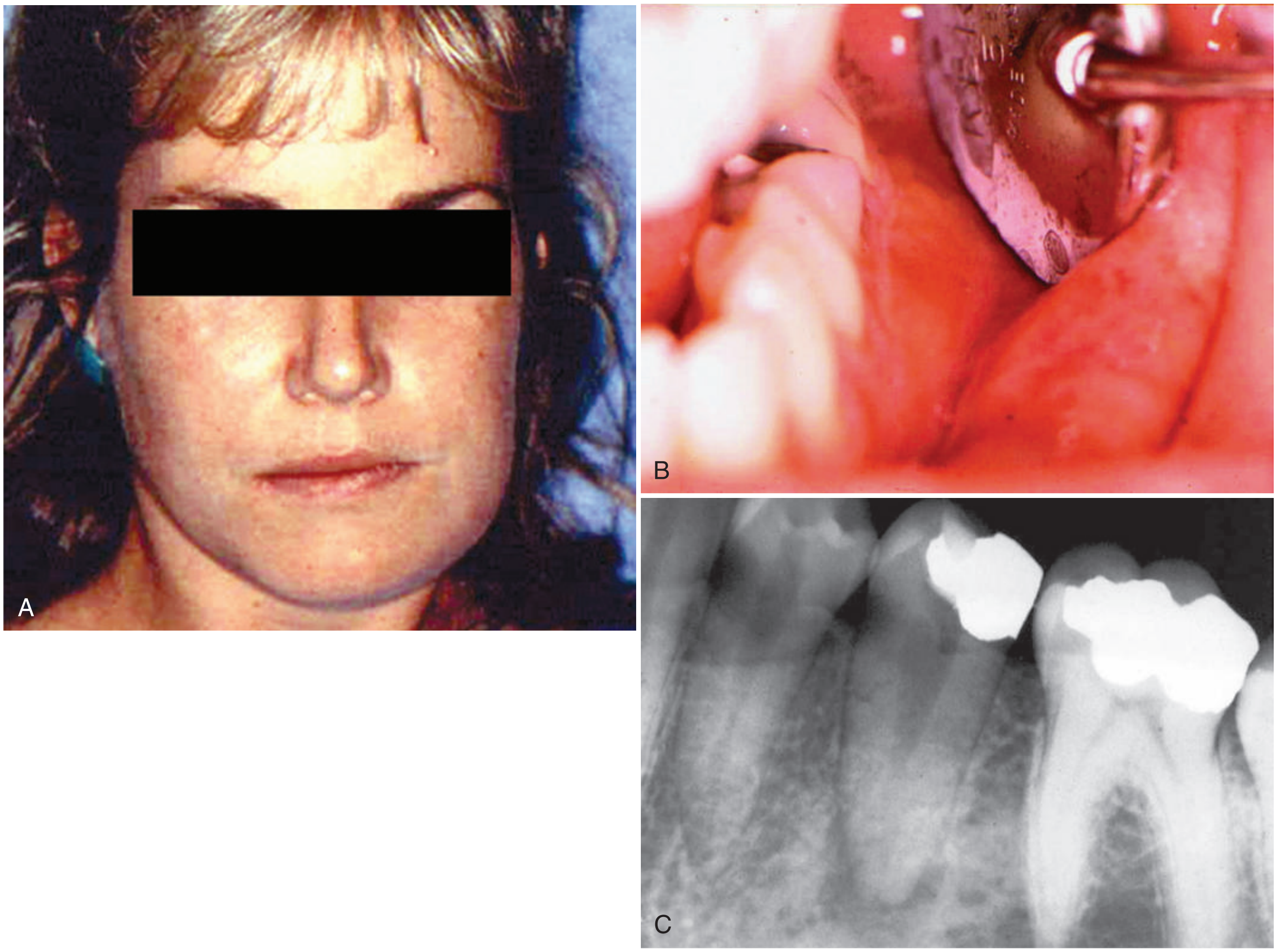

FIG. 1-7 **A,** Buccal space swelling of the left side of the patient's face. Note the asymmetry of the left side of the face. **B,** Intraoral view shows swelling present in the left posterior mucobuccal fold. **C,** This buccal space infection was associated with periradicular disease from the mandibular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

would be involved. For infections associated with these teeth, the root apices of the maxillary teeth must lie superior 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.[77]

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. Further discussions of fascial space infections may be found in Chapter 14.

Sinus tracts of odontogenic origin may also open through the skin of the face (Figs. 1-9 and 1-10).[2,56,64] 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. 1-10, *C* and *D*). Many patients with extraoral sinus tracts give a history of being treated by general physicians, dermatologists, or plastic surgeons with systemic or topical antibiotics or surgical procedures in

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

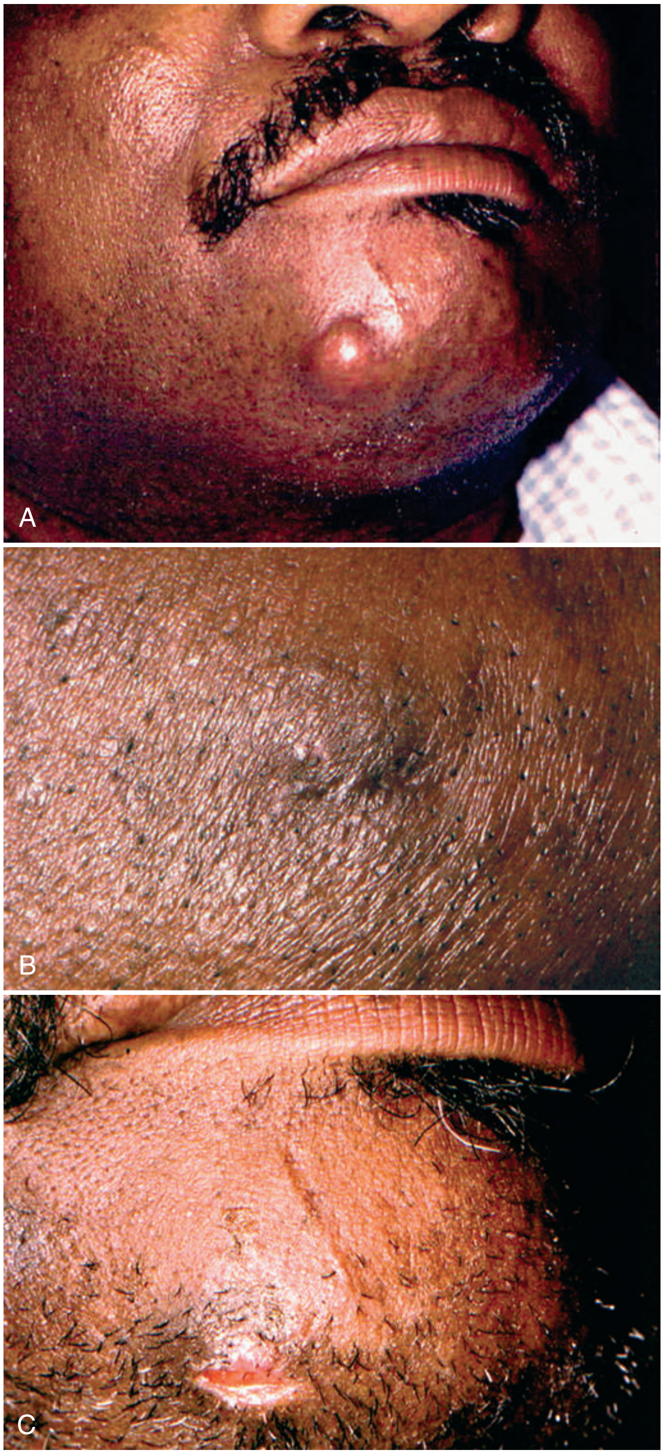

FIG. 1-9 **A,** Extraoral drainage associated with periradicular disease from the mandibular right canine. Note the parulis on the right anterior side of the face. **B,** Initial scar associated with the extraoral drainage incision after the parulis was drained and root canal therapy performed on the canine. **C,** Three-month follow-up shows healing of the incision area. Note the slight inversion of the scar tissue.

attempts to heal the extraoral stoma. In these particular cases, after multiple treatment failures, the patients may finally be referred to a dental clinician to determine whether there is a dental cause. Raising the awareness of physicians to such cases will aid in more accurate diagnosis and faster referral to the dentist or endodontist.

Intraoral Examination

The intraoral examination may give the clinician insight as to which intraoral areas may need a more focused evaluation. Any abnormality should be carefully examined for either prevention or early treatment of associated pathosis.[4,30,75,113,110,126] Swelling, localized lymphadenopathy, or a 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 mucosa should be dried with either a low-pressure air syringe or a 2-by-2-inch gauze pad. By retracting the tongue and cheek, all of the soft tissue should be examined for abnormalities in color or texture. Any raised lesions or ulcerations should be documented and, when necessary, evaluated with a biopsy or referral.[82]

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 origin 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. 1-11) 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 in the posterior palate (Fig. 1-12) is most likely associated with the palatal root of one of the maxillary molars.[77]

Intraoral swelling present in the mucobuccal fold (Fig. 1-13) 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 14). 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.[77,80]

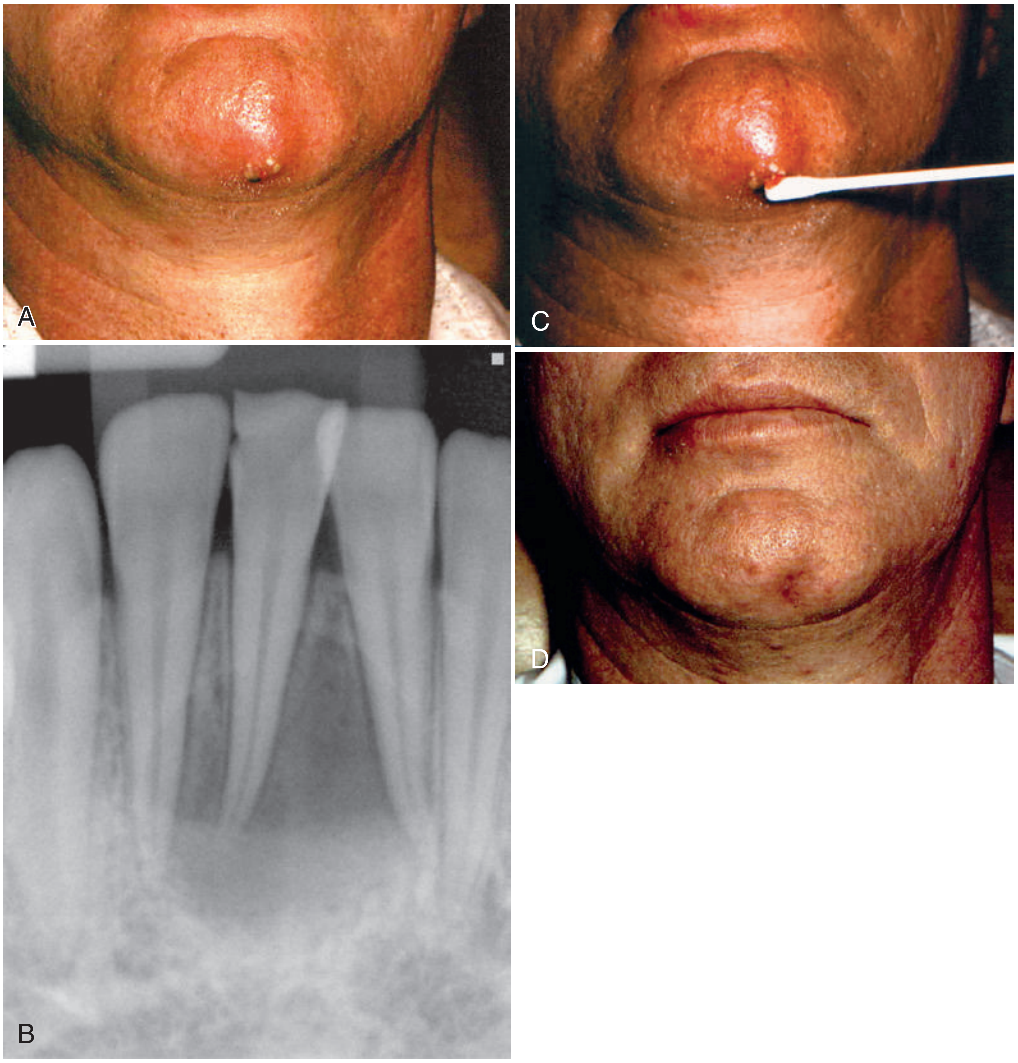

FIG. 1-10 **A,** Extraoral sinus tract opening onto the skin in the central chin area. **B,** Radiograph showing large radiolucency associated with the mandibular incisors. **C,** A culture is obtained from the drainage of the extraoral sinus tract. **D,** The healed opening of the extraoral sinus tract 1 month after root canal therapy was completed. Note the slight skin concavity in the area of the healed sinus tract.

FIG. 1-11 Fluctuant swelling in the anterior palate associated with periradicular disease from the palatal root of the maxillary first premolar.

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*.[12] This pathway, 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 pathway between two internal organs or from one epithelium-lined surface to another epithelium-lined surface.[6]

Histologic studies have found that most sinus tracts are not lined with epithelium throughout their entire length. One study found that only 1 out of the 10 sinus tracts examined were lined with epithelium, whereas the other nine specimens were lined with granulation tissue.[55] Another study, with a larger sample size, found that two thirds of the specimens did not have epithelium extending beyond the level of the surface mucosa rete ridges.[12] The remaining specimens had some

FIG. 1-12 Fluctuant swelling in the posterior palate associated with periradicular disease from the palatal root of the maxillary first molar.

FIG. 1-13 Fluctuant swelling in the mucobuccal fold associated with periradicular disease from the maxillary central incisor.

epithelium that extended from the oral mucosa surface to the periradicular lesion.[12] 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 after treatment will necessitate further diagnostic procedures to determine whether other sources of infection 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 magnitudes of discomfort before 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 or #30 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 origin of the sinus tract is determined by following the path taken by the gutta-percha cone (Fig. 1-14). This will direct the clinician to the tooth involved and, more specifically, to the root of the root of the tooth that is the source of the pathosis. Once the causative factors related to the formation of the sinus tract are removed, the stoma and the sinus tract will close within several 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 the 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 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 may assist in verifying the source of infection.[111,112,121]

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 bony 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.

A palpation test is performed by applying firm digital pressure to the mucosa covering the roots and apices. The index finger is used to press the mucosa against the underlying cortical bone. This will detect the presence of periradicular abnormalities or specific areas that produce painful response to digital pressure. A positive response to palpation may indicate an active periradicular inflammatory process. This test does not indicate, however, whether the inflammatory process is of endodontic or periodontal origin.

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

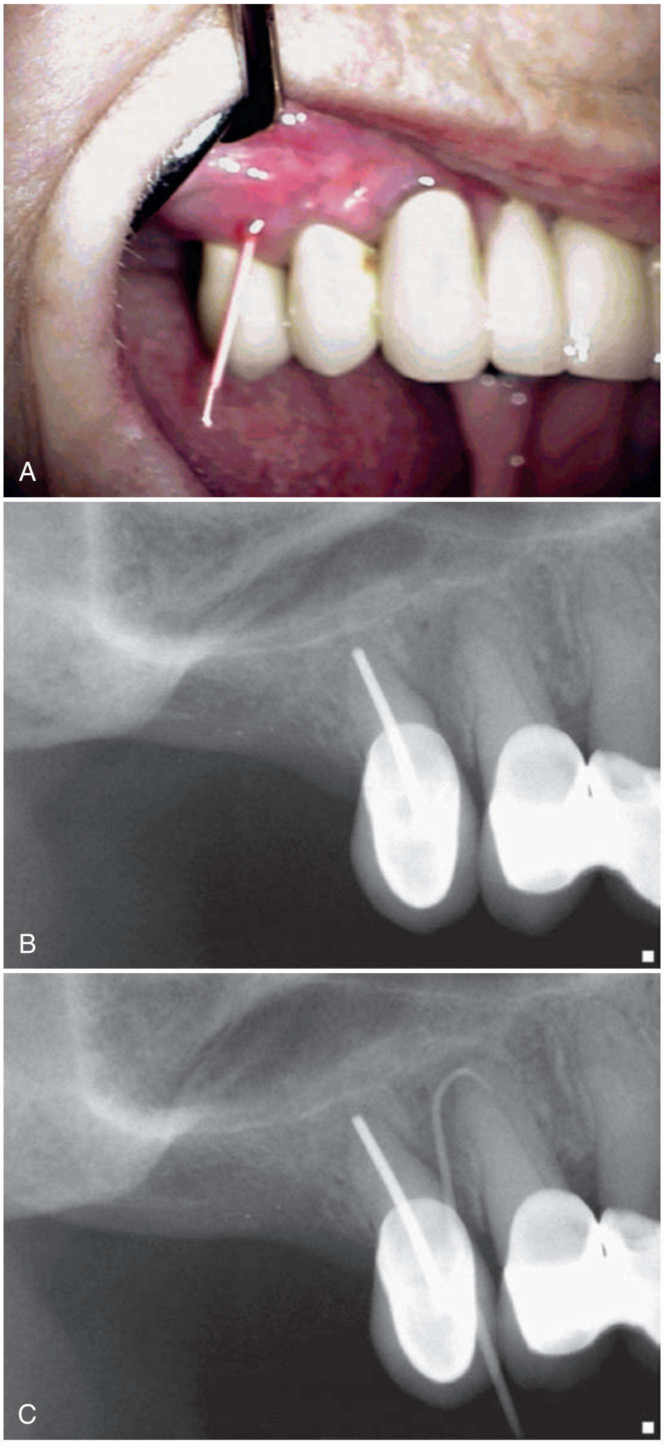

FIG. 1-14 **A,** To locate the source of an infection, the sinus tract can be traced by threading the stoma with a gutta-percha point. **B,** Radiograph of the area shows an old root canal in a maxillary second premolar and a questionable radiolucent area associated with the first premolar, with no clear 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 the maxillary first premolar.

FIG. 1-15 Percussion testing of a tooth, using the back end of a mirror handle.

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 originates is interpreted by the mesencephalic nucleus, receiving its information from proprioceptive nerve receptors. Although subject to debate, the general consensus is that there are relatively few proprioceptors in the dental pulp; however, they are prevalent in the periodontal ligament spaces.[24] 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 lead to more accurate results. The contralateral tooth should first be tested as a control, as should 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.

Percussion is performed by tapping on the incisal or occlusal surfaces of the teeth either with the finger or with a blunt instrument. The testing should initially be done gently, with light pressure being applied digitally with a gloved finger tapping. If the patient cannot detect 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. 1-15). The tooth crown is tapped vertically and horizontally. The tooth 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.

Although this test does not disclose the condition of the pulp, it indicates the presence of a periradicular inflammation.

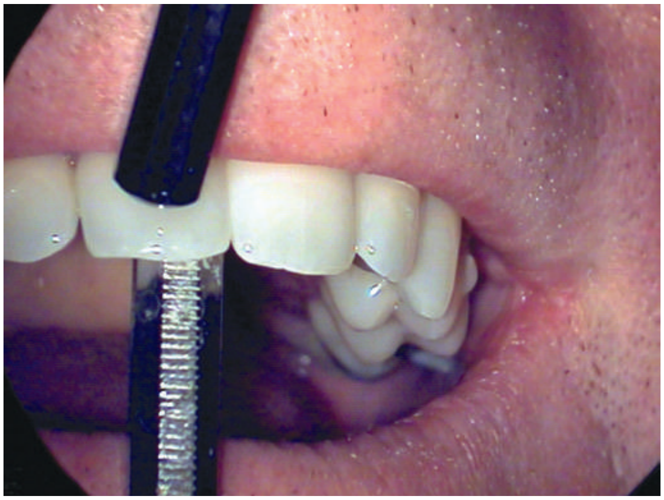

FIG. 1-16 Mobility testing of a tooth, using the back ends of two mirror handles.

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.

An abnormal positive response indicates inflammation of the periodontal ligament that may be of either pulpal or periodontal origin. The sensitivity of the proprioceptive fibers in an inflamed periodontal ligament will help identify the location of the pain. This test should be done gently, especially in highly sensitive teeth. It should be repeated several times and compared with control teeth.

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. Tooth mobility is directly proportional to the integrity of the attachment apparatus or to the extent of inflammation in the periodontal ligament. 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 and one on the lingual aspect of the tooth (Fig. 1-16). Pressure is applied in a facial-lingual direction as well as in a vertical direction and the tooth mobility is scored (Box 1-2). Any mobility that exceeds +1 should be considered abnormal. However, the teeth should be evaluated on the basis of how mobile they are relative to the adjacent and contralateral teeth.

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 origin and is typically more generalized in other areas of the mouth. However, isolated areas of vertical bone loss may be of an endodontic origin, 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 in Chapter 21, 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). Results of pulp tests (described later) will aid in diagnosis.

Pulp Tests

Pulp testing involves attempting to make a determination of the responsiveness of pulpal sensory neurons.[62,63] 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 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.[122,123]

Thermal

Various methods and materials have been used to test the pulp's response to thermal stimuli. The baseline or normal response to either cold or hot is a patient's report that a sensation is felt but disappears immediately upon removal of the thermal stimulus. Abnormal responses include a lack of response to the stimulus, a 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.

Cold testing is the primary pulp testing method used by many clinicians today. It is especially useful for patients presenting with porcelain jacket crowns or porcelain-fused-to-metal crowns where no natural tooth surface (or much metal) is accessible. If a clinician chooses to perform this test with sticks of ice, then the use of a 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*, or *CO_2 stick*, has been found to be reliable in eliciting a positive response if vital pulp tissue is present in the tooth.[46,98,99] One study found that vital teeth would respond to both frozen CO_2 and skin refrigerant, with skin refrigerant producing a slightly quicker response.[66] Frozen carbon dioxide has also been found to be effective in evaluating the pulpal response in teeth with full coverage crowns for which other tests such as electric pulp testing is not possible.[11] For testing purposes, a solid stick of CO_2 is prepared by delivering CO_2 gas into a specially designed plastic cylinder (Fig. 1-17). 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-by-2-inch gauze or cotton roll so the frozen CO_2 will not come into contact with these structures. Because of the extremely cold temperature of the frozen CO_2 (−69°F to −119°F; −56°C to −98°C), burns of the soft tissues can occur. It has been demonstrated on extracted teeth that frozen CO_2 application has resulted in a significantly greater intrapulpal temperature decrease than either skin refrigerant or ice.[11] Also, it appears 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.[61,104]

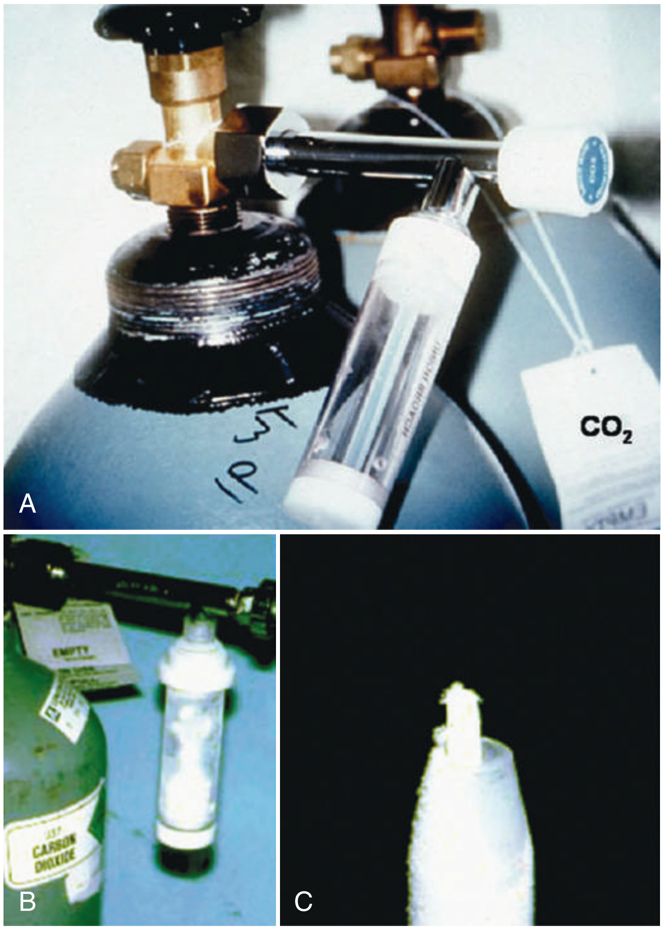

FIG. 1-17 A, Carbon dioxide tank with apparatus attached to form solid CO_2 stick/pencil. B, CO_2 gas being transformed into a solid stick/pencil. C, CO_2 stick/pencil extruded from end of a plastic carrier and ready for use.

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 frozen CO_2.[46,66,96,141] One of the current products contains 1,1,1,2-tetrafluoroethane, which has zero ozone depletion potential and is environmentally safe. It has a temperature of −26.2°C.[66] The spray is most effective for testing purposes when it is applied to the tooth on a large #2 cotton pellet (Fig. 1-18). In one study,[65] 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 mid-facial area of the tooth or crown. As with any other pulp testing method, adjacent or contralateral "normal" teeth should also be tested to establish a baseline response. It appears that frozen 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.[11,46] However, one study found that periodontal attachment loss and gingival recession may influence the reported pain response with cold stimuli.[116]

To be most reliable, cold testing should be used in conjunction with an electric pulp tester (described later in this chapter) so that the results from one test will verify the findings of the other test. If a mature, nontraumatized tooth does not respond to both cold testing and electric pulp testing, then the pulp should be considered necrotic.[23,98,141] However, a multirooted tooth, with at least one root containing vital pulp tissue, may respond to a cold test and electric pulp test even if one or more of the roots contain necrotic pulp tissue.[98]

Another thermal testing method involves the use of heat. 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 the onset of symptoms. This method can also be used to apply cold water to the entire crown for cases in which cold is the precipitating stimulus.

FIG. 1-18 A, Refrigerant spray container. B, A large cotton pellet made of a cotton roll or a ready-made 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 should not be used to deliver the refrigerant to the tooth surface. C, A large cotton pellet sprayed with the refrigerant and ready to be applied to the tooth surface. (*A,* Courtesy Coltène/Whaledent, Cuyahoga Falls, OH.)

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 and is not recommended. Another approach is the use of electronic heat-testing instruments.[20]

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. The patient may present with cold liquids in hand just to minimize the pain (Fig. 1-19). In such 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.

Electric

Assessment of pulp neural responses (*vitality*) can also be accomplished by electric pulp testing.[79] Electric pulp testers of different designs and manufacturers have been used for this purpose. Electric pulp testers should be an integral part of any dental practice. It should be noted that the vitality of the pulp is determined by the intactness and health of the vascular supply, not by the status of the pulpal nerve fibers. Even though

FIG. 1-19 Irreversible pulpitis associated with the mandibular right second molar. Patient 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.

BOX 1-4

Potential Common Interpretation Errors of Responses Obtained from Electric Pulp Testing

False-Positive Responses
- Partial pulp necrosis
- Patient's high anxiety
- Ineffective tooth isolation
- Contact with metal restorations

False-Negative Responses
- Calcific obliterations in the root canals
- Recently traumatized teeth
- Immature apex
- Drugs that increase patient's threshold for pain
- Poor contact of pulp tester to tooth

advances are being made with regard to determining the vitality of the pulp on the basis of the blood supply, this technology has not been perfected enough at this time to be used on a routine basis in a clinical setting.

The electric pulp tester has some limitations in providing predictable 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.[122,123] 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. Numeric 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[122,123] 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. In addition, false-positive and false-negative responses can occur (Box 1-4), and the clinician must take it into account when formulating the final diagnosis.

The electric pulp tester will not work unless the probe can be placed in contact with or be bridged to the natural tooth structure.[95] With the advent of universal precautions for infection control, the use of rubber gloves prevents the clinician from completing the circuit.[7] Some pulp testers may require the patient to place a finger, or fingers, on the tester probe to complete the electric circuit; however, the use of lip clips is an alternative to having patients hold the tester. Proper use of the electric pulp tester requires the evaluated teeth to be carefully 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 as to 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.[86] 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.[15] Once the probe is in contact with the tooth, the patient is asked to touch or grasp the tester probe, unless a lip clip is used (Fig. 1-20, *A*). This completes the circuit and initiates the delivery of electric current to the tooth.

FIG. 1-20 **A,** Electric pulp tester with probe. The probe tip will be coated with a conducive 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 front right 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, CA.)

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 readings from the pulp tester are recorded (Fig. 1-20, *B*) and will be evaluated once all the appropriate teeth have been tested by the electric pulp tester and the 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.[95] 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.

One study compared the ability of thermal and electric pulp testing methods to register the presence of vital pulp tissue.[99] 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%.

Some studies have indicated there might not be a significant difference between pulp testing results obtained by electric pulp tester and those obtained by the thermal methods.[46,98,99] Cold tests, however, have been shown to be more reliable than electric pulp tests in younger patients with less developed root apices.[5,42,98] This is the reason to verify the results obtained by one testing method and compare them with results obtained by other methods. 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.

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's frequency will shift when hitting 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.[114]

Several studies[40,60,69,84,114,115,117] have found LDF to be an accurate, reliable, and reproducible method of assessing pulpal blood flow. One of the great advantages of pulp testing with devices such as the LDF is that the collected data are based on objective findings rather than subjective patient responses. As is discussed in Chapter 20, 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.[130] This technology, however, is not being used routinely in the dental practice.

Pulse Oximetry

The pulse oximeter is another noninvasive device (Fig. 1-21). 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; the amount 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. 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.[118] 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.

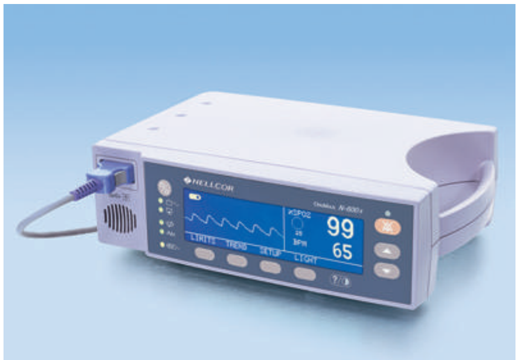

FIG. 1-21 Nellcor OxiMax N-600x pulse oximeter. (Courtesy Nellcor Puritan Bennett, Boulder, CO; now part of Covidien.)

Custom-made sensors have been developed and were found to be more accurate than electric and thermal pulp tests.[31,54] This sensor has been especially useful in evaluating teeth that have been subjected to traumatic injuries, as such teeth tend to present, especially in the short term, with questionable vitality using conventional pulp testing methods.[8,31,53]

Studies regarding the ability of pulse oximetry to diagnose pulp vitality draw various conclusions. Several studies have found pulse oximetry to be a reliable method for assessing pulp vitality.[69,70,118,125,140] Others have stated that in its present form the pulse oximeter may not be predictable in diagnosing pulp vitality.[140] Most of the problems appear to be related to the currently available technology. Some investigators have concluded that the devices used for pulp testing are too cumbersome and complicated to be used on a routine basis in a dental practice.[68,118,140]

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 *symptomatic apical 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 typically elicit pain only when the percussion or bite test is applied in a certain direction to one cusp or section of the tooth.[22,108]

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 tip applicators, toothpicks, orangewood sticks, and rubber polishing wheels. There are several devices specifically designed to perform this test. The Tooth Slooth (Professional Results, Laguna Niguel, CA) (Fig. 1-22) 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 and contralateral teeth should

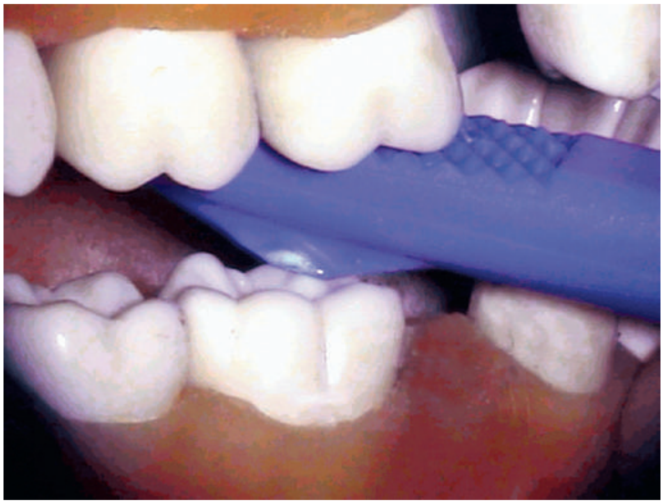

FIG. 1-22 To determine which tooth, or tooth part, is sensitive to mastication, having the patient bite on a specially designed bite stick is often helpful.

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 upon release of biting pressure.

Test Cavity

The test cavity method for assessing pulp vitality is not routinely used since, by definition, it is an invasive irreversible test. 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 can 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, this 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 a tooth, the application of a stain to the area is often of great assistance. It may be necessary to remove the restoration in the tooth to better visualize a crack or fracture. Methylene blue dye, when painted on the tooth surface with a cotton tip applicator, will penetrate into cracked areas. The excess dye may be removed with a moist application of 70% isopropyl alcohol. The dye will indicate the possible location of the crack.

Transillumination using a bright fiberoptic light probe to the surface of the tooth may be very helpful (Fig. 1-23). Directing a high-intensity light directly on the exterior surface of the tooth at the cementum-enamel junction (CEJ) may reveal the extent of the fracture. Teeth with fractures block transilluminated light. The part of the tooth that is proximal to the light source will absorb this light and glow, whereas the area beyond this fracture will not have light transmitted to it and will show as gray by comparison.[101] Although the presence of a fracture may be evident using dyes and transillumination, the depth of the fracture cannot always be determined.

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 the pain is not eliminated after an appropriate period of time, then the clinician should similarly repeat this technique on the mandibular teeth below. It should be understood that periodontal ligament injections may anesthetize an adjacent tooth and thus are more useful for identifying the arch rather than the specific tooth.

Radiographic Examination and Interpretation

Intraoral Radiographs

The radiographic interpretation of a potential endodontic pathosis is an integral part of endodontic diagnosis and prognosis assessment. 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 the diagnosis, the potential for inappropriate treatment may frequently exist if the radiograph alone is used for making final diagnosis. The clinician should not subject the patient to unnecessary multiple radiation exposures; two pretreatment images from different angulations are often sufficient. Under extenuating circumstances, however, especially when the diagnosis is difficult, additional exposures may be necessary to determine the presence of multiple roots,

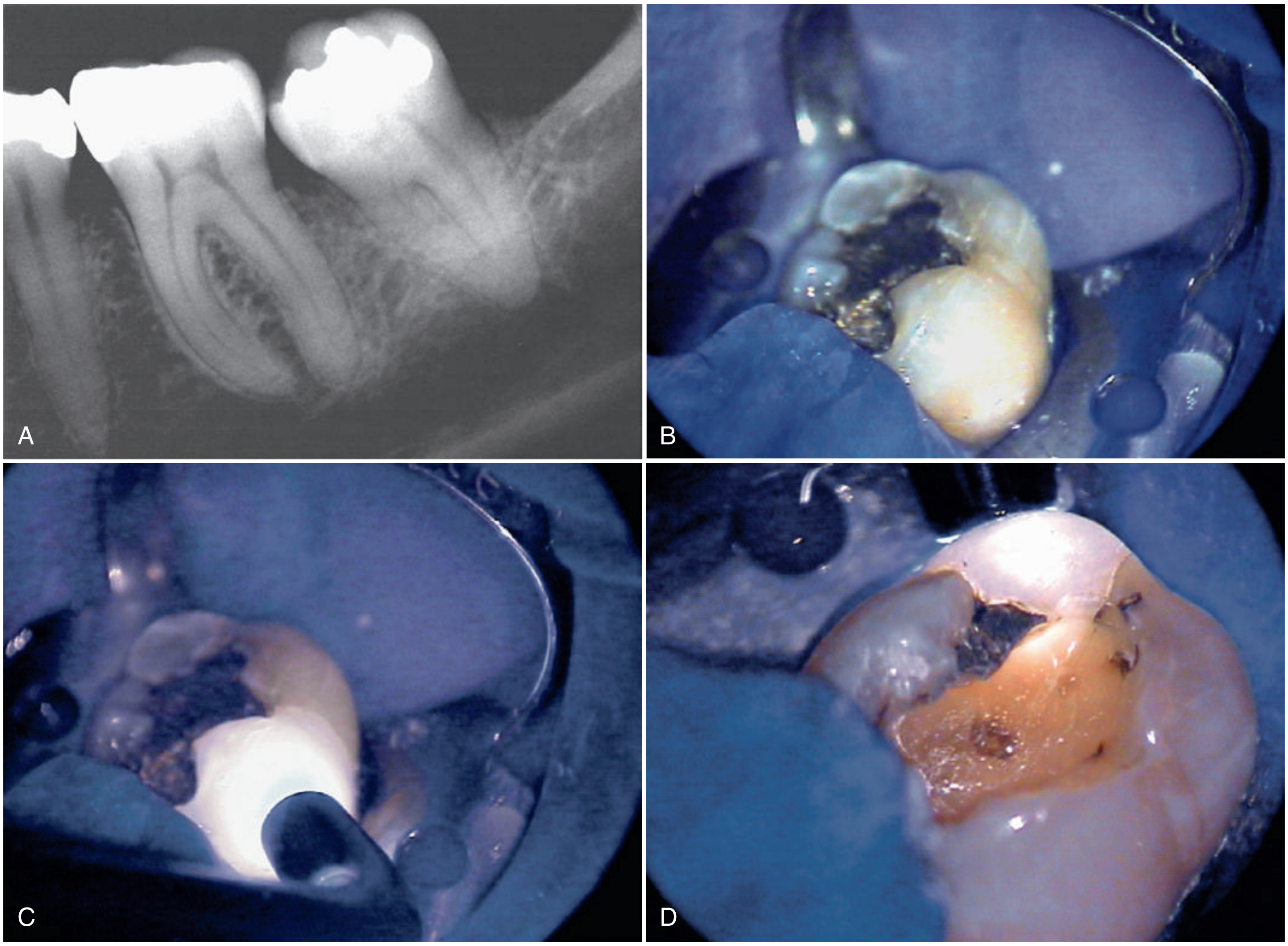

FIG. 1-23 Sometimes there is no clear indication of why a tooth is symptomatic. This radiograph shows a mandibular second molar with a moderately deep restoration (A); the pulp tests nonvital. Without any transillumination, a fracture cannot be detected (B). However, by placing a high-intensity light source on the tooth surface, a root fracture can be observed on the buccal surface (C) and the distal-lingual surface (D).

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, there was only 50% agreement among interpreters for the radiographic presence of pathosis.[49] When the cases were reevaluated several months later, the same evaluators agreed with their own original diagnosis less than 85% of the time.[50] This further emphasizes the necessity for additional 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. Thus, 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 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 pathosis may present merely as a widening or break in the lamina dura—the most consistent radiographic finding when a tooth is nonvital[67]—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 accessory canal. On occasion there may be no radiographic change at all, even in the presence of a disease process in the alveolar bone.

FIG. 1-24 Radiograph showing what appears to be a mandibular lateral incisor associated with periapical lesion of a nonvital tooth. Although pulp necrosis can be suspected, the tooth tested vital. In this case, the appearance of apical bone loss is secondary to a cementoma.

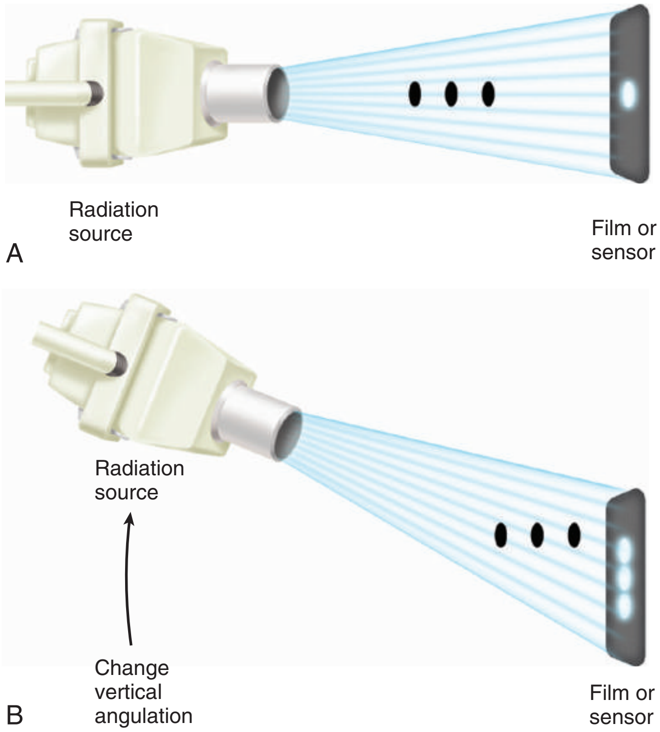

FIG. 1-25 Radiographic images are only two-dimensional, and often it is difficult to discriminate the relative location of overlapping objects. **A,** When the source of radiation is directly perpendicular to overlapping objects, the image is captured without much separation of the objects. However, 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.

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. 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 not be detected if the loss is only in cancellous bone.[16] However, the radiographic evidence of pathosis will be observed once this bone loss extends to the junction of the cortical and cancellous bone. In addition, certain teeth are more prone to exhibit radiographic changes than others, depending on their anatomic location.[17] 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. The apices of most anterior and premolar teeth are located close to the cortical-cancellous bone junction. Therefore, periapical pathosis from these teeth is exhibited sooner on the radiograph. 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.

Digital Radiography

Digital radiography has been available since the late 1980s and has recently been refined with better hardware and more user-friendly software. It has the ability to capture, view, magnify, enhance, and store radiographic images in an easily reproducible format that does not degrade over time. Significant advantages of digital radiographs over conventional radiographs include lower radiation doses, instant viewing, convenient manipulation, efficient transmission of an image via the Internet, simple duplication; and easy archiving.

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 wirelessly 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, enhanced, and analyzed. 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 2.

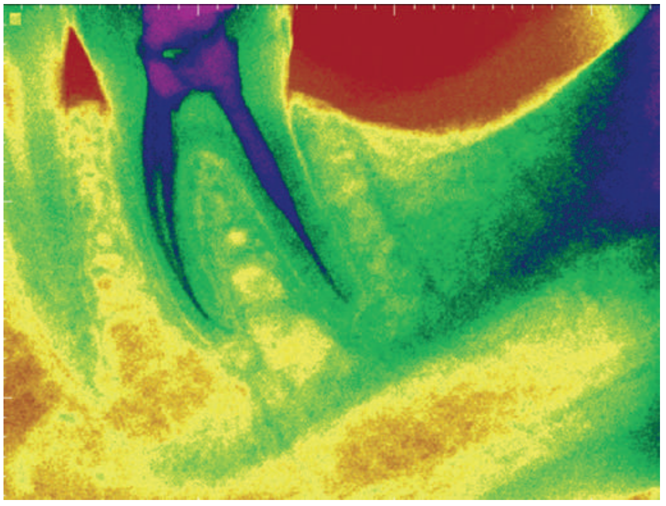

FIG. 1-26 Digital radiography has an advantage over conventional film in that the image can be enhanced and colorized, a useful tool for patient education.

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. The clinician can magnify different areas on the radiograph and then digitally enhance the image in order to better visualize certain anatomic structures; in some cases the image can even be colorized, a useful tool for patient education (Fig. 1-26).

In the past, x-ray film has had a slightly better resolution than most digital radiography images, at about 16 line pairs per millimeter (lp/mm).[87] Some sensor manufacturers, however, now claim to offer resolutions beyond that of conventional film. 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. 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 acceptance 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.[39,73,97] Furthermore, it was found that the interpretation of a digital radiograph can be subjective, similar to that of the conventional film.[134] Factors that appear to have the most impact on the interpretation of the image are the years of experience of the examiner and familiarity of the operator with the given digital system.[134]

Cone-Beam Computerized Tomography

Limitations in conventional two-dimensional radiography promulgated a need for three-dimensional imaging, known as *cone-beam computerized tomography* (CBCT) (also known as *cone-beam volumetric tomography* [CBVT]) or as *cone-beam volumetric imaging* [CBVI]. Although a form of this technology has existed since the early 1980s,[106] specific devices for dental use first appeared almost two decades later.[90] 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).[37,33] The survey of the scans can be 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 used interactively by another clinician.

In general, many dental applications only require a limited field of vision, confining the study to the maxilla and mandible.

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

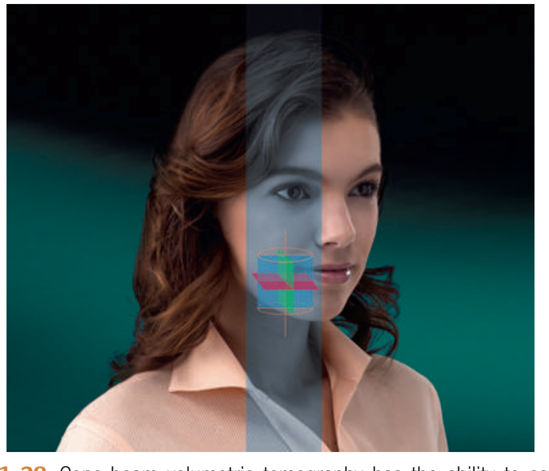

FIG. 1-28 Cone-beam volumetric tomography has the ability to capture, store, and present radiographic images in various horizontal and vertical planes. (Courtesy J. Morita USA, Irvine, CA.)

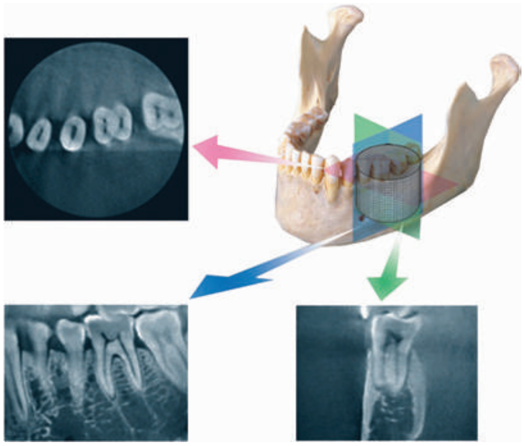

FIG. 1-29 Cone-beam volumetric tomography has the advantage of being able to detect pathosis in the bone or associated with the teeth without the obstruction of anatomic structures. The planes of vision may be axial, sagittal, or coronal. (Courtesy J. Morita USA, Irvine, CA.)

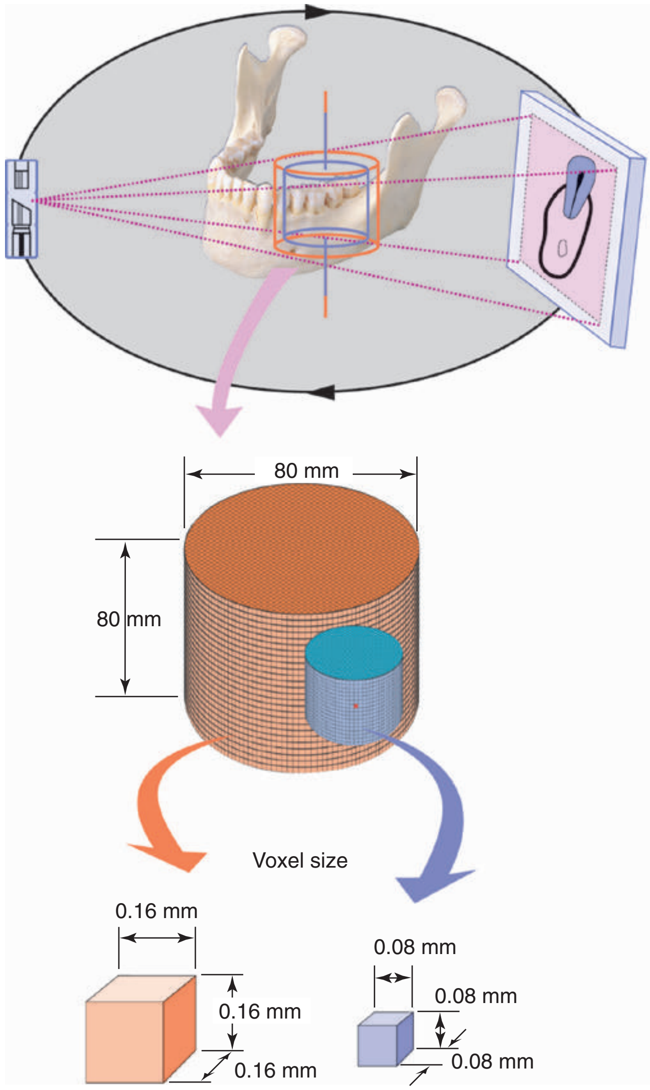

FIG. 1-30 The radiation source in cone-beam volumetric tomography is conical. The receiving sensor captures the image as "voxels," or three-dimensional pixels of information, allowing digital interpretation.

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 intracranial aneurysms, that when undetected could be life threatening.[91]

The radiation source of CBCT 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 CBCT, 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 and providing for a more accurate interpretation of anatomic structures and pathologic conditions. 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.[41]

Compared with two-dimensional radiographs, CBCT can clearly visualize the interior of the cancellous bone without the superimposition of the cortical bone. Studies show that CBCT is much more predictable and efficient in demonstrating anatomic landmarks, bone density, bone loss, periapical lesions, root fractures, root perforations and root resorptions.[1,21,26,27,38,47,71,78,81,85,92,94,128,131,142]

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 interpretation of conventional radiography sometimes difficult or impossible. Several studies have demonstrated the advantages of CBCT in the differential diagnosis of such structures from pathologic conditions.[21,29,71,137]

Cone-beam computerized 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. CBCT can show great detail in many planes of vision but 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 CBCT for endodontic diagnosis and treatment. It has already proven invaluable in the detection of dental and nondental pathoses (Fig. 1-32). For a further review of CBCT and radiography, see Chapter 2.

Magnetic Resonance Imaging (MRI)

MRI has also been suggested for dental diagnosis. It may offer simultaneous three-dimensional hard- and soft-tissue imaging of teeth without ionizing radiation.[58] The use of MRI in endodontics is still limited.

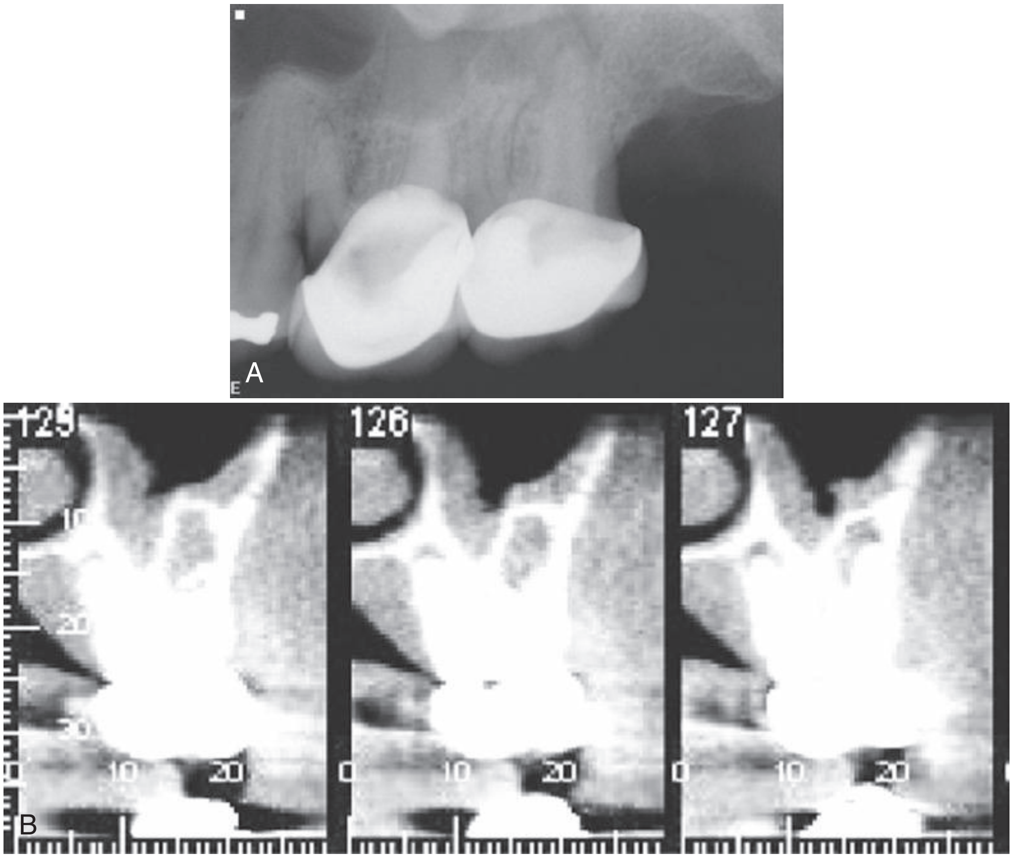

FIG. 1-31 **A**, This standard two-dimensional radiographic image reveals recurrent caries under the mesial margin of the maxillary first molar. However, the patient localized pain to mastication on the maxillary second molar. **B**, Cone-beam volumetric tomography revealed an apical radiolucency associated with the maxillary second molar. The bone loss was obscured on the two-dimensional radiograph by the maxillary sinus, zygoma, and cortical bone.

Cracks and Fractures

The wide variety of types of cracks and fractures in teeth and their associated signs and symptoms often make their diagnosis difficult. The extensiveness of the crack or fracture line may directly alter the prognosis assessment for a given tooth and should be examined before treatment decision making. Certain types of cracks may be as innocent as a superficial enamel craze line, or they may be as prominent as a fractured cusp. The crack may progress into the root system to involve the pulp, or it may split the entire tooth into two separate segments. The crack may be oblique, extending cervically, such that once the coronal segment is removed the tooth may or may not be restorable. Any of these situations may present with mild, moderate, or severe symptoms or possibly no symptoms at all.

Crack Types

There have been many suggestions in the literature of was to classify cracks in teeth. By defining the type of crack present, an assessment of the prognosis may be determined and treatment alternatives can be planned (see Chapter 21). Unfortunately, it is often extremely difficult to determine how extensive a crack is until the tooth is extracted.

Cracks in teeth can be divided into three basic categories:

- Craze lines
- Fractures (also referred to as *cracks*)
- Split tooth/roots

Craze lines are merely cracks in the enamel that do not extend into the dentin and either occur naturally or develop after trauma. They are more prevalent in adult teeth and usually occur more in the posterior teeth. If light is transilluminated through the crown of such a tooth, these craze lines may show up as fine lines in the enamel with light being able to transmit through them, indicating that the crack is only superficial. The use of optical coherence tomography (OCT) has also been suggested for detection of enamel cracks.[59] Craze lines typically will not manifest with symptoms. No treatment is necessary for craze lines unless they create a cosmetic issue.

Fractures extend deeper into the dentin than superficial craze lines and primarily extend mesially to distally, involving the marginal ridges. Dyes and transillumination are helpful for visualizing potential root fractures.

Symptoms from a fractured tooth range from none to severe pain. A fracture in the tooth does not necessarily dictate that the tooth has split into two pieces; however, left alone or especially with provocations such as occlusal prematurities, the fracture may progress into a split root. A fractured tooth may be treated by a simple restoration, endodontics (nonsurgical or surgical), or even extraction, depending on the extent and orientation of the fracture, the degree of symptoms, and whether the symptoms can be eliminated. This makes the clinical management of fractured teeth difficult and sometimes unpredictable.

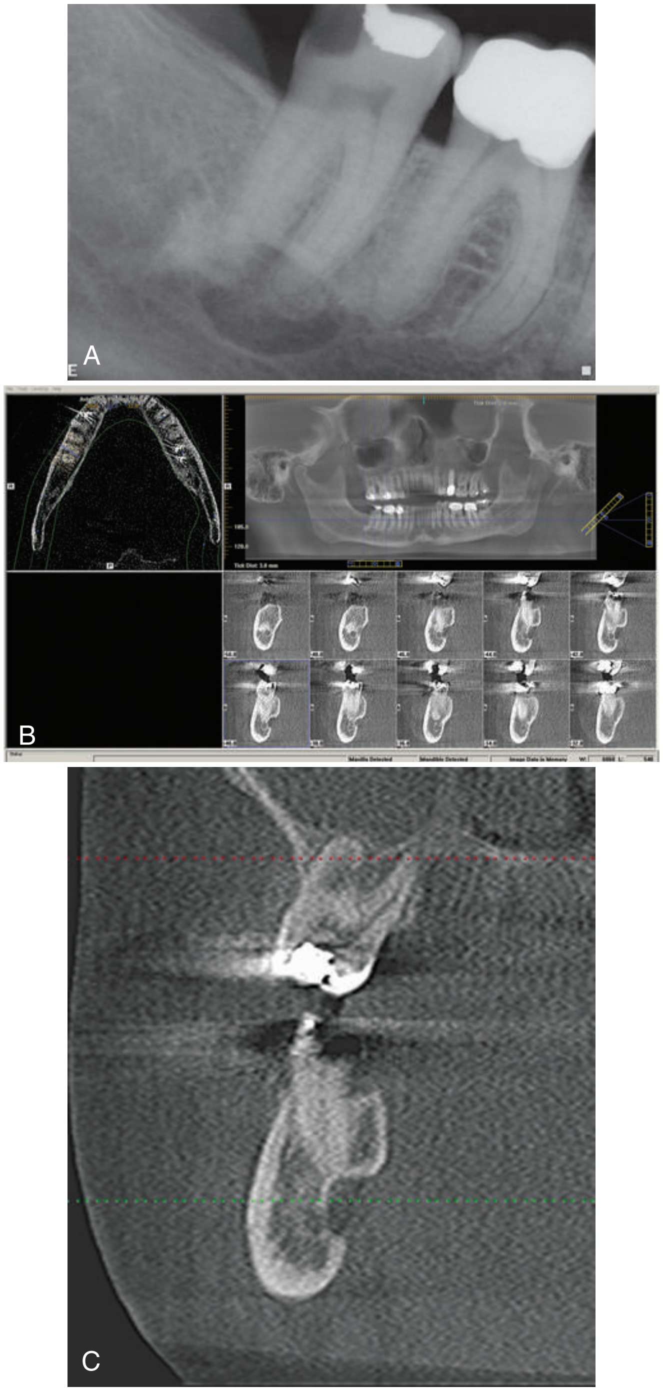

FIG. 1-32 **A,** Periapical radiograph showing a large apical radiolucency associated with the mandibular second molar. Apical pathosis should be ruled out. **B,** Cone-beam volumetric tomography revealed salivary indentation of the mandible in the area apical and lingual to the mandibular second molar, consistent with a Stafne defect. **C,** Enlargement of coronal section in the area of the mandibular second molar and the Stafne defect located on the lingual aspect of the mandible.

A definitive combination of factors, signs, and symptoms that, when collectively observed, allows the clinician to conclude the existence of a specific disease state is termed a *syndrome*. However, given the multitude of signs and symptoms that fractured roots can present with, it is often difficult to achieve an objective definitive diagnosis. For this reason, the terminology of *cracked tooth syndrome*[22,108] should be avoided.[6] The subjective and objective factors seen in cases of fractured teeth will generally be diverse; therefore, a tentative diagnosis of a fractured tooth will most likely be more of a prediction. Once this prediction is made, the patient must be properly informed as to any potential decrease in prognosis of the pending dental treatment. Because treatment options for repairing fractured teeth have only a limited degree of success, early detection and prevention, and proper informed consent, are crucial.[9,10,72,119,120,124,132]

Split tooth/roots occur when a fracture extends from one surface of the tooth to another surface of the tooth, with the tooth separating into two segments. If the split is more oblique, it is possible that once the smaller separated segment is removed, the tooth might still be restorable—for example, a fractured cusp. However, if the split extends below the osseous level, the tooth may not be restorable and endodontic treatment may not result in a favorable prognosis.

Proper prognosis assessment is imperative before any dental treatment but is often difficult in cases of cracked teeth. Because of the questionable long-term success from treating cases of suspected or known fractures, the clinician should be cautious in making the decision to continue with treatment and should avoid endodontic treatment in cases of a definitive diagnosis of split roots.

Vertical Root Fractures

One of the more common reasons for recurrent endodontic pathosis is the *vertical root fracture,* a severe crack in the tooth that extends longitudinally down the long axis of the root (Figs. 1-33 and 1-34). Often it extends through the pulp and to the periodontium. It tends to be more centrally located within the tooth, as opposed to being more oblique, and typically traverses through the marginal ridges. These fractures may be present before endodontic treatment, secondary to endodontic treatment, or may develop after endodontic treatment has been completed. Because diagnosing these vertical root fractures may be difficult, they often go unrecognized. Therefore, diagnosing the existence and extent of a vertical root fracture is imperative before any restorative or endodontic treatment is done, as it can dramatically affect the overall success of treatment.

A patient who consents to endodontic treatment must be informed if the tooth has a questionable prognosis. The clinician must be able to interpret the subjective and objective findings that suggest a vertical root fracture or split tooth, be able to make a prediction as to the eventual potential of healing, and convey this information to the patient. A more detailed discussion on vertical root fractures is described in Chapter 21.

Perforations

Root perforations are clinical complications that may lead to treatment failure. When root perforation occurs, communications between the root canal system and either periradicular tissues or the oral cavity may reduce the prognosis of treatment. Root perforations may result from extensive carious lesions, resorption, or operator error occurring during root canal instrumentation or post preparation.

The treatment prognosis of root perforations depends on the size, location, time of diagnosis and treatment, degree of periodontal damage, as well as the sealing ability and biocompatibility of the repair material.[45] It has been recognized that

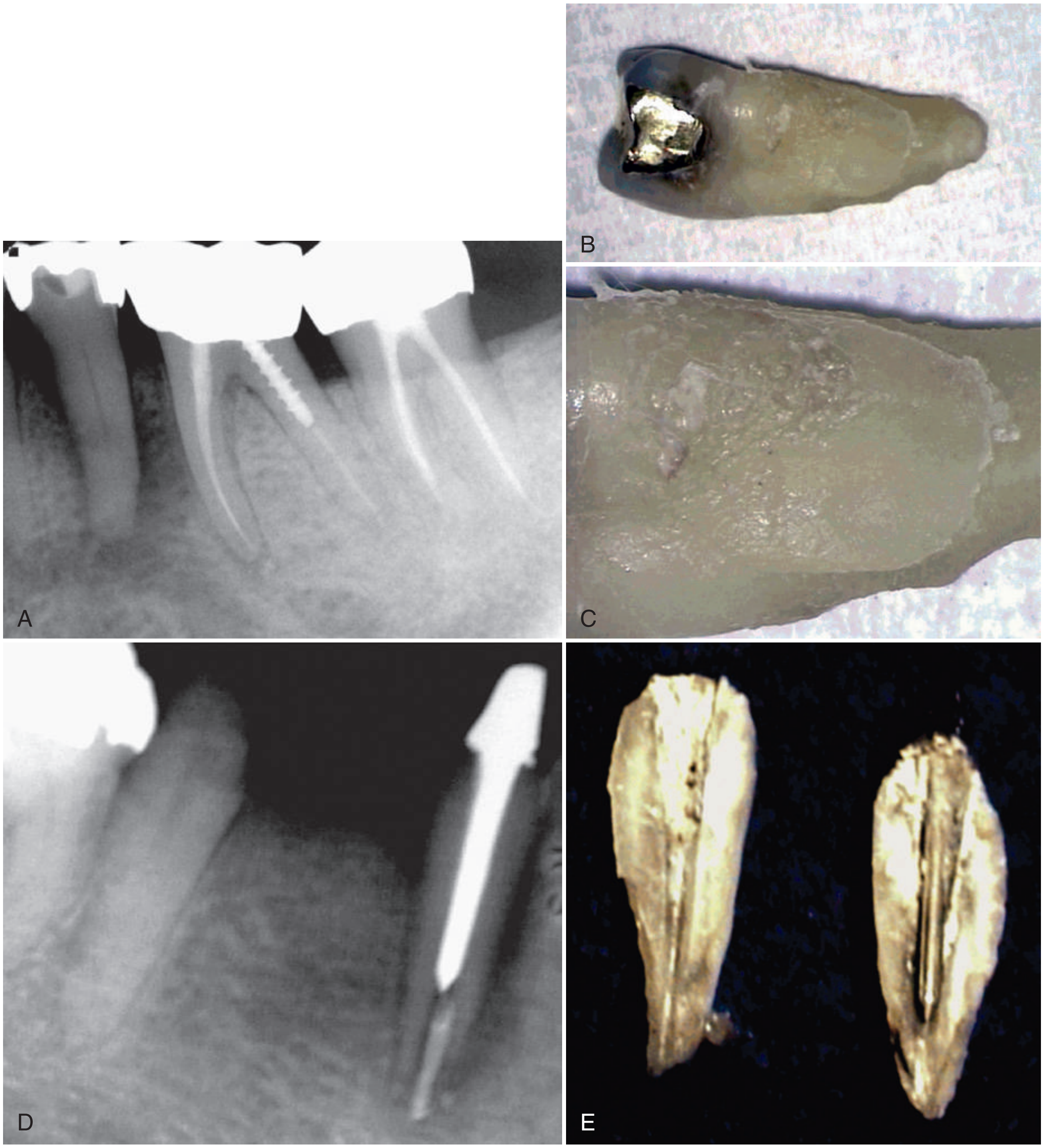

FIG. 1-33 Poorly fitting intracoronal restorations can place stresses within the tooth that can cause a vertical root fracture. **A,** This radiograph of a mandibular second premolar (with a gold inlay) reveals extensive periapical and periradicular bone loss, especially on the distal aspect. **B,** The tooth pulp tested nonvital, and there was an associated 12-mm-deep, narrow, isolated periodontal pocket on the buccal aspect of the tooth. After the tooth was extracted, the distal aspect was examined. **C,** On magnification (×16) the distal aspect of the root revealed an oblique vertical root fracture. Similarly, the placement of an ill-fitting post may exert intraradicular stresses on a root that can cause a fracture to occur vertically. **D,** This radiograph depicts a symmetrical space between the obturation and the canal wall, suggesting a vertical root fracture. **E,** After the tooth is extracted, the root fracture can be easily observed.

treatment success depends mainly on immediate sealing of the perforation and appropriate infection control. Among the materials that are commonly used to seal root perforations are mineral trioxide aggregate (MTA), Super EBA, intermediate restorative material (IRM), glass ionomer cements, and composites. The topic of perforations is further discussed in Chapter 19.

CLINICAL CLASSIFICATION OF PULPAL AND PERIAPICAL DISEASES

Many attempts have been made over the years to develop classifications of pulpal and periapical disease. However, studies have shown that making a correlation between clinical signs and symptoms and the histopathology of a given clinical

FIG. 1-34 Physical trauma from sports-related injuries or seizure-induced trauma, if directed accordingly, may cause a vertical root fracture in a tooth. This fracture occurred in a 7-year-old child secondary to trauma from a grand mal seizure.

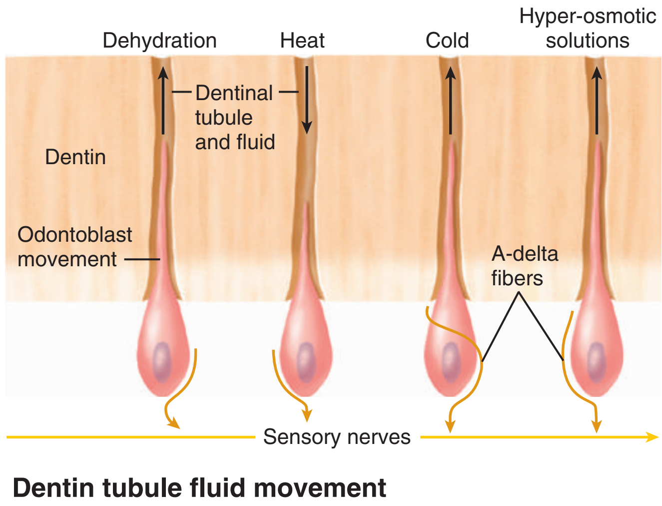

FIG. 1-35 Dentinal tubules are filled with fluid that, when stimulated, will cause sensation. Temperature changes, air, and osmotic changes can provoke the odontoblastic process to induce the stimulation of underlying A-delta fibers.

condition is challenging.[122,123] Therefore, *clinical* classifications have been developed in order to formulate treatment plan options. In the most general terms, the objective and subjective findings are used to classify the suspected pathosis, with the assigned designations merely representing the presence of healthy or diseased tissue.

The terminology and classifications that follow are based on those suggested by the American Association of Endodontists in 2012.[6]

Pulpal Disease

Normal Pulp

This is a clinical diagnostic category in which the pulp is symptom-free and normally responsive to pulp testing.[6] Teeth with normal pulp do not usually exhibit any spontaneous symptoms. The symptoms produced from pulp tests are mild, do not cause the patient distress, and result in a transient sensation that resolves in seconds. Radiographically, there may be varying degrees of pulpal calcification but no evidence of resorption, caries, or mechanical pulp exposure. No endodontic treatment is indicated for these teeth.

Pulpitis

This is a clinical and histologic term denoting inflammation of the dental pulp, clinically described as reversible or irreversible and histologically described as acute, chronic, or hyperplastic.[6]

Reversible Pulpitis

This is a clinical diagnosis based on subjective and objective findings indicating that the inflammation should resolve and the pulp return to normal.[6] When the pulp within the tooth is irritated so that the stimulation is uncomfortable to the patient but reverses quickly after irritation, it is classified as *reversible pulpitis*. Causative factors include caries, exposed dentin, recent dental treatment, and defective restorations. Conservative removal of the irritant will resolve the symptoms. Confusion can occur when there is exposed dentin, without evidence of pulp pathosis, which can sometimes respond with sharp, quickly reversible pain when subjected to thermal, evaporative, tactile, mechanical, osmotic, or chemical stimuli. This is known as *dentin* (or *dentinal*) *sensitivity* (or *hypersensitivity*). Exposed dentin in the cervical area of the tooth accounts for most of the cases diagnosed as dentin sensitivity.[103]

As described in Chapter 12, fluid movement within dentinal tubules can stimulate the odontoblasts and associated fast-conducting A-delta nerve fibers in the pulp, which in turn produce sharp, quickly reversible dental pain (Fig. 1-35). The more open these tubules are (e.g., from a newly exposed preparation, dentin decalcification, periodontal scaling, tooth-bleaching materials, or coronal tooth fractures), the more the tubule fluid will move and, subsequently, the more the tooth will display dentin sensitivity when stimulated. When making a diagnosis, it is important to discriminate this dentin sensitivity sensation from that of reversible pulpitis, which would be secondary to caries, trauma, or new or defective restorations. Detailed questioning about recent dental treatment and a thorough clinical and radiographic examination will help to separate dentin sensitivity from other pulpal pathosis, as the treatment modalities for each are completely different.[18]

Irreversible Pulpitis

As the disease state of the pulp progresses, the inflammatory condition of the pulp can change to *irreversible pulpitis*. At this stage, treatment to remove the diseased pulp will be necessary. This condition can be divided into the subcategories of *symptomatic* and *asymptomatic* irreversible pulpitis.

Symptomatic Irreversible Pulpitis

This is a clinical diagnosis based on subjective and objective findings indicating that the vital inflamed pulp is incapable of healing.[6] Teeth that are classified as having *symptomatic irreversible pulpitis* exhibit intermittent or spontaneous pain. Rapid exposure to dramatic temperature changes (especially to cold stimuli) will elicit heightened and prolonged episodes of pain even after the thermal stimulus has been removed. The pain in these cases may be sharp or dull, localized, diffuse, or referred. Typically, there are minimal or no changes in the radiographic appearance of the periradicular bone. With advanced irreversible pulpitis, a thickening of the periodontal ligament may become apparent on the radiograph, and there may be some evidence of pulpal irritation by virtue of extensive pulp chamber or root canal space calcification. Deep restorations, caries, pulp exposure, or any other direct or indirect insult to the pulp, recently or historically, may be present. It may be seen radiographically or clinically or may be suggested from a complete dental history. Patients who present with symptomatic anterior teeth for which there are no obvious etiologic factors should be also questioned regarding past general anesthesia or endotracheal intubation procedures.[3,127,138] In addition, patients should be questioned about a history of orthodontic treatment. Typically, when symptomatic irreversible pulpitis remains untreated, the pulp will eventually become necrotic.[109,139]

Asymptomatic Irreversible Pulpitis

This is a clinical diagnosis based on subjective and objective findings indicating that the vital inflamed pulp is incapable of healing.[6] The patient, however, does not complain of any symptoms. On occasion, deep caries will not produce any symptoms, even though clinically or radiographically the caries may extend well into the pulp. Left untreated, the tooth may become symptomatic or the pulp will become necrotic. In cases of *asymptomatic irreversible pulpitis,* endodontic treatment should be performed as soon as possible so that symptomatic irreversible pulpitis or necrosis does not develop and cause the patient severe pain and distress.

Pulp Necrosis

This is a clinical diagnostic category indicating death of the dental pulp. The pulp is usually nonresponsive to pulp testing.[6] When pulpal *necrosis* (or *nonvital pulp*) occurs, the pulpal blood supply is nonexistent and the pulpal nerves are nonfunctional. It is the only clinical classification that directly attempts to describe the histologic status of the pulp (or lack thereof). This condition is subsequent to symptomatic or asymptomatic irreversible pulpitis. After the pulp becomes completely necrotic, the tooth will typically become asymptomatic until such time when there is an extension of the disease process into the periradicular tissues. With pulp necrosis, the tooth will usually not respond to electric pulp tests or to cold stimulation. However, if heat is applied for an extended period of time, the tooth may respond to this stimulus. This response could possibly be related to remnants of fluid or gases in the pulp canal space expanding and extending into the periapical tissues.

Pulpal necrosis may be partial or complete and it may not involve all of the canals in a multirooted tooth. For this reason, the tooth may present with confusing symptoms. Pulp testing over one root may give no response, whereas over another root it may give a positive response. The tooth may also exhibit symptoms of symptomatic irreversible pulpitis. Pulp necrosis, in the absence of restorations, caries, or luxation injuries, is likely caused by a longitudinal fracture extending from the occlusal surface and into the pulp.[19]

After the pulp becomes necrotic, bacterial growth can be sustained within the canal. When this infection (or its bacterial byproducts) extends into the periodontal ligament space, the tooth may become symptomatic to percussion or exhibit spontaneous pain. Radiographic changes may occur, ranging from a thickening of the periodontal ligament space to the appearance of a periapical radiolucent lesion. The tooth may become hypersensitive to heat, even to the warmth of the oral cavity, and is often relieved by applications of cold. As previously discussed, this may be helpful in attempting to localize a necrotic tooth (i.e., by the application of cold one tooth at a time) when the pain is referred or not well localized.

Previously Treated

This is a clinical diagnostic category indicating that the tooth has been endodontically treated and the canals are obturated with various filling materials other than intracanal medicaments.[6] In this situation, the tooth may or may not present with signs or symptoms but will require additional nonsurgical or surgical endodontic procedures to retain the tooth. In most such situations, there will no longer be any vital or necrotic pulp tissue present to respond to pulp testing procedures.

Previously Initiated Therapy

This is a clinical diagnostic category indicating that the tooth has been previously treated by partial endodontic therapy (e.g., pulpotomy, pulpectomy).[6] In most instances, the partial endodontic therapy was performed as an emergency procedure for symptomatic or asymptomatic irreversible pulpitis cases. In other situations, these procedures may have been performed as part of vital pulp therapy procedures, traumatic tooth injuries, apexification, or apexogenesis therapy. At the time these cases present for root canal therapy it would not be possible to make an accurate pulpal diagnosis because all, or part, of the pulp tissue has already been removed.

Apical (Periapical) Disease

Normal Apical Tissues

This classification is the standard against which all of the other apical disease processes are compared. In this category the patient is asymptomatic and the tooth responds normally to percussion and palpation testing. The radiograph reveals an intact lamina dura and periodontal ligament space around all the root apices.

Periodontitis

This classification refers to an inflammation of the periodontium.[6] When located in the periapical tissues it is referred to as apical periodontitis. Apical periodontitis can be subclassified to symptomatic apical periodontitis and asymptomatic apical periodontitis.

Symptomatic Apical Periodontitis

This condition is defined as an inflammation, usually of the apical periodontium, producing clinical symptoms including a painful response to biting or percussion or palpation. It might or might not be associated with an apical radiolucent area.[6]

This tooth may or may not respond to pulp vitality tests, and the radiograph or image of the tooth will typically exhibit at least a widened periodontal ligament space and may or may not show an apical radiolucency associated with one or all of the roots.

Asymptomatic Apical Periodontitis

This condition is defined as inflammation and destruction of apical periodontium that is of pulpal origin, appears as an apical radiolucent area, and does not produce clinical symptoms.[6] This tooth does not usually respond to pulp vitality tests, and the radiograph or image of the tooth will exhibit an apical radiolucency. The tooth is generally not sensitive to biting pressure but may "feel different" to the patient on percussion. Manifestation of persistent apical periodontitis may vary among patients.[89]

Acute Apical Abscess

This condition is defined as an inflammatory reaction to pulpal infection and necrosis characterized by *rapid onset*, spontaneous pain, tenderness of the tooth to pressure, pus formation, and swelling of associated tissues.[6] A tooth with an *acute apical abscess* will be acutely painful to biting pressure, percussion, and palpation. This tooth will not respond to any pulp vitality tests and will exhibit varying degrees of mobility. The radiograph or image can exhibit anything from a widened periodontal ligament space to an apical radiolucency. Swelling will be present intraorally and the facial tissues adjacent to the tooth will almost always present with some degree of swelling. The patient will frequently be febrile, and the cervical and submandibular lymph nodes may exhibit tenderness to palpation.

Chronic Apical Abscess

This condition is defined as an inflammatory reaction to pulpal infection and necrosis characterized by *gradual onset*, little or no discomfort, and the intermittent discharge of pus through an associated sinus tract.[6] In general, a tooth with a *chronic apical abscess* will not present with clinical symptoms. The tooth will not respond to pulp vitality tests, and the radiograph or image will exhibit an apical radiolucency. Usually the tooth is not sensitive to biting pressure but can "feel different" to the patient on percussion. This entity is distinguished from asymptomatic apical periodontitis because it will exhibit intermittent drainage through an associated sinus tract.

REFERRED PAIN

The perception of pain in one part of the body that is distant from the actual source of the pain is known as *referred pain*. Whereas pain of nonodontogenic origin can refer pain to the teeth, teeth may also refer pain to other teeth as well as to other anatomic areas of the head and neck (see Chapters 4 and 17). This may create a diagnostic challenge, in that the patient may insist that the pain is from a certain tooth or even from an ear when, in fact, it is originating from a distant tooth with pulpal pathosis. Using electronic pulp testers, investigators found that patients could localize *which* tooth was being stimulated only 37.2% of the time and could narrow the location to three teeth only 79.5% of the time, illustrating that patients may have a difficult time discriminating the exact location of pulpal pain.[44]

Referred pain from a tooth is usually provoked by an intense stimulation of pulpal C fibers, the slow conducting nerves that when stimulated cause an intense, slow, dull pain. Anterior teeth seldom refer pain to other teeth or to opposite arches, whereas posterior teeth may refer pain to the opposite arch or to the periauricular area but seldom to the anterior teeth.[14] Mandibular posterior teeth tend to transmit referred pain to the periauricular area more often than maxillary posterior teeth. One study showed that when second molars were stimulated with an electric pulp tester, patients could discriminate accurately which arch the sensation was coming from only 85% of the time, compared with an accuracy level of 95% with first molars and 100% with anterior teeth.[136] The investigators also pointed out that when patients first feel the sensation of pain, they are more likely to accurately discriminate the origin of the pain. With higher levels of discomfort, patients have less ability to accurately determine the source of the pain. Therefore, in cases of diffuse or referred pain, the history of where the patient first felt the pain may be significant.

Because referred pain can complicate a dental diagnosis, the clinician must be sure to make an accurate diagnosis to protect the patient from unnecessary dental or medical treatment. If after all the testing procedures are complete and it is determined that the pain is not of odontogenic origin, then the patient should be referred to an orofacial pain clinic for further testing. For further information on pain of nonodontogenic origin, see Chapter 17.

SUMMARY

Endodontics is a multifaceted specialty, with much emphasis on how cases are clinically treated. Clinicians have increased their ability to more accurately perform endodontic procedures by way of increased visualization using the operating microscope, precise apical foramen detection using electronic apex locators, enhanced imaging techniques using digital radiography, and more. Practices have incorporated more refined canal cleaning and shaping techniques by using ultrasonics and rotary-driven nickel titanium files facilitated with computer-assisted electronic handpieces. Many other advancements have also been introduced with the objective of achieving an optimal result during endodontic treatment. However, these advancements are useless if an incorrect diagnosis is made. Before the clinician ever considers performing any endodontic treatment, the following questions must be answered:

- Is the existing problem of dental origin?
- Are the pulpal tissues within the tooth pathologically involved?
- Why is the pulpal pathosis present?
- What is the prognosis?
- What is the appropriate form of treatment?

Testing, questioning, and reasoning are combined to achieve an accurate diagnosis and to ultimately form an appropriate treatment plan. The art and science of making this diagnosis are the first steps that must be taken before initiating any endodontic treatment.

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CHAPTER 2

Radiographic Interpretation

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CHAPTER OUTLINE

RADIOGRAPHIC INTERPRETATION

Interpretation of information captured by radiographic imaging modalities is central to the diagnostic process. It is very important to capture a diagnostically useful image using appropriate exposure parameters and view it with interactive manipulation of brightness and contrast or window/level (for cone beam computed tomography [CBCT] studies) in an optimal environment to adequately evaluate anatomy and diagnose pathoses. Accurate interpretation of root and canal morphology, determination of radiographic canal length, diagnosis of radicular and periradicular disease (Fig. 2-1), and postsurgical and long-term evaluation of the outcome of endodontic treatment are some of the routine diagnostic imaging tasks in endodontics.[181] Systematic and methodical interpretation processes must be followed for all images. Recognition of anatomy, anatomic variants, and pathologic conditions or deviations from normal is important. Various imaging modalities exist in radiology. Some use ionizing radiation, whereas others use ultrasonic waves (ultrasonography, or US) or powerful external magnetic fields (magnetic resonance imaging, or MRI). Interventional and noninterventional imaging modalities are also available. Imaging modalities using ionizing radiation are most frequently used in endodontic diagnoses. The different image capture modalities include conventional intraoral film and the more modern digital receptors.

Imaging Modalities

Digital radiography using electronic sensors or photostimulable phosphor (PSP) plates is widely used in endodontics. The advantages of using digital sensors over film are many. Significant advantages include noteworthy dose reduction (especially in comparison with D-speed film used with round collimation); almost instantaneous generation of high-resolution digital images with resolution approaching or equaling that of film for specific diagnostic tasks; the ability to postprocess images for enhanced diagnostic outcomes; elimination of variables associated with wet processing of conventional film; ease of transmission and of archiving and retrieving images from databases or picture archiving and communication systems (PACS); facilitation of use of an all-electronic patient record[123,188]; reduced exposure of personnel to hazardous chemicals; and reduced environmental impact.

Digital imaging modalities in endodontics use different image capture technologies, which include a charge-coupled device (CCD), a complementary metal oxide semiconductor (CMOS), or a PSP (also sometimes referred to as an indirect acquisition modality). Film images also can be digitized using a flatbed scanner or CCD/CMOS-based cameras mounted on a camera stand, with images captured using a frame grabber from a mounted, lighted platform.

CCD-based solid-state sensors were used extensively in endodontics initially. However, the earlier generation sensors had

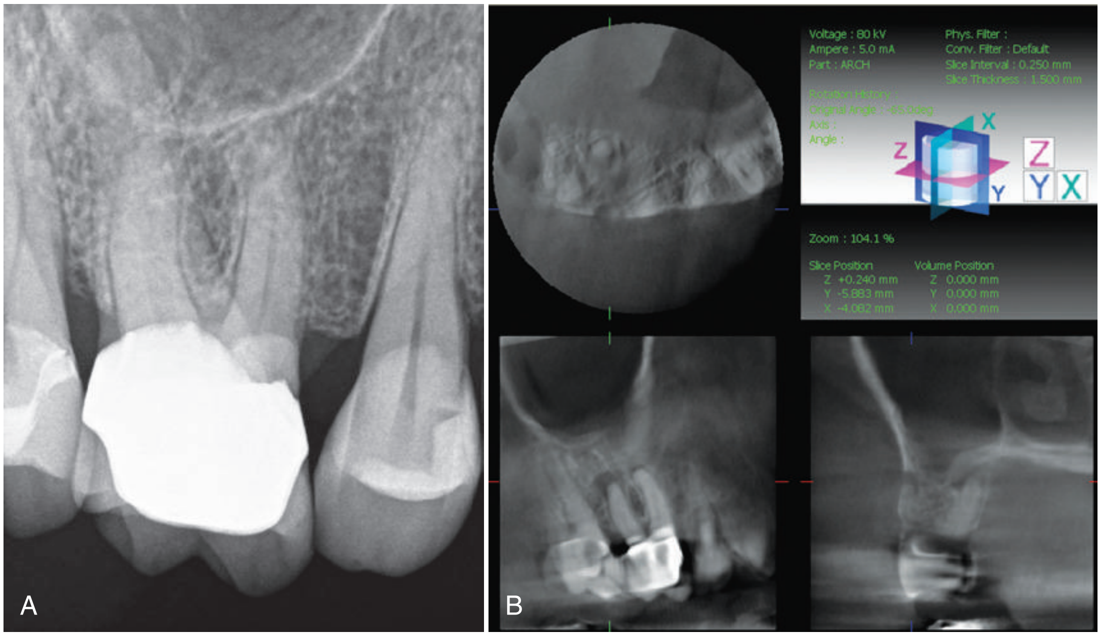

FIG. 2-1 **A,** A well-angulated periapical radiograph of the maxillary right first molar taken during a diagnostic appointment for endodontic evaluation of the maxillary right quadrant. At first glance, there is little radiographic evidence of significant or periradicular change. **B,** Contemporaneous CBCT image of same tooth gives an entirely different perspective; periapical changes are visible on all three roots in all three anatomic planes of section. (*B taken* with J. Morita Veraviewepocs 3D [J. Morita, Osaka, Japan]).

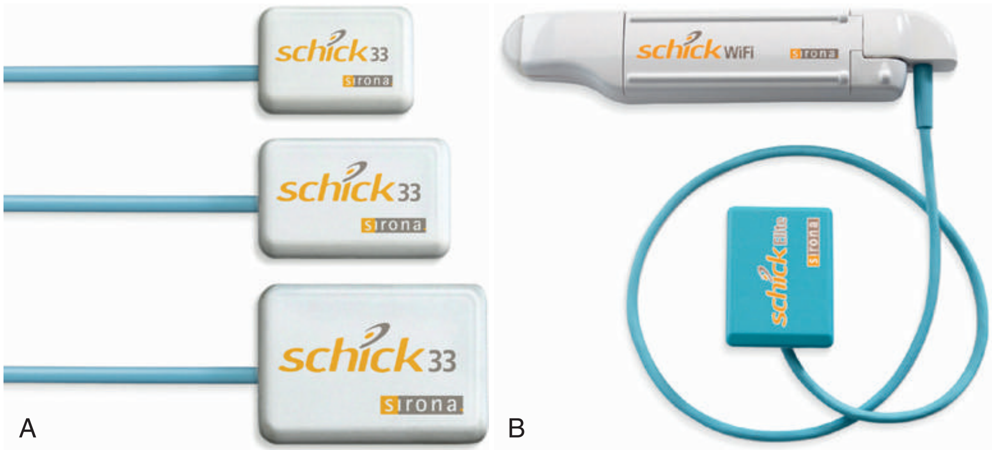

FIG. 2-2 **A** and **B,** High-resolution complementary metal oxide semiconductor (CMOS) sensors are available from many manufacturers. Note that Figure B shows wireless CMOS sensors transmit images to the chairside workstation by 2.4 GHz radio frequency. (Courtesy SIRONA DENTAL SYSTEMS, Long Island City, NY.)

a smaller active area and limited x-ray absorption and conversion efficiency, in addition to being bulky. Sensors use an array of radiation-sensitive elements that generate electric charges proportionate to the amount of incident radiation. To reduce the amount of radiation needed to capture an image, a light-sensitive array was developed that uses a scintillation layer laid on top of the CCD chip or added with a fiberoptic coupling. The generated charge is read out in a "bucket brigade" fashion and transferred to an analog-to-digital converter in the frame grabber assembly of the workstation. The digital information is processed, and an image is formed. CMOS-based sensors, on the other hand, have an active transistor at each element location. The area available for signal generation is relatively less, and there is a fixed pattern noise. These sensors are less expensive to manufacture and have been shown to be equally useful for specific diagnostic tasks.[4] Unlike the CCD, the CMOS chip requires very little electrical energy; therefore, no external power supply is needed to support USB utilization, and wireless applications are feasible. Wireless sensors are available (Fig. 2-2). However, radiofrequency interference may be a problem with these sensors. The current WiFi sensor is less bulky and has a wire attached to it that enables transmission via 802.11 b/g standard. It uses a lithium-ion polymer battery that can last for approximately 100 exposures.

Yet another type of sensor uses PSPs for image capture. PSP technology is also referred to as *computed radiography* (CR).[94,169]

Unlike the CCD and CMOS sensors, PSP sensors are wireless. The phosphor is activated by a process called *doping,* which enables charges to be generated and stored when exposed to radiation. A latent image is stored in the sensor, and a PSP reader with a laser beam of specific wavelength is used to read out the image. Previously captured images can be erased by exposing the PSP sensor to white light. PSP plates can be damaged easily by scratching, but they are not as expensive as CCD or CMOS sensors. Incomplete erasure of the image can lead to ghost images when the plate is reused, and delayed processing can result in a decrease in image clarity.[2] PSP-based sensors are used in high-volume scenarios. Spatial resolution is lower with this type of sensor, but it has a wider dynamic range. These sensors can tolerate a wider range of exposures to produce a diagnostically useful image.

Radiation dose continues to be a concern with all imaging studies. The lowest possible dose must be delivered for each study. Most dental offices would not be in compliance with the latest recommendations of the National Council for Radiation Protection (NCRP) on reducing the radiation dose from intraoral radiographs (Box 2-1). Two terms have been specifically defined in the NCRP's report. The terms *shall* and *shall not* indicate that adherence to the recommendation would be in compliance with the standards of radiation safety. The terms *should* and *should not* indicate prudent practice and acknowledge that exceptions may be made in certain circumstances. In addition, the report establishes nine new recommendations for image processing of conventional film.

A strong argument can be made for clinicians to switch to a direct digital radiography (DDR) system to avoid all the drastic changes necessary to ensure compliance with the new recommendations. Even though restriction of an intraoral dental x-ray beam is mandated by federal law to a circle no greater than 7 cm, rectangular collimation has been proven to significantly reduce the radiation dose to the patient.

The American Dental Association (ADA) Council on Scientific Affairs has made the following statement:

> Tissue area exposed to the primary x-ray beam should not exceed the minimum coverage consistent with meeting diagnostic requirements and clinical feasibility. For periapical and bitewing radiography, rectangular collimation should be used whenever possible because a round field beam used with a rectangular image receptor produces … unnecessary radiation exposure to the patient.[1]

BOX 2-1

Recommendations of the National Council on Radiation Protection

1. Dentists must examine their patients before ordering or prescribing x-ray images (this is not a new guideline).
2. The use of leaded aprons on patients shall not be required if all other recommendations in this report are rigorously followed (read full Report #145).
3. Thyroid shielding shall be used for children and should be provided for adults when it will not interfere with the examination (e.g., panoramic imaging).
4. Rectangular collimation of the beam, which has been recommended for years, shall be routinely used for periapical radiographs. Each dimension of the beam, measured in the plane of the image receptor, should not exceed the dimension of the image receptor by more than 2% of the source-to-image receptor distance. Similar collimation should be used, when feasible, for bitewing radiographs.
5. Image receptors of speeds slower than ANSI speed Group E films shall not be used for intraoral radiography. Faster receptors should be evaluated and adopted if found acceptable. For extraoral radiography, high-speed (400 or greater) rare earth screen-film systems or digital-imaging systems of equivalent or greater speed shall be used.
6. Dental radiographic films shall be developed according to the film manufacturer's instructions using the time-temperature method. In practical application, this means that sight development (reading wet x-ray films at the time of the procedure) shall not be used.
7. Radiographic techniques for digital imaging shall be adjusted for the minimum patient dose required to produce a signal-to-noise ratio sufficient to provide image quality to meet the purpose of the examination.
8. Clinicians designing new offices or remodeling existing locations will need shield protection to be provided by a qualified expert.

Modified from the National Council on Radiation Protection and Measurements: Radiation protection in dentistry, Report #145, Bethesda, Md, 2003. Available at: www.ncrppublications.org/Reports/145.

Image Characteristics and Processing

Spatial resolution achieved with current generation digital sensors is equally good or better than that of conventional intraoral radiographic film. Intraoral film has a resolution of 16 line pairs per millimeter (lp/mm) as measured using a resolution tool, and it increases to 20 to 24 lp/mm with magnification. *Spatial resolution* is defined as the ability to display two objects that are close to each other as two separate entities. *Contrast resolution* is defined as the ability to differentiate between areas on the image based on density. Most diagnostic tasks in endodontics require a high-contrast resolution.[121] However, image quality is not just a function of spatial resolution. The choice of appropriate exposure parameters, sensor properties, the image processing used, and viewing conditions and modalities directly affect diagnostic accuracy.

Postprocessing of images may be carried out to alter image characteristics. Radiographs need not be reexposed if image quality is not adequate. Diagnostic information can be teased out of the image if appropriate image processing is used. However, the original image must be acquired with optimal exposure parameters to accomplish meaningful image processing.[178] Suboptimally exposed images cannot be processed to yield diagnostic information, which may lead to a reduction in the diagnostic accuracy of the image. Image enhancement must be task specific. Signal-to-noise ratio (SNR) must be optimized to extract necessary information from the image. The bit-depth of images also has a direct relationship to image quality. It indicates the number of shades of gray that the sensor can capture for display. For example, an 8-bit image can depict 256 shades of gray. Most sensors are 12 or 14 bits in depth, capturing 4,096 or 65,536 shades of gray, respectively. If the sensor captures several thousand shades of gray, the image can be manipulated through enhancement techniques to display those shades of gray that best depict the anatomy of interest. The human visual system is limited in the number of shades of gray that can be read at any point in time. Therefore, image enhancement is a must for all images, so as to delineate signals of interest through manipulation of the grayscale. Most endodontic tasks require a high contrast and thus a shorter grayscale.

Digital radiographs can be saved in different file formats. Several file formats are available: DICOM (*D*igital *I*maging and *C*ommunications in *M*edicine); tiff (*t*agged *i*mage *f*ile *f*ormat); jpeg (*j*oint *p*hotographic *e*xperts *g*roup); gif (*g*raphics *i*nterchange *f*ormat); BMP (Windows' bitmap image file); PNG (*p*ortable *n*etwork *g*raphics); and so on. There also are several proprietary formats. "Lossy" and "lossless" compression schemes can be used for saving images, although lossless compression is preferred.[58]

Digital Imaging and Communications in Medicine (DICOM)

DICOM is a set of international standards established in 1985 by the American College of Radiology (ACR) and the National Electrical Manufacturers Association (NEMA)[46,175] to address the issue of vendor-independent data formats and data transfers for digital medical images.[77] The ADA has promoted the interoperability of dental images through the efforts of its Working Group 12.1.26. DICOM serves as a standard for the transferal of radiologic images and other medical information between computers, allowing digital communication between systems from various manufacturers and across different platforms (e.g., Apple iOS or Microsoft Windows).[78] The DICOM standard provides for several hundred attribute fields in the record header, which contains information about the image (e.g., pixel density, dimensions, and number of bits per pixel), in addition to relevant patient data and medical information. Although earlier versions did not specify the exact order and definition of the header fields, each vendor is required to publish a DICOM conformance statement, which gives the location of pertinent data. The big hurdle is to support medical and dental consultations between two or more locations with different imaging software. With DICOM in place, dental clinicians can change vendors and maintain database interoperability. Most software vendors are striving to achieve full DICOM compliance, and some have achieved at least partial compliance. However, proprietary DICOM images are still produced in different systems, with the capability to export in universal DICOM format as needed. Diagnostic images are best saved as DICOM files to preserve image fidelity or as tiff files with no compression. Diagnosis suffers when images undergo lossy compression.[50,103,180]

Based on the DICOM model, the ADA Standards Committee on Dental Informatics has identified four basic goals for electronic standards in dentistry: (1) interoperability, (2) electronic health record design, (3) clinical workstation architecture, and (4) electronic dissemination of dental information.[7] The dental profession must continue to promote DICOM compatibility so that proprietary software and file types do not hinder communication and risk making data obsolete.

DIAGNOSTIC TASKS IN ENDODONTICS

Working Length Determination

Digital imaging systems perform as well as intraoral film or better for working length determination.[121] No significant difference was noted between measurements made on digital images.[99] Older studies compared the early generation digital sensors with limited bit-depth to D-speed films, and the films showed better performance. It is important to analyze the type of sensor used, software, processing, video card and monitor, and viewing conditions to determine whether the sensor is good for a specific diagnostic task. Calibration improves the diagnostic accuracy.[108] Likewise, the use of optimal processing parameters improves image quality to the extent of making a significant difference in the diagnostic outcome. For instance, density plot analysis was shown to help with endodontic file measurements.[146] The major advantage of direct digital radiography (CCD, CMOS) is that the dose is significantly less compared with that required for film. The use of DDR, therefore, is justified when its performance is comparable to that of film with no statistically significant differences.[101]

The three types of measurement generally available with digital imaging software are (1) linear measurement, the distance between two points in millimeters (Fig. 2-3); (2) angle measurement, the angle between two lines; and (3) area measurement, the area of the image or a segment of the image. Because magnification and distortion errors play a significant role in the accuracy of two-dimensional (2D) radiographic measurement, both film and digital systems are subject to parallax error. However, a study that compared endodontic file length images of human teeth taken with a custom jig suggested that "measurement error was significantly less for the digital images than the film-based images."[49] This was true even though, as the authors pointed out, the measurement differences may not have been clinically significant. Sophisticated calibration algorithms are under development, and accurate measurement of parallel images should be more feasible in the future.[30]

Diagnosis and Healing

Image enhancement of direct and indirect digital radiographs based on the diagnostic task at hand has been shown to increase diagnostic accuracy compared to film-based images, which cannot be enhanced.[2,190] Posttreatment endodontic evaluation of healing of apical radiolucent areas is a challenge. Early changes indicating healing and bone fill are difficult to detect on conventional or digital radiographs. However, bone fill can be detected using more sensitive techniques, such as digital subtraction radiography, in which two images, separated in time but acquired with the exact same projection geometry and technique factors, can be subtracted from one another to tease out subtle changes in the periodontium and surrounding bone. Subtraction techniques are difficult to carry out in routine clinical practice because they are technique sensitive and can yield incorrect information if not performed accurately. Several studies have shown the usefulness of subtraction radiography using digital sensors.[117,129,194]

Three-Dimensional Imaging

Computed tomography (CT) was introduced by Sir Godfrey Hounsfield in the 1970s. *Tomography* refers to "slice imaging," in which thin slices of the anatomy of interest are captured and synthesized manually or using an algorithm. CT makes use of automated reconstruction. Medical-grade CT used a translate-rotate image acquisition scheme as the technology developed, but the modality always resulted in higher radiation dose delivery because of redundancy of data capture, in addition to longer scan times with the potential for motion artifact.

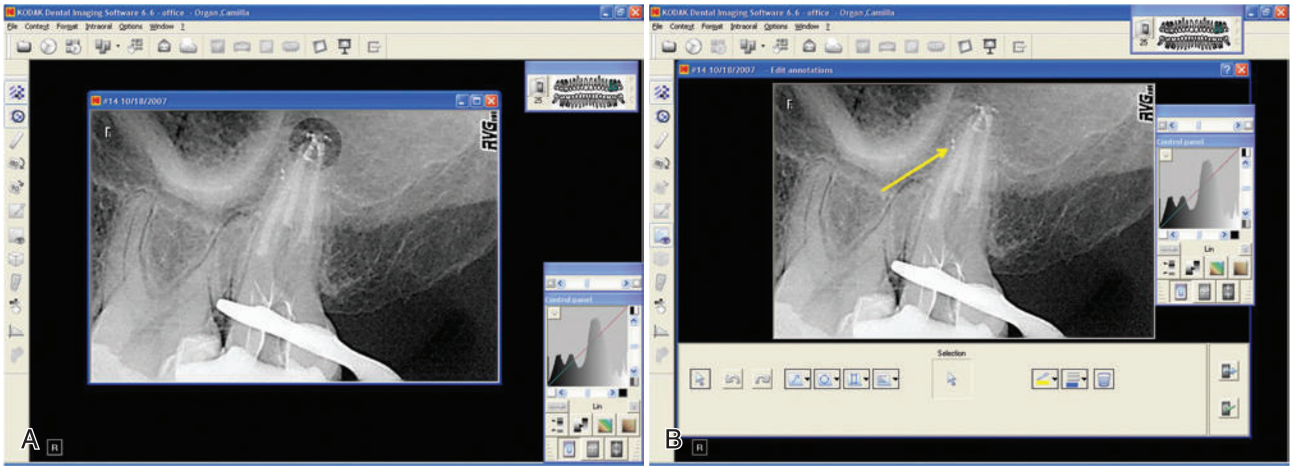

FIG. 2-3 **A**, Certain regions of interest (ROI) can be highlighted with a preset contrast tool that can be moved around the image. **B**, Preprogramed filters that enhance sharpness and contrast can be selected to optimize the image acquired. (Courtesy Carestream Dental LLC, Atlanta, GA.)

Multiple detectors and x-ray sources were used in later generations of CT units to reduce scanning times. The increased radiation dose, artifacts from metallic restorations, cost of scanning, long acquisition times, and lack of adequate dental-specific software have been drawbacks limiting the use of the technology in dentistry until recently. The advent of cone beam volumetric computed tomography (CBVCT) introduced a faster, low-dose, low-cost, high-contrast imaging modality that could capture information in three dimensions using a limited field of view.

CBVCT, or cone beam CT (CBCT), is a relatively new diagnostic imaging modality that has been recently added to the endodontic imaging armamentarium. This modality uses a cone beam instead of a fan-shaped beam in multidetector computed tomography (MDCT), acquiring images of the entire volume as it rotates around the anatomy of interest. Compared with MDCT images, CBCT offers relatively high-resolution, isotropic images, allowing effective evaluation of root canal morphology and other subtle changes within the root canal system. Even though the resolution is not as high as that of conventional radiographs (18 microns), the availability of three-dimensional (3D) information, the relatively higher resolution, and a significantly lower dose compared to MDCT make CBCT the imaging modality of choice in challenging situations demanding localization and characterization of root canals.

The adoption of advanced imaging modalities such as CBCT for select diagnostic tasks is becoming popular with clinicians performing endodontic procedures. Two-dimensional grayscale images, whether conventional film based or digital, cannot accurately depict the full 3D representation of the teeth and supporting structures. In fact, traditional images are poor representations of even the pulpal anatomy. They grossly underestimate canal structure and often cannot accurately visualize periapical changes, especially where there is thick cortical bone, as in the presence of anatomic obstructions (Fig. 2-4, *A*). CBCT, however, allows the clinician to view the tooth and pulpal structures in thin slices in all three anatomic planes: axial, sagittal, and coronal. This capability alone allows visualization of periapical pathoses and root morphology previously impossible to assess (Fig. 2-4, *B* and *C*). Several tools available in CBCT, such as the ability to change the vertical or horizontal angulation of the image in real time, in addition to thin-slice, grayscale data of varying thicknesses, will never be available for conventional or even digital radiography. Furthermore, the use of CBCT data to view the region of interest in three anatomic planes of section at very low x-ray doses has never been as easy or accessible as it is today.

Microcomputed tomography (micro-CT) has also been evaluated in endodontic imaging.[87,144,145] Comparison of the effects of biomechanical preparation on the canal volume of reconstructed root canals in extracted teeth using micro-CT data was shown to assist with characterization of morphologic changes associated with these techniques.[145] Peters et al.[144] used micro-CT to evaluate the relative performance of nickel-titanium (Ni-Ti) instruments after the shaping of root canals of varying preoperative canal geometry (for examples, see Chapter 6). A study to examine the potential and accuracy of micro-CT for imaging of filled root canals showed it to be a highly accurate and nondestructive method for the evaluation of root canal fillings and its constituents. The qualitative and quantitative correlations between histologic and micro-CT examination of root canal fillings were high.[87] However, it is important to note that micro-CT remains a research tool and cannot be used for human imaging in vivo.

This chapter discusses the principles, applications, imaging attributes, image artifacts, and potential liability of adopting CBCT technology for endodontic procedures. Given this information, the student of endodontics will begin to realize the significant advantages, limitations, and diagnostic and treatment planning capabilities of this radiographic imaging modality.

PRINCIPLES OF CONE BEAM COMPUTED TOMOGRAPHY

Three important parameters of cone beam imaging are described in the following sections:

- Voxel size
- Field of view (FOV)
- Slice thickness/measurement accuracy

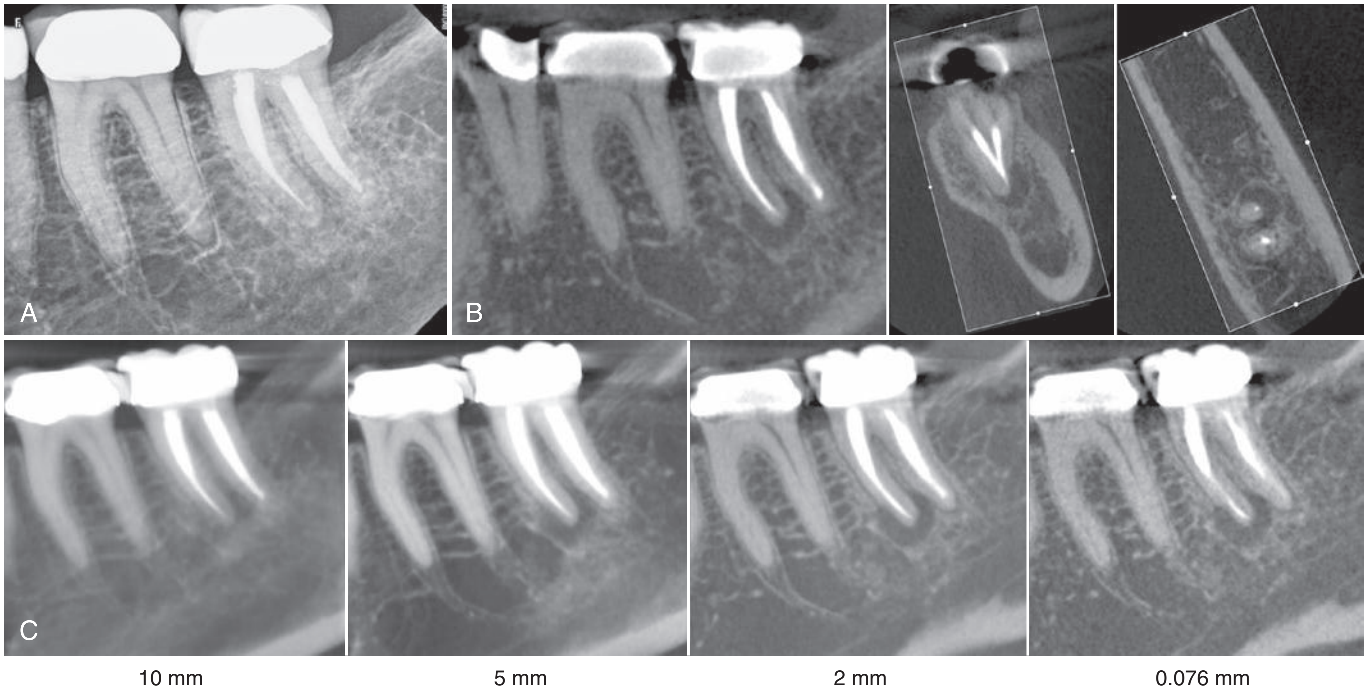

FIG. 2-4 This case demonstrates the difficulty in assessing lesions in the mandibular posterior region when there is a dense cortex. This well-angulated periapical radiograph (**A**) does not clearly show any radiolucencies associated with the mandibular left second molar, for which the patient has presented for evaluation and possible retreatment. The CBCT corrected sagittal, coronal, and axial reconstructed multiplanar views (**B**, *left to right,* sagittal, coronal, and axial views) show previous endodontic treatment, with a 6-mm diameter radiolucency with a well-defined, mildly corticated border, centered over a point on the buccal aspect of the root, 2 mm coronal to the apex; these are features consistent with an apical rarefying osteitis. The ray sum images of the sagittal view, where the image is "thinned" by decreasing the number of adjacent voxels using postprocessing software, simulates a curvilinear projection, showing diminishing superimposition (**C**, *left to right,* image layer of 10 mm, 5 mm, 2 mm, and 0.076 mm). (Data acquired and reformatted at 0.076 mm voxel size using a CS 9000 3D unit [Carestream Dental, Atlanta, Ga].)

Voxels and Voxel Sizes

Voxels are cuboidal elements that constitute a 3D volume, unlike pixels, which are 2D. Data are acquired and represented in three dimensions using voxels. Unlike with medical computed tomography (MDCT), cone beam units acquire x-ray information using low kV and low mA exposure parameters in a single pass from 180 to 360 degrees of rotation around the anatomy of interest. Medical scanners use higher voltages of 120 kV or more and current of about 400 mA. Several units used in maxillofacial imaging use significantly lower exposure parameters (Figs. 2-5 to 2-7). The x-ray dose for all cone beam units is significantly lower than the dose received from a MDCT unit. Image attributes are also different in that volumes are reconstructed from isotropic voxels; that is, the images are constructed from volumetric detector elements that are cubical in nature and have the same dimensions of length, width, and depth. These voxel sizes can be as small as 0.076 to 0.6 mm.[118] By comparison, MDCT slice data are 0.5 mm to 1 cm thick. Fig. 2-8 illustrates the difference between a pixel and a voxel, the difference between an anisotropic pixel of MDCT and an isotropic pixel (voxel) of CBCT, and how the pixel data are acquired from both modalities.

FIG. 2-5 i-CAT unit. (Courtesy Imaging Sciences International, Hatfield, Pa.)

The patient is positioned on a gantry in an MDCT unit, and images are acquired multiple slices at a time, which

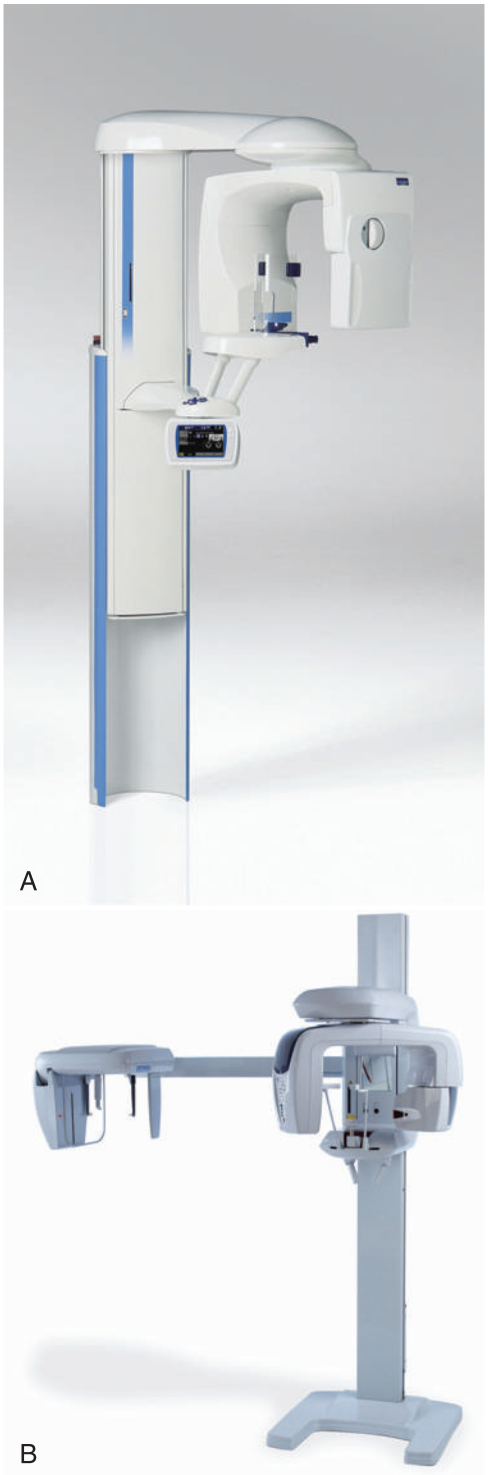

FIG. 2-6 **A,** Planmeca ProMax 3D. **B,** J. Morita Veraviewepocs 3D. (**A** courtesy Planmeca Oy, Helsinki, Finland; **B** courtesy J. Morita Corp, Osaka, Japan.)

prolongs the acquisition time. The number of slices acquired is a direct function of the sensor array configuration. Spiral CT uses continuous translator motion of the gantry as images are acquired, thus shortening the acquisition time. This results in significantly higher absorbed x-ray doses for the patient. A typical CBCT examination would expose the patient to only about 20 to 500 μSv in a single study, whereas a typical medical examination of the head would approach 2100 μSv[2] because the image data are gathered one section at a time. Therefore, soft tissue imaging is better with MDCT because the signal intensity is higher. However, this is not a requirement for dental diagnostic tasks because hard tissue visualization is more important. Consequently, CBCT data have a much higher resolution than MDCT data for hard tissue visualization because of the smaller voxel sizes that medical-grade scanners are incapable of achieving at a significantly lower dose. Increased noise is observed as a result of volumetric acquisition, but the SNR is maintained at a desirable level that facilitates adequate diagnosis based on hard tissue signals.

Field of View

The field of view (FOV) (Figs. 2-9 and 2-10) ranges from as small as a portion of a dental arch to an area as large as the entire head. The selection of the FOV depends on several factors. Among the most important are the following:

- Diagnostic task
- Type of patient
- Spatial resolution requirements

Diagnostic Task

The diagnostic task is the single most important determinant of the FOV in any imaging study. Based on the outcome of the clinical assessment, history, and evaluation of previous and other available imaging studies, a segment of the jaw or a larger area may need to be imaged using an appropriate FOV. If systemic conditions or generalized disorders are suspected, a larger FOV is sometimes required. For most endodontic purposes, a limited FOV can be used, if no signs or symptoms of systemic conditions are reported or noted. Under no circumstances should a screening study be done using a large FOV in the absence of signs and symptoms justifying the procedure. Several multifunctional cone beam units are available that allow the clinician to acquire several image types. Image quality has a direct impact on the diagnostic outcome; therefore, the choice of an FOV should be made carefully. Figure 2-11 illustrates the advantages of using multiple image types for an endodontic case.

Additional benefits of CBCT imaging software include allowing the clinician to format the volume to generate an image that looks like a panoramic radiograph. Conventional panoramic machines, although not commonly used by endodontists, use the focal trough, or zone of sharpness, to position patients so as to minimize distortion along multiple axes. All inherent problems associated with panoramic imaging, including distortion, magnification, blurring, ghost shadows, and other artifacts, can be expected on the resulting image if patient positioning is not accurate. With CBCT, such artifacts are not generated, resulting in a distortion-free panoramic reconstruction (Fig. 2-12). However, it must be noted that CBCTs should not be generated in patients requiring a panoramic radiograph alone, because of dose concerns.

Newer hybrid units, such as the CS 9300 3D Extraoral Imaging System (Carestream Dental, Atlanta, Georgia), have a wide range of FOV choices for a variety of diagnostic tasks, in addition to a conventional panoramic imaging option

FIG. 2-7 **A,** CS 9000 3D and CS 8100 Extraoral imaging systems. **B,** Morita Accu-i-tomo 170. (**A** Courtesy Carestream Dental LLC, Atlanta, GA; **B** Courtesy J Morita, Irvine, CA.)

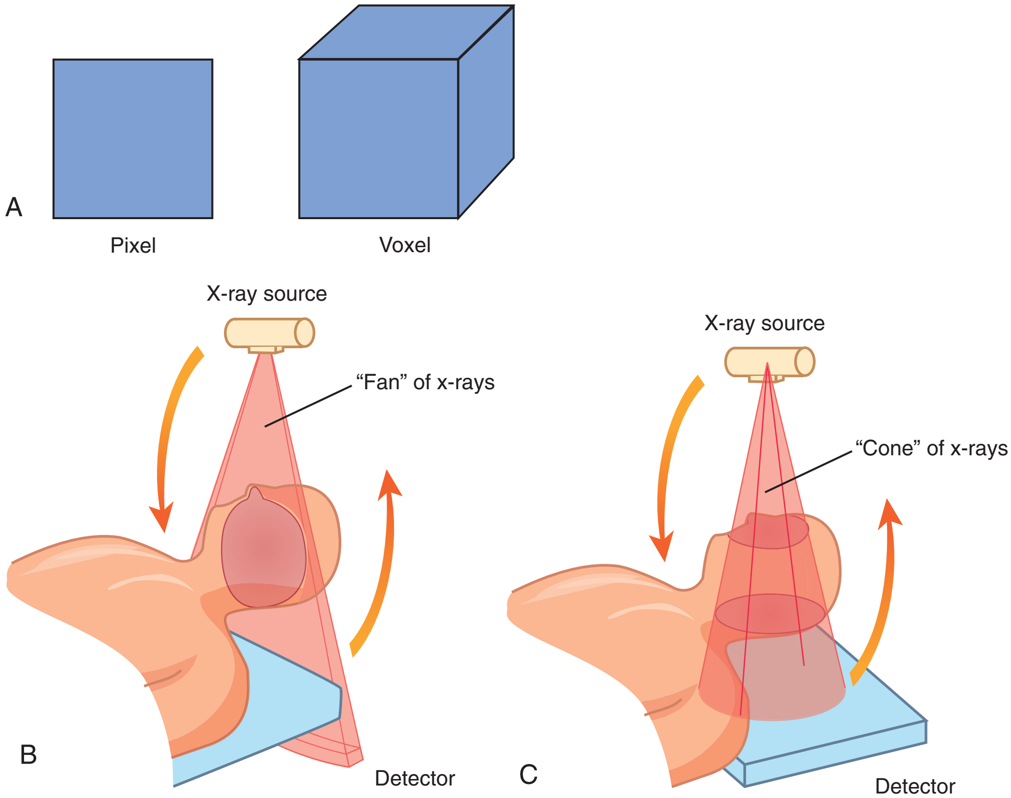

FIG. 2-8 *Left,* Drawing represents a *pixel* (picture element), the image capture and display element of any traditional digital image displayed on the computer. Shades of gray or color are displayed in these pixels to represent a 2D image. *Right,* Drawing represents a *voxel* (volume element). Voxels in CBCT are isometric and have the same dimension or length on all sides. They are very small (from 0.076 to 0.60 microns) and are the capture elements for cone beam imaging devices. Principles of conventional fan beam and cone beam computed tomography are presented in (**B**) and (**C**), respectively. (**B** and **C** from Babbush CA: *Dental implants: the art and science,* ed 2, St Louis, 2011, Elsevier/Saunders.)

(Fig. 2-13). The CS 9000 unit offers the lowest voxel size of 76 microns, whereas the CS 9300 can resolve down to 90 microns, with a range extending to 500 microns for larger FOV studies. Likewise, the Morita 3D Accuitomo 80 (J. Morita USA, Irvine, California) generates isotropic voxels of 80 microns. Although not necessary for use in every case, this technology, when appropriate, improves visualization and ultimately leads to better care in select situations. A record of exposure and doses must be maintained for each patient.

Type of Patient

Patient size and thus the amount of regional anatomy captured in the study also help determine the FOV. The smallest possible FOV must be chosen for the task at hand. Just because a

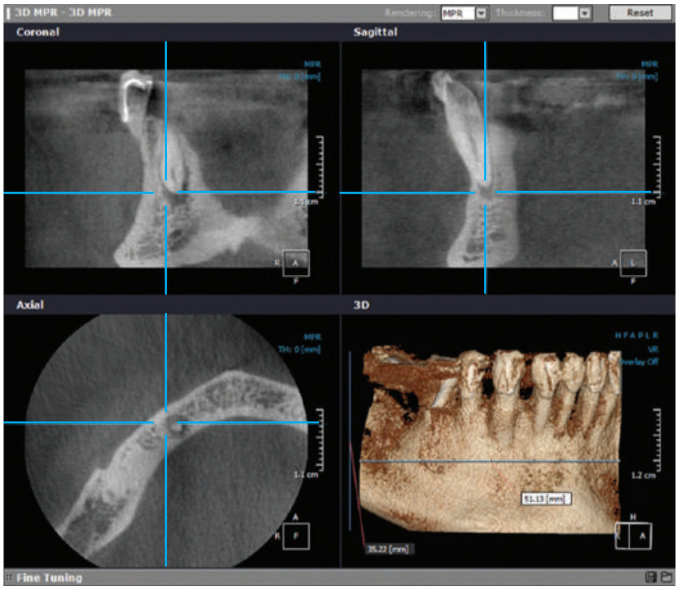

FIG. 2-9 Multiplanar and 3D color reconstructed views of the mandibular quadrant taken on a CBCT machine with a volume size of 37 × 50 mm. (Data acquired and reformatted at 0.076 mm voxel size using a CS 9000 3D unit [Carestream Dental, Atlanta, Ga].)

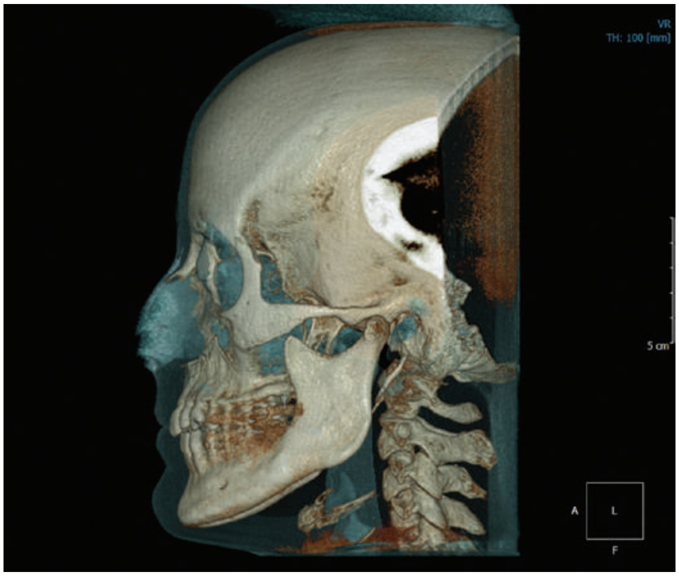

FIG. 2-10 Image of entire head (17 × 23 cm) from a large FoV machine. (Image acquired with i-CAT unit [Imaging Sciences International, Hatfield, Pa].)

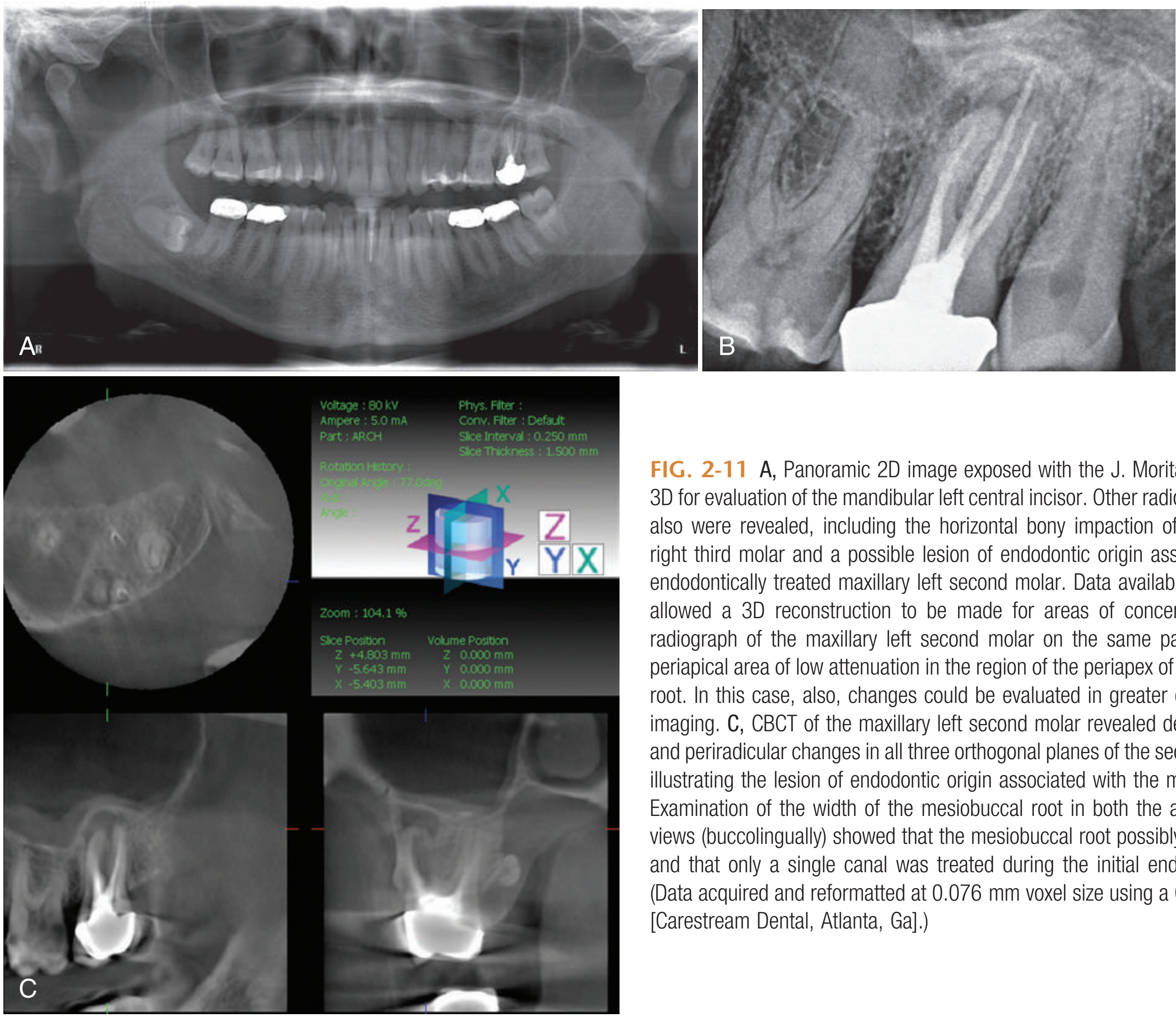

FIG. 2-11 **A,** Panoramic 2D image exposed with the J. Morita Veraviewepocs 3D for evaluation of the mandibular left central incisor. Other radiographic findings also were revealed, including the horizontal bony impaction of the mandibular right third molar and a possible lesion of endodontic origin associated with the endodontically treated maxillary left second molar. Data available from the scan allowed a 3D reconstruction to be made for areas of concern. **B,** Periapical radiograph of the maxillary left second molar on the same patient revealed a periapical area of low attenuation in the region of the periapex of the mesiobuccal root. In this case, also, changes could be evaluated in greater detail with CBCT imaging. **C,** CBCT of the maxillary left second molar revealed detailed periapical and periradicular changes in all three orthogonal planes of the section, specifically illustrating the lesion of endodontic origin associated with the mesiobuccal root. Examination of the width of the mesiobuccal root in both the axial and coronal views (buccolingually) showed that the mesiobuccal root possibly had two canals and that only a single canal was treated during the initial endodontic therapy. (Data acquired and reformatted at 0.076 mm voxel size using a CS 9000 3D unit [Carestream Dental, Atlanta, Ga].)

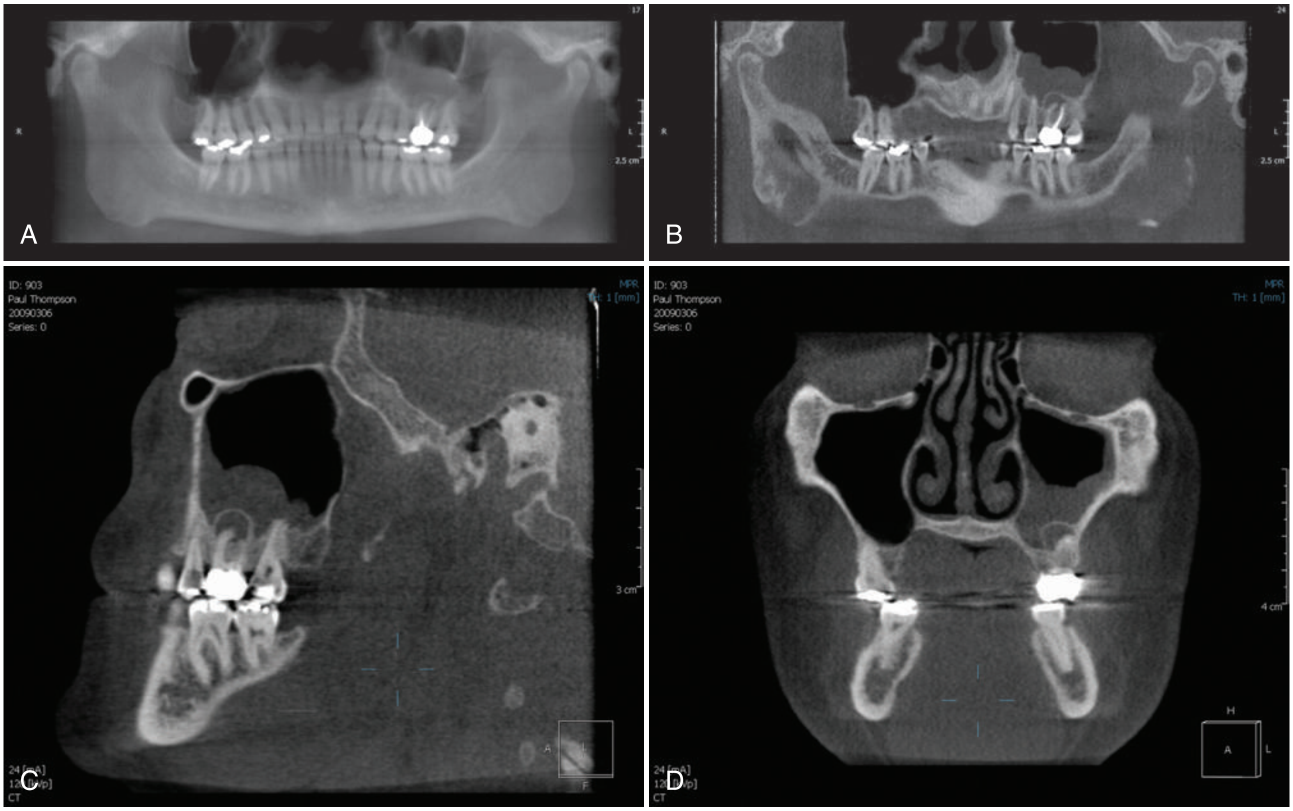

FIG. 2-12 **A,** This reconstructed panoramic image from CBCT data approximates the view one would see with a conventional panoramic radiograph. It is somewhat difficult to see the lesion on the maxillary left first molar. **B,** This thin-slice pseudopanoramic image shows the lesion more precisely because the thin slice (0.10 mm) removes most of the anatomic superimposition. These slices of the maxillary left first molar show the lesion in sagittal **(C)** and coronal **(D)** views, confirming the features seen in the pseudopanoramic view.

FIG. 2-13 CS 9300 3D Extraoral Imaging System. (Courtesy Carestream Dental LLC, Atlanta, GA.)

clinician owns a cone beam machine does *not* mean that every patient should be exposed to a cone beam study.[119] If previous studies are available, they need to be evaluated first in a recall patient. Use of imaging in children must be minimized. Cone beam machines with smaller FOVs can somewhat limit the radiation dose to critical organs and tissues of the head and neck in these cases.

Spatial Resolution Requirements

All endodontic imaging procedures require high spatial resolution. Assessment of canal structure, canal length, and lesions of endodontic origin (LEOs)[160] showing apical change, in addition to an understanding of possible revision cases, are important tasks requiring minute detail. If CBCT is used, the data acquisition should be performed at the smallest voxel size: the smaller the voxel size, the higher the spatial resolution. Many of the larger stand-alone cone beam machines, such as the i-CAT (Imaging Sciences International, Irvine, California), default to a 0.4 mm voxel size. This voxel size is inadequate for high spatial detail. However, these units often have a voxel size selection option that allows smaller voxel sizes to be used during the image acquisition. The absolute maximum voxel size for endodontic imaging should be 0.2 mm.[35] Units typically use voxel sizes of 0.076 to 0.16 mm for their native image capture (Fig. 2-14).

FIG. 2-14 **A,** Axial slice from data obtained with a 0.4 mm voxel size. Compare the trabecular pattern and outline of the mental foramina to the same location in an axial slice from data obtained with a 0.16 mm voxel size **(B)**.

IMAGING TASKS IMPROVED OR SIMPLIFIED BY CONE BEAM VOLUMETRIC COMPUTED TOMOGRAPHY

The Executive Opinion of the American Academy of Oral and Maxillofacial Radiology and, later, the position paper on the use of CBCT in endodontics jointly developed by the American Association of Endodontists (AAE) and the American Academy of Oral and Maxillofacial Radiology (AAOMR), list indications for potential use in selected cases, including evaluation of the anatomy and complex morphology, differential diagnosis of complex pathoses with certain qualifiers, intraoperative or postoperative assessment of endodontic treatment, dentoalveolar trauma, resorption, presurgical case planning, and dental implant case planning.[34] Use of CBCT must be determined on a case-by-case basis only. These indications do not in any way mandate the use of CBCT for every case that falls into one of the preceding categories. For endodontic treatment and assessments, there are at least five primary imaging tasks in which CBCT scans have a distinct advantage over traditional 2D radiographs. These tasks include evaluation of the following factors:

1. Differential diagnosis
   a. Lesions of endodontic origin
   b. Lesions of nonendodontic origin
   c. Diagnosis of endodontic treatment failures
   d. Vertical root fractures
2. Evaluation of anatomy and complex morphology
   a. Anomalies
   b. Root canal system morphology
3. Intraoperative or postoperative assessment of endodontic treatment complications
   a. Overextended root canal obturation material
   b. Separated endodontic instruments
   c. Calcified canal identification
   d. Localization of perforation
4. Dentoalveolar trauma
5. Internal and external root resorption
6. Presurgical case planning
7. Dental implant case planning
8. Assessment of endodontic treatment outcomes

Differential Diagnosis

Lesions of Endodontic Origin

Clinical endodontic diagnosis relies on subjective and objective information collected during patient examinations. Diagnosis of the pulpal status of the teeth can sometimes be challenging if adequate radiographic information is unavailable. It is fundamental to understand that lesions of endodontic origin arise secondary to pulpal breakdown products and form adjacent to canal portals of exit.[155,161] These radiolucent lesions, formed as a result of loss of bone mineralization, can and do form three dimensionally anywhere along the root surface anatomy.[154] A 30% to 40% mineral content loss is needed for these lesions to be visualized on conventional radiographs.[116] Furthermore, the thickness of the cortical plate covering the lesion may significantly affect the radiographic appearance of the lesion on a conventional image.[192] In a comparative investigation of the use of CBCT and periapical (PA) radiography in the evaluation of the periodontal ligament (PDL), Pope et al.[148a] showed that necrotic teeth examined with CBCT had widened PDLs, but healthy, vital teeth showed significant variation. They called for further investigation to determine whether health and disease can be appropriately judged by the use of CBCT in epidemiologic investigations.

Digital subtraction radiography (DSR) has been observed to increase diagnostic capability; observers identified incipient periapical lesions in more than 70% of the cases.[116] Before the advent of CBCT, clinicians were unable to routinely visualize the presence, specific location, and extensiveness of periapical bone loss using conventional radiography.[107] This was especially true in areas with superimposition of anatomic structures. Visual obstruction from anatomic features, such as buccal bone and the malar process over the apices of maxillary roots, simply “disappears” when the examiner can scroll through the slices of the bone from facial to palatal in 0.1 mm sections while also changing axial orientations. CBCT showed significantly higher rates of detection of

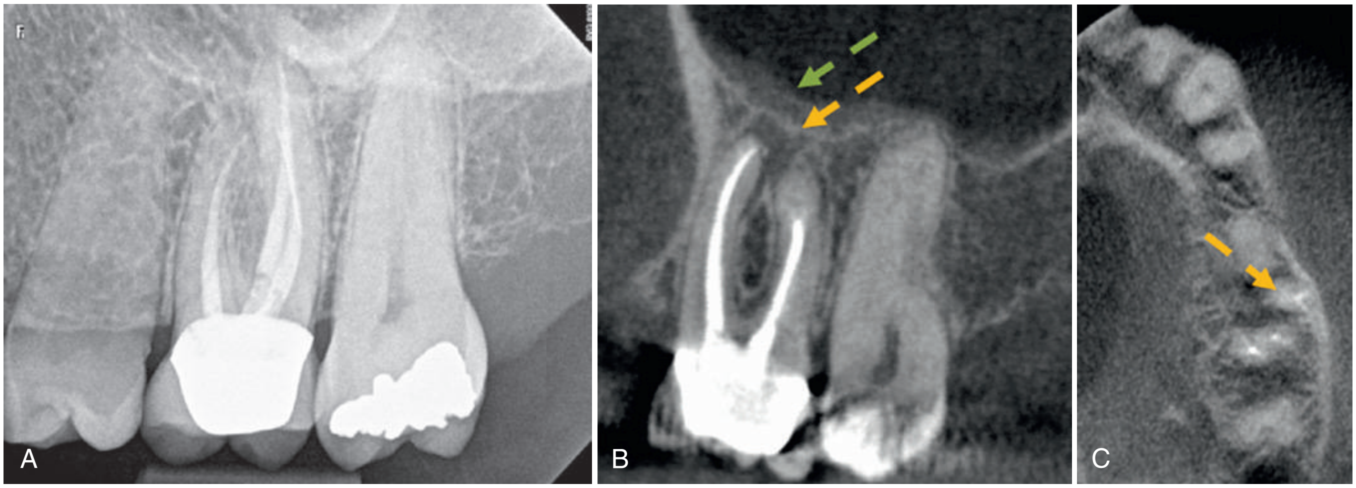

FIG. 2-15 A 62-year-old female was referred for evaluation and possible treatment for chronic continuous dentoalveoar pain (CCDAP) in the maxillary left region. The patient could alleviate this condition by placing a moist cotton roll in the adjacent vestibule to prevent the buccal mucosa from contacting the alveolus supporting the maxillary teeth in this area. This condition began after a history of local anesthetic administration, persisted for 1 year, and led to three successive new crowns and endodontic treatment on the "offending tooth," in an effort to remedy the condition without improvement. The response to endodontic tests, TMJ, and myofascial evaluations were normal. Application of topical xylocaine resulted in cessation of pain for 15 minutes. A PA radiograph (**A**) showed a root-treated, maxillary left first molar with no apparent radiographic lesion. A limited FOV CBCT of the maxillary left posterior was exposed. The corrected sagittal view (**B**) showed an approximately 4 mm, well-defined oval, mildly corticated area of low attenuation (radiolucent) centered over the apex of the mesiobuccal root and extending to the junction of the middle and apical third of the mesiobuccal root (yellow arrow). There was a mild mucositis (green arrow). There was a previously untreated mesioaccessory canal (**C**) and a mild mucositis. A diagnosis of neuropathic pain and a chronic apical periodontitis was made. Daily application of topical ketamine, gabapentin, and clonidine was prescribed. Endodontic revision of the maxillary left first molar was performed 3 months after the patient was stabilized with the topical medications. (Data acquired and reformatted at 0.076 mm voxel size using a CS 9000 3D [Carestream Dental, LLC, Atlanta, GA].)

periapical lesions in maxillary molars and premolars compared to PA radiography.[109]

Lesions of Nonendodontic Origin

Differential diagnosis of periapical pathology is crucial to endodontic treatment planning. Substantial evidence in the literature points to a significant chance that lesions of the tooth-supporting structures are nonendodontic in origin, such as periapical cemento-osseous dysplasia; central giant cell granulomas; simple bone cysts; odontogenic cysts, tumors, or malignancies; and neuropathic pain (Fig. 2-15).*

Neuropathic orofacial pain or atypical odontalgia (AO), also known as *chronic continuous dentoalveolar pain* (CCDAP)[131a] and *persistent idiopathic facial pain* (PDAP),[80a] is related to a tooth, teeth, or pain at an extraction site where no clinical or radiographic pathosis is evident. Two systematic reviews of AO showed the incidence of persistent pain of more than 6 months' duration after nonsurgical and surgical endodontic treatment, excluding local inflammatory causes, was 3.4%.[130a] The pathophysiology of this pain is uncertain, but it is hypothesized to involve deafferentation of peripheral sensory neurons in predisposed patients. The diagnosis of AO is challenging and depends on the patient history and clinical examination findings, in addition to the absence of radiographic findings. In some cases the symptoms from AP and AO are closely related.

*References 28, 54, 56, 81, 130, 143, 151, and 152.

Pigg et al.[146a] conducted a study of 20 patients with AO. All of the patients had at least one tooth in the region of discomfort that had undergone invasive treatment; 21 of 30 teeth had undergone endodontic treatment. These researchers found that 60% had no periapical lesions, and among those who did, CBCT showed 17% more periapical lesions than conventional radiography. This study demonstrated that CBCT may be a useful supplement to 2D radiography (see Fig. 2-15).

The 3D radiographic appearance of a periapical lesion provides additional information about the lesion's relationship to the tooth and other anatomic structures (e.g., the vascular bundle) and about the aggressiveness of the lesion. This information, along with pulp sensitivity testing, is useful for adequate treatment planning and management of these conditions.

Diagnosis of Endodontic Treatment Failures

Failure of previous endodontic therapy can be attributed to various factors, such as procedural errors, missed canals, or persistent periapical pathosis. Knowledge of the cause of failure is pertinent to the treatment of these cases because it allows the cause to be adequately rectified. With the advent of CBCT, in select cases of retreatment in which the cause of failure is otherwise undetectable, adequate information may be collected to apply to the treatment plan (Fig. 2-16). The technology is most useful in detecting uninstrumented and unfilled

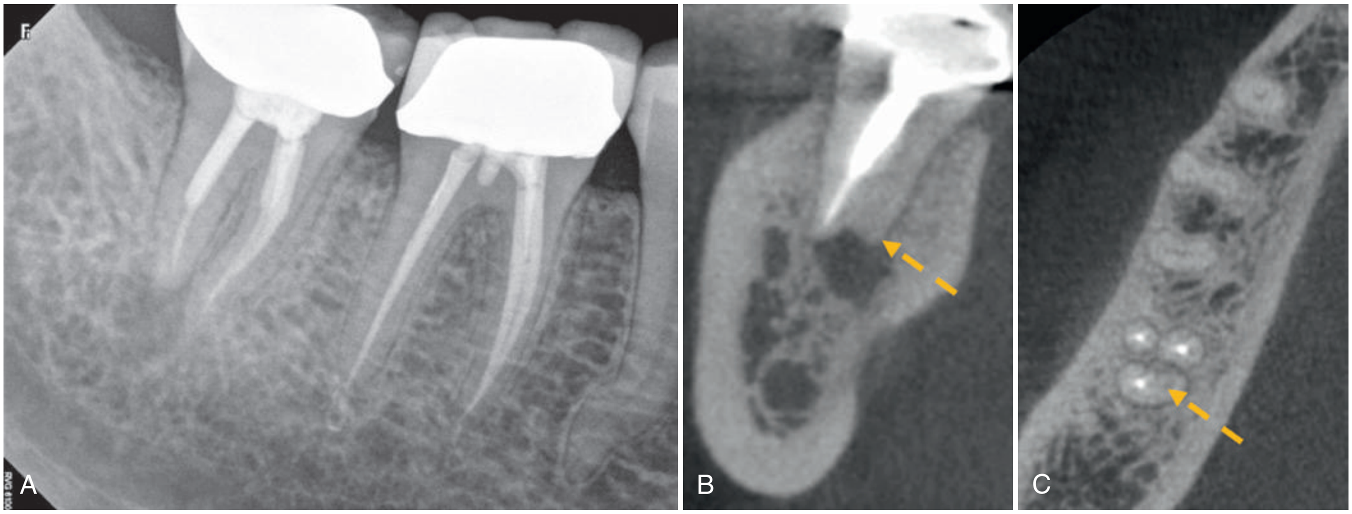

FIG. 2-16 This 38-year-old female patient presented for evaluation and treatment of a symptomatic mandibular right second molar, which had been endodontically treated more than 10 years previously. This tooth was sensitive to percussion and biting forces; periodontal findings were normal. Microscopic examination of the exposed dentin was negative for a vertical fracture. The PA radiograph (A) showed the previous endodontic treatment; a post present in the distal canal; and an approximately 5 mm diameter, unilocular, diffuse area of low density centered at the periapex of the distal root. Contemporaneous CBCT sagittal (B) and axial (C) images revealed a previously untreated distobuccal canal. (Data acquired and reformatted at 0.076 mm voxel size using a CS 9000 3D unit [Carestream Dental, Atlanta, Ga].)

canals, extension of the root canal filling, and the presence and extent of periradicular bone loss. The sensitivity of CBCT and PA radiographs for diagnosing strip perforations in root-filled teeth has been shown to be low.[51] Radiopaque filling materials in the root canals of endodontically treated teeth can produce streak artifacts, which can mimic fracture lines or perforations.[166,198]

Vertical Root Fractures

Vertical root fractures (VRFs) that run along the long axis of a tooth are often difficult to diagnose clinically. The prevalence of VRF in endodontically treated teeth has been reported to range from 8.8% to 13.4%.[61,174,196] These fractures typically run in the buccolingual direction and are confined to the roots, making it difficult to visualize the fracture. Visualizing the fracture on a conventional radiograph is possible when the x-ray beam is parallel to the plane of the fracture.[153] Challenges in diagnosis with regard to the extent and exact location of the fracture often lead to unwarranted extraction of teeth. Since the introduction of CBCT to dentistry, various reports of the application of the technology to detect vertical root fractures have been published. The reported sensitivity for detection of VRFs has ranged from 18.8% to 100%[115]; by comparison, conventional radiographs have a reported sensitivity of approximately 37%[48,75] (Fig. 2-17). CBCT has been used to visualize VRFs in controlled clinical studies in which clinical diagnosis was difficult.[48] Vertical root fractures were successfully detected at a spatial resolution ranging from 76 to 140 microns. However, only a limited number of units provide such high resolution. A comparison of various CBCT units for the detection of VRFs demonstrated that the units with flat panel detectors (FPDs) were superior to the image intensifier tube/charge-coupled device (IIT/CCD)–based detectors; the smaller FOV and the ability to view axial slices also improved detection of VRFs.[76] Continued improvement of sensor technology, including the use of FPDs, has resulted in enhanced resolution. Voxel dimensions are smaller in these units. Detection of vertical root fractures with thickness ranging from 0.2 to 0.4 mm was found to be more accurate with CBCT than with digital radiography.[133,138] The presence of root canal filling in the teeth lowers the specificity of CBCT in detecting vertical root fractures[75,76,95]; this has been attributed to the radiopaque material causing streak artifacts that mimic fracture lines.[198]

Evaluation of Anatomy and Complex Morphology

The precise location and visualization of dental anomalies, root morphology, and canal anatomy are vastly improved with CBCT data. Root curvature, additional roots, and anomalies within the canals themselves (e.g., obstructions, narrowing, bifurcation) are made more apparent when all three anatomic planes of section are available for review, especially with the capability of narrowing the slice thickness to as little as 0.076 mm. Visual obstruction from anatomic features such as buccal bone and the malar process over the apices of maxillary roots simply will “disappear” when you can scroll through the slices of the bone from facial to palatal in 0.076 mm sections while also changing axial orientations (Fig. 2-18).

Dental Anomalies

The use of CBCT technology has been reported in the diagnosis and treatment planning of various dental anomalies (e.g., dens invaginatus) that often have complex morphologic presentations.[131] The prevalence of dens invaginatus was as high as 6.8% in the adolescent Swedish population studied.[14] The complex nature of the anomaly presents a diagnostic challenge

FIG. 2-17 Root fracture in an endodontically obturated maxillary right central incisor. **A,** Axial view with artifacts from a highly attenuating (opaque) obturant. **B,** View without artifacts from obturant. **C,** Oblique parasagittal view. **D,** Paracoronal view. (Data acquired and reformatted at 0.076 mm voxel size using a CS 9000 3D unit [Carestream Dental, Atlanta, Ga].)

when conventional radiographs are used.[137] In case reports in which CBCT was used for diagnosis and treatment planning, treatment options included conservative endodontic treatment of the invagination, surgical treatment of the periapical pathology, and complete revascularization of the dens after removal of the invagination (Fig. 2-19).[124,185]

Root Canal System Morphology

As the adage goes, nature seldom makes a straight line and never makes two of the same. This statement is dramatically illustrated in the evaluation of root canal system morphology. With ever-present unusual and atypical root shapes and numbers, there is sometimes a need to look further than what a clinician can see or imagine with 2D radiography (Fig. 2-20). Variations in root canal morphology have been studied using various in vitro techniques.[57,147,182,183] The results of these studies point to the fact that there is significant variation in the root canal morphology among various ethnic population groups.[3,72,73,128,187] CBCT has been reported to be comparable to canal staining and clearing techniques for identification of the root canal morphology,[125] and CBCT studies report variation in the root canal morphology among various ethnic groups.[126,173,197,199]

INTRAOPERATIVE OR POSTOPERATIVE ASSESSMENT OF ENDODONTIC TREATMENT COMPLICATIONS

Materials Extending Beyond the Root Canal

CBCT scans provide the opportunity to map endodontic treatment complications through the examination of 3D representations of the teeth and supporting structures in different planes. Few high-level studies related to the effects of endodontic treatment complications have been published in the endodontic literature.[176] However, it is generally recognized that overfilling of the root canal, causing damage to vital structures such as the inferior alveolar neurovascular bundle (IAN) (Fig. 2-21) or the maxillary sinus, can cause significant morbidity.[24,25,60,64]

Endodontic therapy undertaken in close proximity to the IAN should receive special attention because direct trauma, mechanical compression, chemical neurotoxicity, and an increase in temperature greater than 10° C may cause irreversible damage.[51,68,71,179] Scolozzi et al.[162] reported that sensory disturbances can include pain, anesthesia, paresthesia,

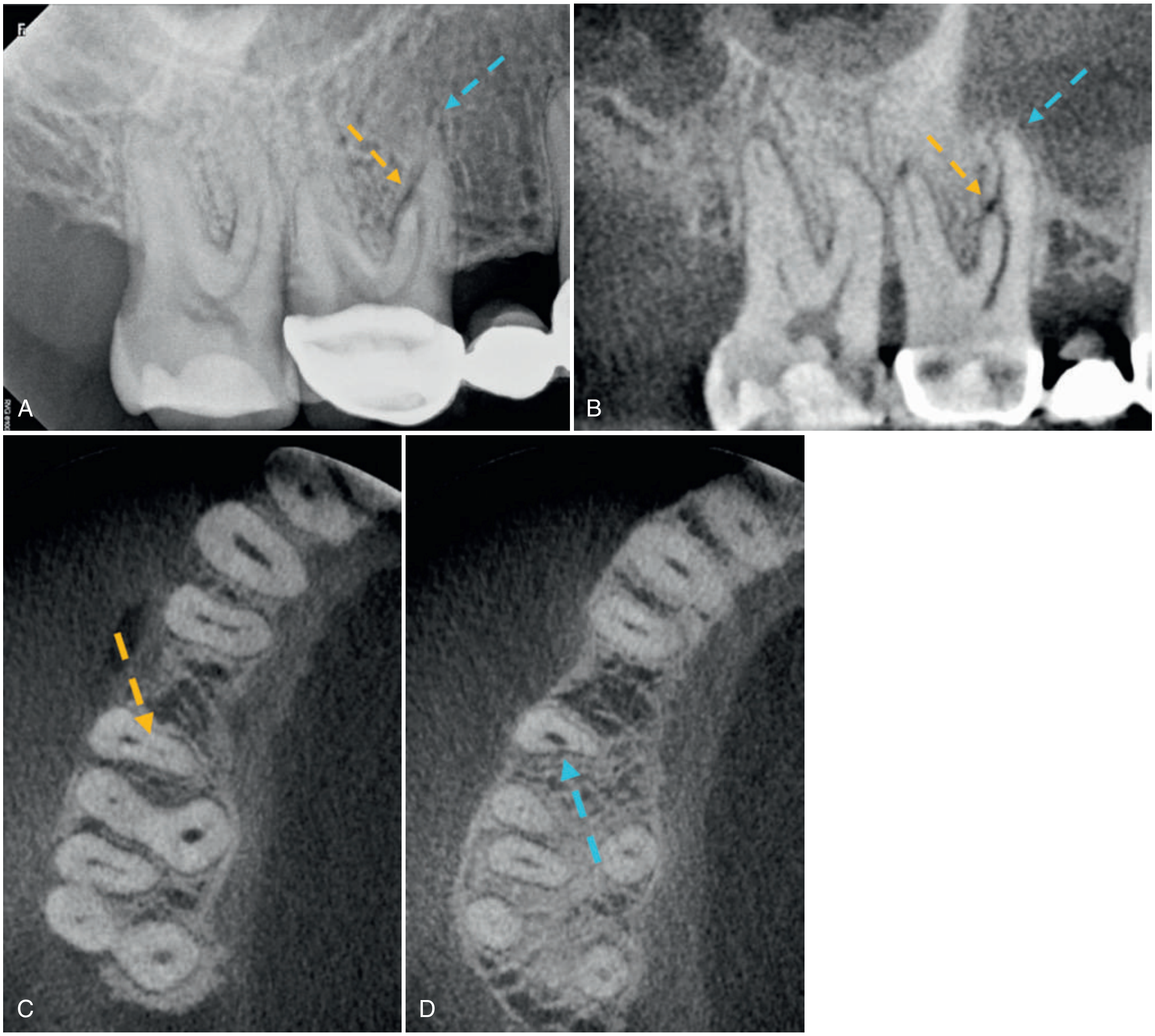

FIG. 2-18 This patient was referred for evaluation and possible treatment after emergency pulp extirpation performed by others. The location of the physiologic terminus and radiographic apex did not appear to coincide even remotely in the PA radiograph (A), so a CBCT-aided assessment was required. A CBCT scan was able to clearly show the exact location of the canal terminus and radiographic apex (B), the presence of a mesioaccessory canal with an isthmus (C), and the oval canal (D), facilitating treatment of this case. (Courtesy Dr. Anastasia Mischenko, Chevy Chase, Md. Data acquired and reformatted at 0.076 mm voxel size using a CS 9000 3D unit [Carestream Dental, Atlanta, Ga].)

hypoesthesia, and dysesthesia.[162] The IAN is located in the cribriform bone-lined mandibular canal and courses obliquely through the ramus of the mandible and horizontally through the mandible body to the mental foramen and the incisive foramen.[8] There are many anatomic variations of the IAN, including the anterior loop and bifid mandibular canals.[35] Kovisto et al.[97] used CBCT measurements from 139 patients to show that the apices of the mandibular second molar were closest to the IAN. In females, the mesial root of the second molar was closer than in males, and the distances in all roots measured increased with the age of the patient. There was a high correlation between the measurements from left to right side in the same patient; an average distance of 1.51 to 3.43 mm in adults.[97] Procedures involving the mandibular second molar were most likely to cause nerve damage.[106] Further research is required to clarify the risks and benefits of CBCT when endodontic treatment is contemplated on teeth with a proximal relationship between the IAN and root apices. Porgrel[148] treated 61 patients with involvement of the IAN after root canal therapy during a 7-year period. Eight patients were asymptomatic; 42 patients were seen for mild symptoms or were examined more than 3 months postoperatively, with only 10% experiencing improvement. Five patients underwent surgical treatment before 48 hours elapsed and recovered completely.

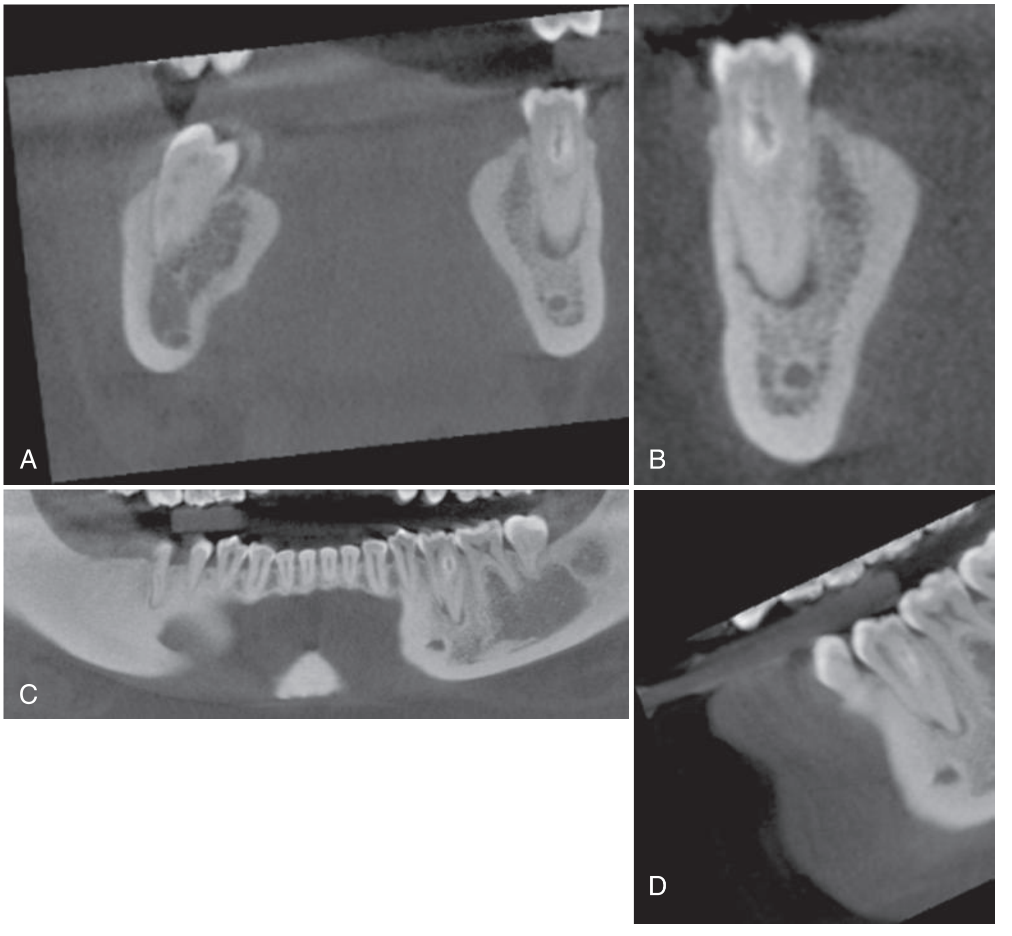

FIG. 2-19 **A,** Dens in dente of the mandibular left second bicuspid; coronal slice. **B,** Coronal view. **C,** Panoramic reconstruction from CBCT. **D,** Sagittal view. (Data acquired and reformatted at 0.076 mm voxel size using a CS 9000 3D unit [Carestream Dental, Atlanta, Ga].)

Six patients underwent surgery between 10 days and 3 months, with four experiencing partial recovery; the remaining two had no improvement.[148]

New imaging technologies, such as high-resolution magnetic resonance imaging (MRI-HR) and magnetic resonance neurography (MRN), promise to improve isolation of the IAN from the neighboring artery and vein contained within the inferior alveolar bony canal. MRN studies have documented the ability to demonstrate nerve continuity and localize extraneural nerve compression before surgical nerve exploration. Postoperative periapical radiographs should be exposed on the day of endodontic treatment completion or a suspected iatrogenic event, and any suspected compromise of the IAN or other vital structures should be evaluated immediately. In all cases in which trauma to the IAN is suspected from periapical or panoramic radiography or by the report of symptoms consistent with nerve injury, exposure of a CBCT image volume should be considered. It is generally accepted that immediate surgical debridement should be attempted to maximize recovery.[51,149] With the introduction of MRI algorithms for dental diagnostic purposes, it is expected that this imaging modality will be increasingly used in diagnostic and treatment planning. MRI has the capability to demonstrate vascularity to the tooth of interest, in addition to the presence of inflammatory exudates in the apical regions, without exposing the patient to ionizing radiation. Receiver coils are being developed to enhance the image quality of maxillofacial and dental magnetic resonance studies.

The accidental introduction of root canal instruments, irrigating solutions, obturation material, and root tips into the maxillary sinus has been reported. Serious consequences associated with the intrusion of foreign bodies into the maxillary sinus include pain, paresthesia, and aspergillosis, a rare but well-documented complication of endodontic treatment.[16a] Guivarc'h et al.[71a] reported that the overextension of heavy metal–containing root canal sealers, such as zinc oxide eugenol cement, may promote fungal infection in immunocompromised patients, leading to bone destruction and damage to adjacent structures. This case report described the use of computed tomography to assess the patient before surgery and at 6 months.[71a] The use of CBCT as an aid in the localization and retrieval of an extreme overextension of thermoplasticized injectable gutta-percha into the sinus and contiguous soft tissues has been described by Brooks and Kleinman.[26]

Fractured Instruments

Instrument fracture can occur at any stage of endodontic treatment, and in any canal location. The incidence of this complication, reported in clinical studies on a per canal or per tooth basis, ranges from 0.39% to 5.0%.[44,135] Molars are

FIG. 2-20 A, Mandibular left second molar referred for endodontic evaluation and possible treatment. This 2D radiograph reveals significant pulp stones and canal calcification developing not only in the coronal aspect of the root canal system, but also extending down the visible distal canal. The apical third of the canal system appears unusual and dilacerated. Cone beam volumetric tomography (CBVT) would be beneficial in visualizing the root canal anatomy, so as to create the ideal endodontic access. B, Single slice of the CBVT image for tooth #18. Information about the direction of the root canal anatomy is provided in all three planes of the section: axial, coronal, and sagittal. Interestingly, the axial slice shows that the mesial lingual root actually traverses buccally as it approaches its terminal extent. This is valuable information for the clinician before the entire root canal system is cleaned and shaped; it also establishes a higher degree of treatment predictability.

predominantly affected by instrument fracture, with the highest incidence found in the apical third of mandibular molars.[4,40,103,127]

A systematic review and meta-analysis showed that when endodontic treatment was performed at a high technical standard, instrument fracture did not significantly reduce the prognosis. More specifically, when no initial radiographic periapical lesion was present initially, 92.4% of cases remained healthy; when a periapical lesion was present initially, 80.7% of periapical lesions showed radiographic healing. However, the presence or absence of periradicular lesions on preoperative and postoperative examinations was based on planar radiographic assessments, which calls these findings into question.[134] Other studies showed that the chances of endodontic failure increased if the canal system could not be thoroughly disinfected, if a periradicular periodontitis was present, or if technical standards were compromised.[39,91,168,170] Use of CBCT to triangulate the retained instrument and assess the canal shape, especially in cases in which the operating microscope does not allow direct visualization, can be helpful in formulating a removal strategy. If the fractured instrument is lodged in the lingual aspect of a ribbon-shaped canal, for example, an instrument may be inserted toward the buccal to bypass and remove the imbedded instrument without forcing the fragment further apically. Without the use of CBCT, intracanal instruments can be reliably removed or bypassed in 85.3% of cases if straight-line access is possible; however, reliable removal or bypass is possible in only 47.7% of cases if the instrument is not visible (Fig. 2-22).[127] When a separated instrument is lodged in the apical third of a root canal, the chances of retrieval are the lowest, but the apical terminus may be adequately sealed by treatment of an anastomosing canal, if present.[63] The possibility of instrument removal based on CBCT triangulation has not been published to date.

Calcified Canals

According to the Pew Research Center, 10,000 U.S. individuals will reach the age of 65 every day until 2030, and the nation's 65-year-old and over cohort will grow to 81 million in 2050, up from 37 million in 2005 (also see Chapter 26).[82] This aging population will present increasing challenges for dental clinicians because calcification of the root canal system increases as part of the natural aging process,[69] possibly leading to more untreated canals that may serve as a niche for microorganisms.[19,88] Pulp chambers in the crown of the tooth decrease in size, forming more rapidly on the roof and floor of posterior teeth.[184] Typically, root canals calcify at the coronal aspect first, with decreasing calcification as the canal travels apically. Magnification and illumination are essential tools for the identification and treatment of calcified canals, but CBCT can assist in the perioperative treatment of such conditions.[16] Preoperative assessment of calcified teeth using CBCT can suggest the best tactic for locating calcified canals in the chamber floor and

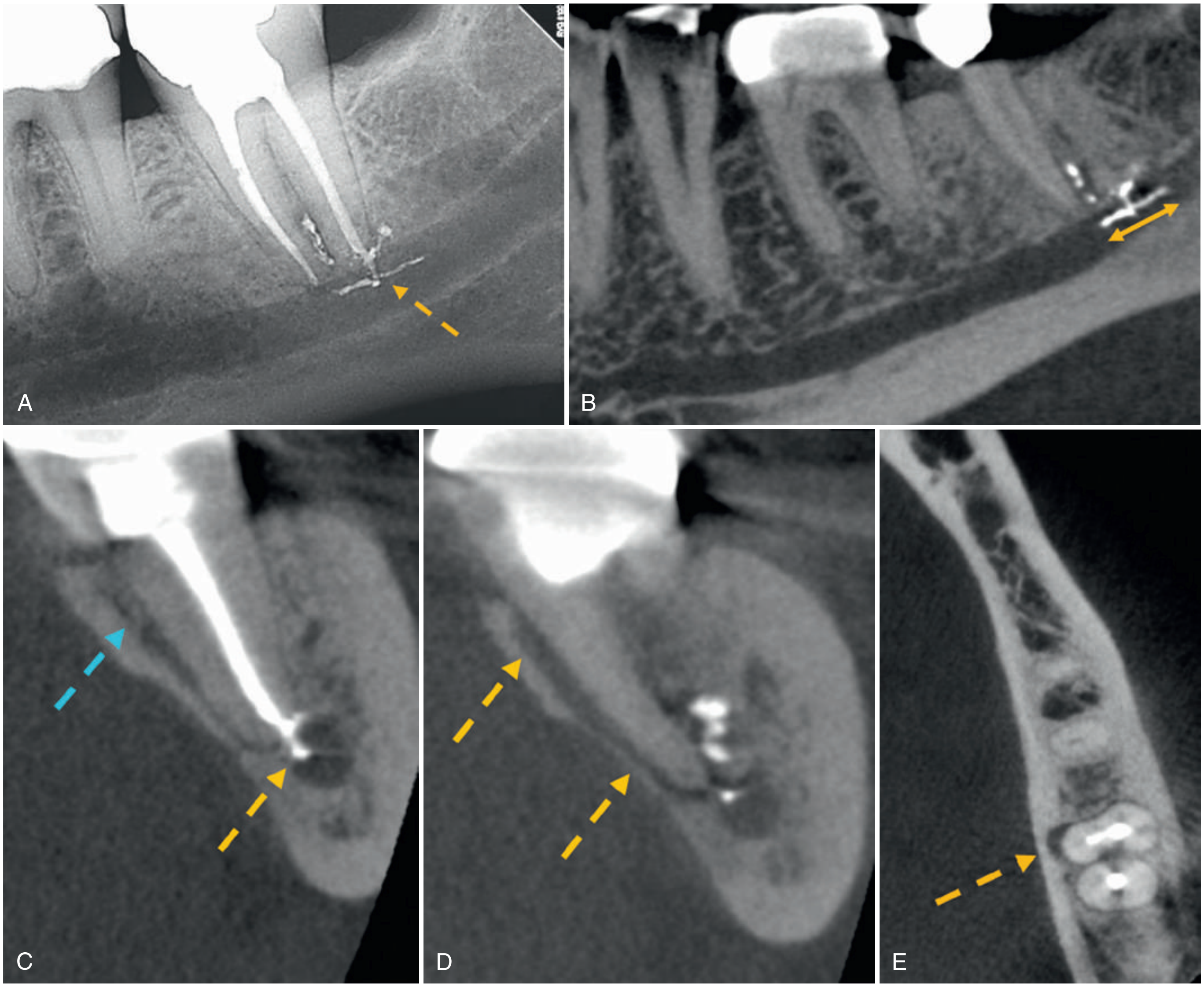

FIG. 2-21 This 64-year-old male patient presented with sensitivity when biting on the mandibular left second molar. The history included endodontic revision more than 6 months earlier and subsequent transient paresthesia and dysesthesia along the distribution of the inferior alveolar nerve, which persisted for 1 week after the retreatment. The results of periodontal probing and microscopic examination of the exposed root surface at the sulcus were normal. The PA radiograph showed the approximate location of the excess radiopaque material, a feature consistent with extruded sealer (A, *yellow arrow*). The length of approximately 3.4 mm and the true location of the offending material in the mandibular canal were assessed in the corrected sagittal view (B, *yellow arrow*) and corrected cross-sectional view (C, *yellow arrow*). The corrected cross-sectional view also showed a lesion of low attenuation extending from the apex to an area near the crest of the alveolus with erosion of the lingual cortical plate (C, *blue arrow;* D, *yellow arrows*). The same lesion was shown in the corrected axial view (E, *yellow arrow*). Examination of the extracted tooth revealed a vertical fracture at the lingual aspect of the distal root. (Data acquired and reformatted at 0.076 mm voxel size using a CS 9000 3D unit [Carestream Dental, Atlanta, Ga].)

roots using software-based measurement tools. The insertion of radiopaque markers, such as instruments or obturation material, can facilitate reliable canal localization using available multiplanar reformations. The increased sensitivity and specificity provided by CBCT can also assist in the determination of the periapical status of calcified root canals that may not require measures that can lead to procedural errors, such as off-course access, instrument fracture, or root perforation.[83] The difficulty in locating calcified canals can be further compounded by morphologic anomalies associated with gender and ethnic origin.[163] CBCT can be an important adjunct to magnification and illumination in these cases.

Perforations

A *perforation* is defined as a "mechanical or pathologic communication between the root canal system and external tooth surface"[6]; it is usually associated with an iatrogenic event,[159] accounting for about 10% of all nonhealed cases.[85] Root perforations can be caused by a post preparation, the search for a calcified canal, a strip perforation, or an attempt to retrieve a

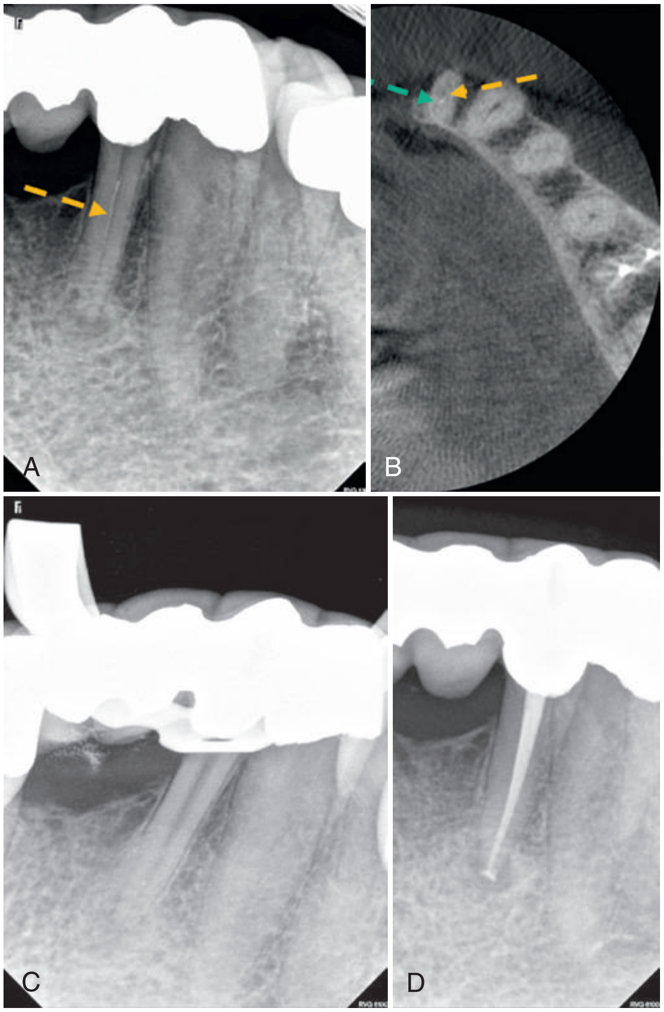

FIG. 2-22 Unexpected torsional and flexural failure of endodontic instruments can occur during instrumentation. This PA radiograph (A) shows a separated stainless steel hand file located at the midroot of the mandibular left lateral incisor in a patient referred for revision therapy. To aid development of a retreatment strategy, CBCT was used to localize the instrument (B, *yellow arrow*) in the lingual canal. The patient's buccal canal was identified (B, *green arrow*), and subsequent instrumentation allowed removal of the offending instrument segment (C), leading to successful completion of treatment (D). (Data acquired and reformatted at 0.076 mm voxel size using a CS 9000 3D unit [Carestream Dental, Atlanta, Ga].)

fractured instrument. They are often difficult to localize with conventional imaging because no information about the buccolingual dimension can be obtained.[195] Shemesh et al.[166] compared the sensitivity and specificity of CBCT scans with two-angulation periapical imaging using phosphor plates to assess the likelihood of detecting root or strip perforations after root canal treatment with laterally compacted gutta-percha and sealer. They found that the two methods showed similar specificity, but the CBCT image volumes showed higher sensitivity. Single-angulated periapical radiographs (PAs) showed 40% of the perforations, and two-angled PAs showed 63%, suggesting that if PAs alone are used, two-angled images were superior. There was no significant difference in the detection of root perforations between PA and CBCT radiography. The researchers noted that the results may have been affected by the small size of the perforations and that the method of obturation did not favor extravasation of obturation material.[166] CBCT images suffer from beam hardening artifact resulting from root canal obturation and restorative materials (e.g., gutta-percha, posts, and perforation repair materials), which creates challenges to the interpretation of root integrity. An approach advocated by Bueno et al.[29] suggested that a map-reading strategy of viewing sequential axial slices reduces the beam hardening effect. Newer root canal obturation materials with lower radiopacity profiles and improved CBCT software algorithms are expected to reduce artifact formation in the future.

Dentoalveolar Trauma

Systematic epidemiologic data suggest that facial trauma is a common occurrence, resulting in injuries to the dentition in 57.8% of household and play accidents, 50.5% of sports accidents, 38.6% of work-related accidents, 35.8% of acts of violence, and 34.2% of traffic accidents, with 31% unspecified.[62] The prevalence of traumatic dental injuries varies according to the population studied, but these injuries occur most commonly in children 7 to 10 years of age (also see Chapter 20).[13] Dental traumatic injuries affect one fourth of all schoolchildren and almost one third of adults, and most injuries occur before the age of 19.[65] Maxillary central incisors sustain approximately 80% of all dental traumatic injuries, followed by maxillary lateral incisors and mandibular incisors.[9] The most common type of traumatic dental injuries in the primary dentition are luxation injuries, whereas crown fractures are the predominant dental injury to the permanent dentition.[98] Determination of the extent of injury to the dentinopulpal complex requires a methodical approach that evaluates the teeth, periodontium, and associated structures (Fig. 2-23) and may result in significant long-term complications.[5,42]

Injuries to the orofacial complex can cause dental trauma that results in the following injuries to the primary and permanent dentition: (1) infraction; (2) crown fracture, uncomplicated and complicated; (3) crown/root fracture; (4) root fracture; (5) concussion; (6) subluxation; (7) lateral luxation; (8) intrusion; (9) extrusion; and (10) avulsion.[12] The International Association of Dental Traumatology's guidelines for the management of traumatic dental injures suggest that CBCT may be beneficial when used to assess and monitor healing in patients after dental traumatic injuries, especially in cases of lateral luxation and root fracture.[45] (These guidelines can be reviewed at *www.dentaltraumaguide.org*.) Intra-alveolar root fractures generally affect the permanent dentition of males and are relatively uncommon, accounting for 0.5% to 7% of dental impact injuries.[12,41,67,132] Root-fractured teeth are a challenging condition to diagnose, and the limitations of planar radiography have been well documented in the dental literature.[38,45,96,136] A systematic retrospective study showed that maxillary central (68%) and lateral (27%) incisors were primarily affected, with only limited occurrence in mandibular incisors (5%). This retrospective study concluded that CBCT allowed improved treatment planning compared with PA imaging alone.[191] At least seven systematic laboratory studies and one systematic in vivo animal study reported significantly improved accuracy for the detection of root fractures when CBCT was compared with periapical radiography.* In a systematic clinical study,

*References 75, 76, 84, 114, 133, and 189.

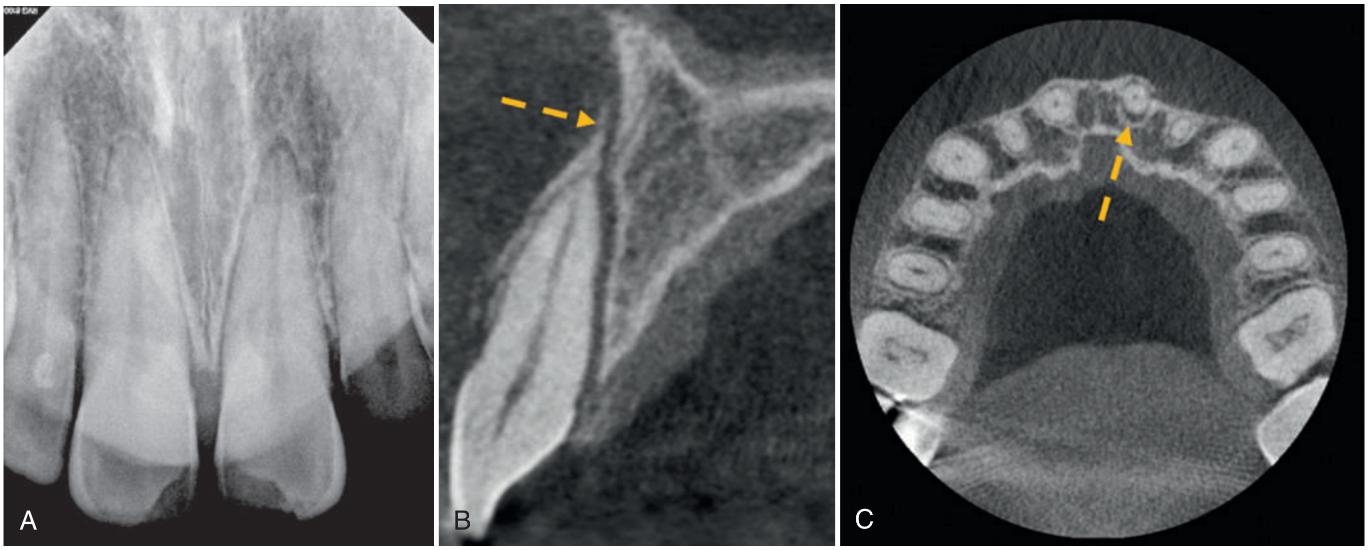

FIG. 2-23 After a traumatic injury to the maxillary right and left central incisors, crown fractures were noted. The PA radiograph showed an extrusive luxation injury in the maxillary left central incisor (**A**). The alveolar fracture (**B**, *yellow arrow*) and true extent of the displacement (**C**, *yellow arrow*) became evident with CBCT. (Data acquired and reformatted at 0.076 mm voxel size using a CS 9000 3D unit [Carestream Dental, Atlanta, Ga].)

Bornstein et al.[23] examined 38 patients with 44 permanent teeth that sustained intra-alveolar fractures. In the study sample reported, 68.2% of teeth had oblique fractures that extended to the cervical third of the root, contradicting the findings of previous studies conducted with periapical imaging alone. CBCT imaging offered improved visualization of the location and angulation of root fractures compared to periapical and occlusal intraoral radiographs.[23]

Several of these studies suggest that lower resolution scans using voxel sizes in excess of 0.3 mm may not improve radiographic assessments.[76,189] A study by Wang et al.[186] showed that the sensitivity and specificity of PA radiography for root fractures were 26.3% and 100%, respectively; the findings for CBCT were 89.5% and 97.5%, respectively. CBCT images of root-filled teeth showed lower sensitivity and unchanged specificity, whereas 2D images showed the same sensitivity and specificity.[186] CBCT allows for the management of traumatic injuries in which a root fracture or alveolar fracture is suspected by providing undistorted multiplanar views of the dentition and supporting bone without the superimposition of anatomic structures.[37,107,157] CBCT image volumes provide superior sensitivity in detecting intra-alveolar root fractures compared with multiple PA radiographs; this allows for the detection of dental and alveolar displacements, including damage to other perioral structures, such as the maxillary sinus and nasal floor.[89] The presence of root canal fillings and posts affected the specificity of the findings as a result of artifact generation.[76,114] Outcome measurements of a region of interest can be compared over time with greater geometric accuracy using CBCT.[74]

The healing of root fractures is influenced by many factors, most prominently the stage of root development, with immature roots showing better healing than mature roots.[59] Other factors that influence healing are the extent of dislocation and repositioning, type of splinting, use of antibiotics, and location of the fracture on the root. The long-term survival of teeth with intra-alveolar root fractures was evaluated in a systematic study by Andreasen et al.[11] This study showed that the type of healing (e.g., hard tissue fusion, PDL interposition with and without bone) and the location of the fracture on the root had the most influence on tooth loss. CBCT should be considered when placement of individual PA radiographs will adversely affect patient management; PA radiographs will produce a higher radiation dose for assessment of the region of interest; or intra-alveolar fracture of the root or supporting structures is suspected and sufficient information cannot be obtained with conventional radiography.[89]

The decision to use CBCT imaging for assessment of traumatic injuries should be based on the diagnostic yield expected and in accordance with the "as low as reasonably achievable" (ALARA) principle. CBCT scan volumes that use the most appropriate detector size and shape, beam projection geometry, and beam collimation should be selected to produce high-resolution images and reduce x-radiation exposure whenever possible.[158] In all cases, it should be recognized that children and young adults are more susceptible to the effects of radiation than adults, and CBCT studies should answer specific clinical questions that cannot be answered by lower dose PA and panoramic imaging technologies.[79] New technologies that allow for comparison of matched CBCT images in a serial fashion at a reduced dose have been tested. This technology promises a dose reduction of 10 to 40 times by using the initial scan as prior knowledge and adaptive prior image constrained compressed sensing (APICCS) algorithms to greatly reduce the number of projections and x-ray tube current levels required (Fig. 2-24).[100]

Internal and External Root Resorption

Most clinicians are aware, and ideally communicate to their patients, that the long-term prognosis for teeth with extensive root resorption may be unpredictable. Endodontic treatment can often resolve these defects, and early diagnosis and treatment typically mean an improved prognosis. CBCT imaging of these resorptive lesions provides the clinician with enhanced

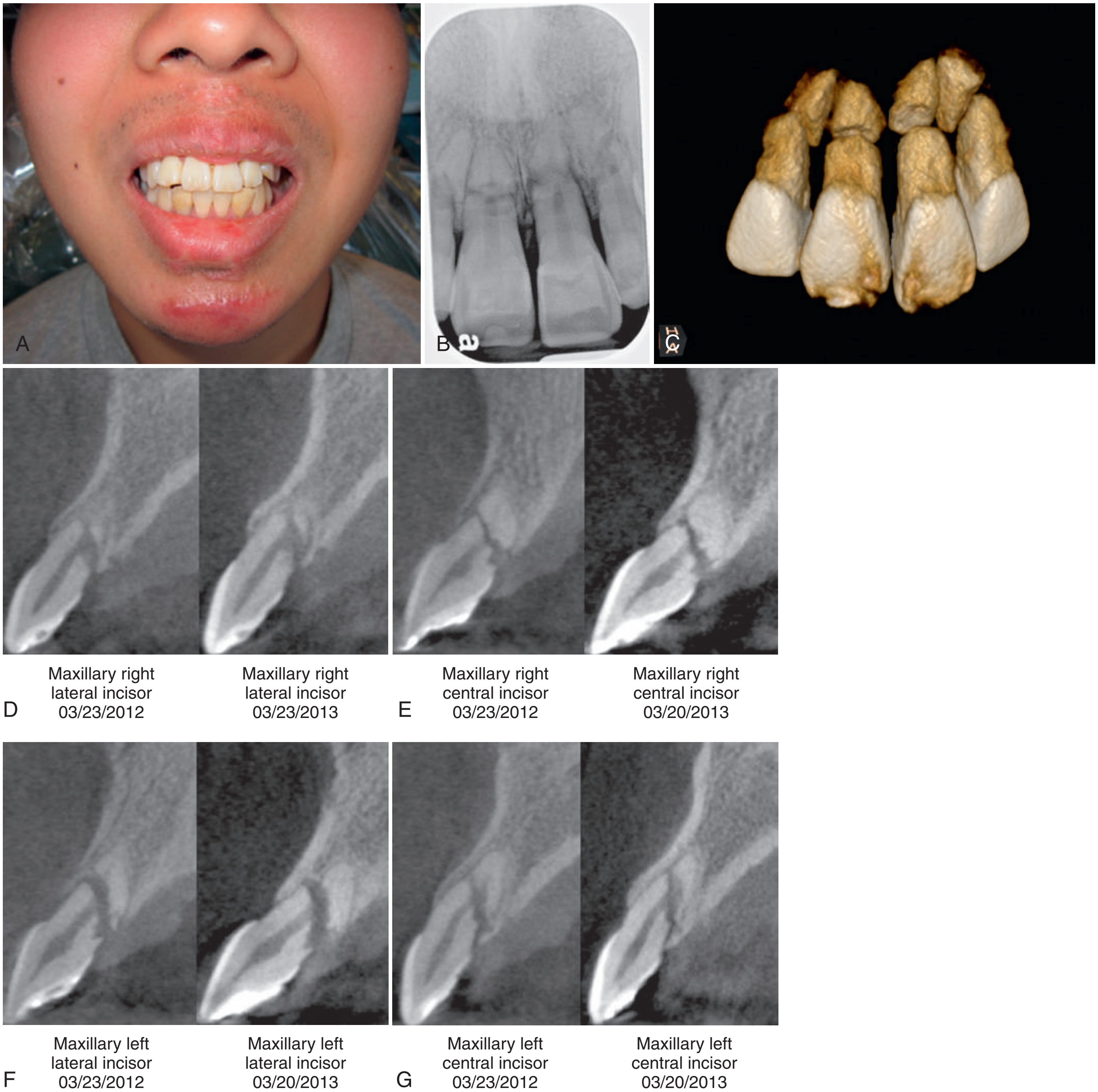

FIG. 2-24 Horizontal root fractures resulting from trauma **(A)** were evident in this 22-year-old male patient, who was referred with a contemporaneous film–based PA radiograph **(B)** for evaluation and possible treatment 9 months after trauma to his maxillary lateral and central incisors. Since the trauma, the teeth had been stabilized with a ribbon-type splint on the palatal surface; they were of normal color and responded to all pulp tests within normal limits. There was slight mobility in all of the traumatized teeth. The true nature of the root fractures (**C,** 3D reconstructed view) was evident in the corrected sagittal views of the maxillary right lateral **(D)** and central **(E)** incisors, and in the maxillary left central **(F)** and lateral **(G)** incisors. Temporal examination revealed no changes at the initial presentation, 12-month, and 30-month reevaluations (left to right in each group). Task-specific exposure parameters allowed each successive CBCT image volume to be exposed with lower kVp and mA, resulting in a 20% radiation dose reduction. (Data acquired and reformatted at 0.076 mm voxel size using a CS 9000 3D unit [Carestream Dental, Atlanta, Ga].)

information so that more appropriate treatment planning options are available.

As described in Chapter 16, root resorption (RR) results in the loss of dentin, cementum, or bone by the action of clastic cells.[15] In the primary dentition, RR is caused by normal physiologic processes, except when resorption is premature; in the permanent dentition, it is caused by inflammatory processes.[36,52,141] The successful management of RR in the adult dentition depends on clinical and radiographic examination leading to early detection and accurate diagnosis.[142] Unfortunately, teeth affected by RR have a poor prognosis if the causative lesion is not treated.[140] Although parallax intraoral imaging techniques can be helpful in localizing RR,[86] only CBCT assessments can provide the true size and position of all resorptive defects in the region of interest.[36,140] Intraoral imaging produced false-negative results in 51.9% of cases studied and false-positive results in 15.3%.[122] The interpretation of RR should rely on the least invasive test that can reliably detect the occurrence of the condition.[140] The use of CBCT in the evaluation of RR eliminates structure superimposition and compression of 3D features. Patel et al.[140] compared the sensitivity and specificity of PA imaging with CBCT scans using the receiver operating characteristic (ROC) curve, a standard measure of diagnostic performance. PA imaging showed satisfactory (Az 0.78) accuracy, whereas CBCT showed perfect results (Az 1.00).[140]

Although the literature describes many classification systems, this section divides inflammatory root resorption into two groups, according to location: internal root resorption (IRR) and external root resorption (ERR).[177] IRR is a relatively rare occurrence that is usually detected on routine diagnostic PA or panoramic radiographs.[102,139] It is characterized by structural changes in the tooth that appear as oval or round radiolucent enlargements of the pulp canal, usually with smooth, well-defined margins.[32] IRR is usually asymptomatic, associated with pulpal necrosis coronal to the resorptive lesion and vital or partially vital pulps where active.[140] These lesions can easily be confused with extracanal invasive cervical resorption because the radiographic appearance of the two lesions can be identical. CBCT is helpful for diagnosing the location and exact size of IRR. In a study by Estrela et al.,[52] 48 PA radiographs and CBCT scans were exposed on 40 individuals.[52] IRR was detected in 68.8% of PA radiographs, whereas CBCT scans showed 100% of the lesions. Conventional radiographs were able to detect only lesions between 1 and 4 mm in 52.1% of the images, whereas CBCT was able to show 95.8% of the lesions. This finding was in agreement with other studies that demonstrated the value of tomographic analysis.[36,105] In a study by Kim et al.,[92] the extent and location of the IRR was accurately reproduced with the fabrication of a rapid prototyping tooth model. Although relatively few systematic studies on artificially induced IRR have been reported because of the difficulty in creating such defects, Kamburoglu and Kursun[90] concluded that high-resolution CBCT imaging performed better than low-resolution CBCT imaging in detecting simulated small internal resorptive lesions.

ERR is typically idiopathic, but severe luxation and avulsion injuries can result in lesions that may progress rapidly, and early treatment is recommended.[47] The recommended timing of radiographic examinations using CBCT has not been established with a strong evidence grade. Many ERR cases involve young patients, in whom the radiation dose is critical, and

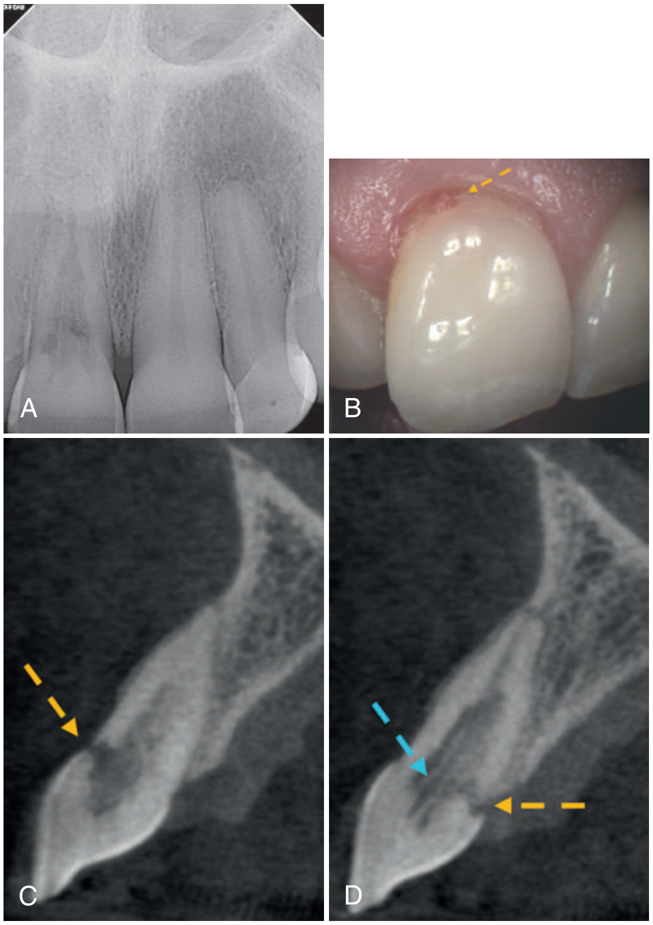

FIG. 2-25 Invasive cervical resorption, a form of external resorption, was evaluated in this patient after a PA radiographic image (**A**) and visual examination (**B**) showed pathognomonic signs of this lesion. A CBCT image was exposed to determine the true extent of resorption and also restorability. The lesion showed a perforative defect at the CEJ on the facial (**C**, *yellow arrow*) and palatal (**D**, *yellow arrow*) aspects. An intact layer of predentin (**D**, *blue arrow*) is a hallmark of this condition. (Data acquired and reformatted at 0.076 mm voxel size using a CS 9000 3D unit [Carestream Dental, Atlanta, Ga].)

multiple scans would be difficult to justify. ERR can be classified as surface resorption, external inflammatory resorption, external replacement resorption, external cervical resorption, and transient apical breakdown (Fig. 2-25).[141] These lesions are always associated with bony resorption, making comparability of laboratory studies problematic because the lesions lack the changes in the periodontal membrane and associated bony changes that would improve visualization. Differentiation between IRR and ERR is challenging, even with multiple changes in x-ray angulation. The early stages of ERR were difficult to view with conventional radiography, and lesions less than 0.6 mm in diameter and 0.3 mm in depth could not be detected. Medium-sized lesions were visible in 6 of 13 cases, with improved visualization for proximal lesions without regard to the root third being examined.[10]

ERR is difficult to detect if the lesion is confined to the buccal, palatal, or lingual surfaces of the root.[20,66] Liedke et al.[105] conducted systematic diagnostic performance tests and showed similar sensitivity and specificity among the different voxel sizes studied (0.4, 0.3, and 0.2 mm); however, the likelihood ratio showed better probability of correct identification of ERR with either 0.3 or 0.2 mm scans. These researchers suggested the use of a 0.3 mm voxel size protocol, rather than a 0.2 mm one, to reduce scanning time and the resulting dose.[105] Although voxel size is an important consideration, the SNR of different detectors, the radiation dose, viewing conditions, and the processing algorithms also affect detection probability.

Even though many in vitro studies have been performed on the ability of CBCT to detect RR, additional evaluations that use in vivo methodology will add to the cumulative knowledge.

PRESURGICAL VISUALIZATION

Surgical endodontic treatment is often performed in cases of endodontic nonhealing when nonsurgical retreatment is not possible. In the past, conventional and digital 2D PA radiographs were the only means of assessing the apical region. Unfortunately, the information available from these images may not adequately prepare the clinician to resolve the pathosis surgically. For example, the clinician may be unable to observe whether the lesion has perforated the buccal or palatal cortical plates, as in the example that follows, or even observe which root or roots are involved. Presurgical confusion is resolved with cone beam imaging. Multiplanar views allow the clinician to see the defect and suspected causes from the axial, sagittal, and coronal aspects; 3D grayscale or color imaging helps the clinician visualize the entire defect before the incision is made. This is an immense improvement over conventional imaging (Fig. 2-26).

The relationship of the teeth and the associated pathology to important anatomic landmarks must be taken into consideration in the treatment planning for endodontic surgical procedures. These anatomic landmarks include, but are not limited to, the maxillary sinus, the mandibular canal, the mental foramen, the incisive canal, and the buccal and lingual/palatine cortical plate. The close proximity of the maxillary posterior teeth to the sinus has been linked to maxillary sinusitis of odontogenic origin; changes in the maxillary sinus have ranged from thickening of the schneiderian membrane to actual accumulation of fluid in the sinuses.[110,111,113] The relationship of the roots of the posterior teeth to the sinus during presurgical treatment planning and the changes within the sinus can be best appreciated with the use of CBCT images.[22,111,165]

The relationship of the roots of the mandibular posterior teeth and associated periapical pathology to the mandibular canal, the presence of an anterior loop, and the distance of the mandibular canal from the buccal and lingual cortical plates are pertinent pieces of information when surgical procedures in mandibular posterior teeth are planned.[21] The 3D nature of

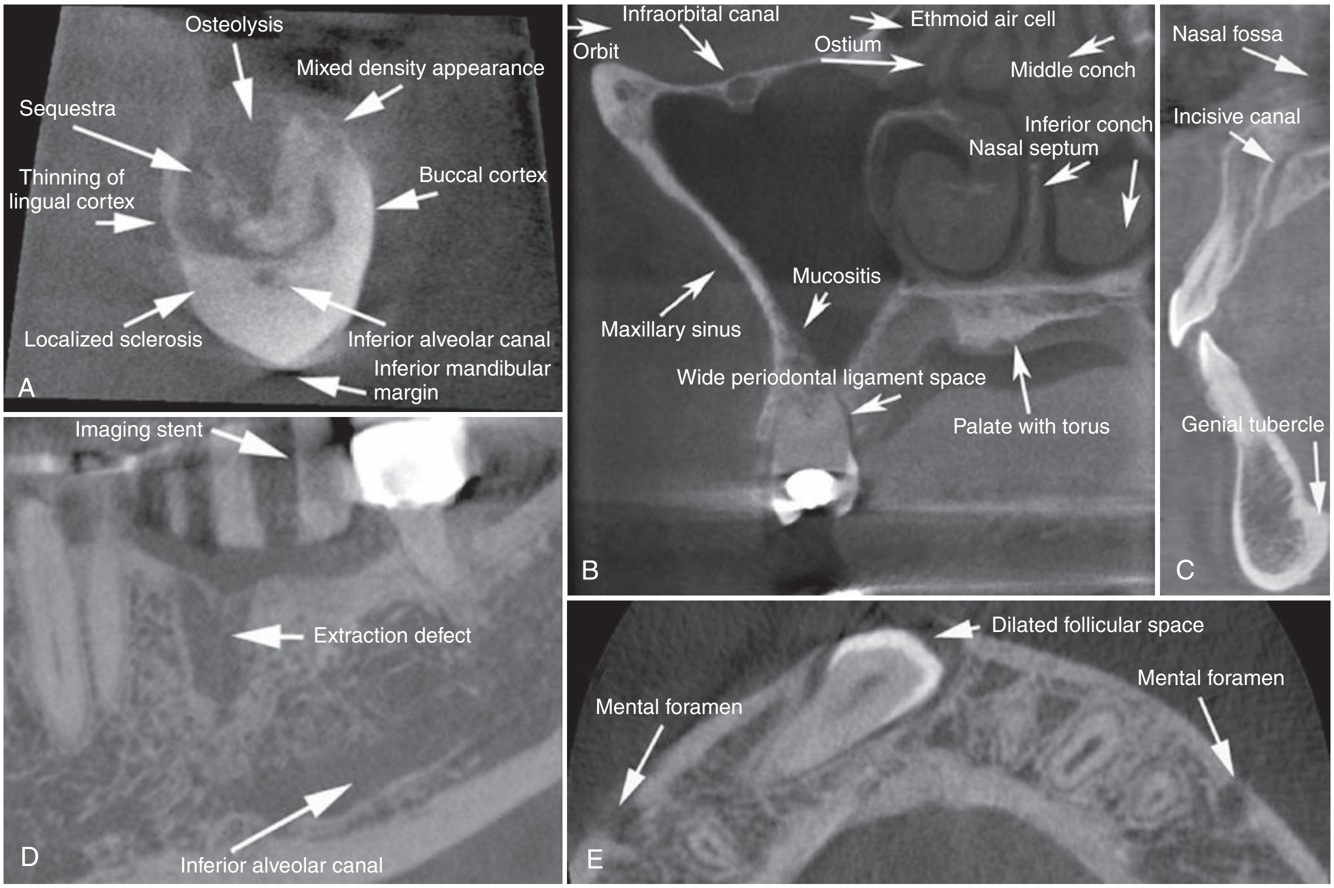

FIG. 2-26 A to W, Anatomic landmarks on CBCT images acquired using CS 9000, CS 9300, and i-CAT units. (Carestream Dental, Atlanta, Ga [CS 9000 and CS 9300 units]; and Imaging Sciences International, Hatfield, Pa [i-CAT unit].)

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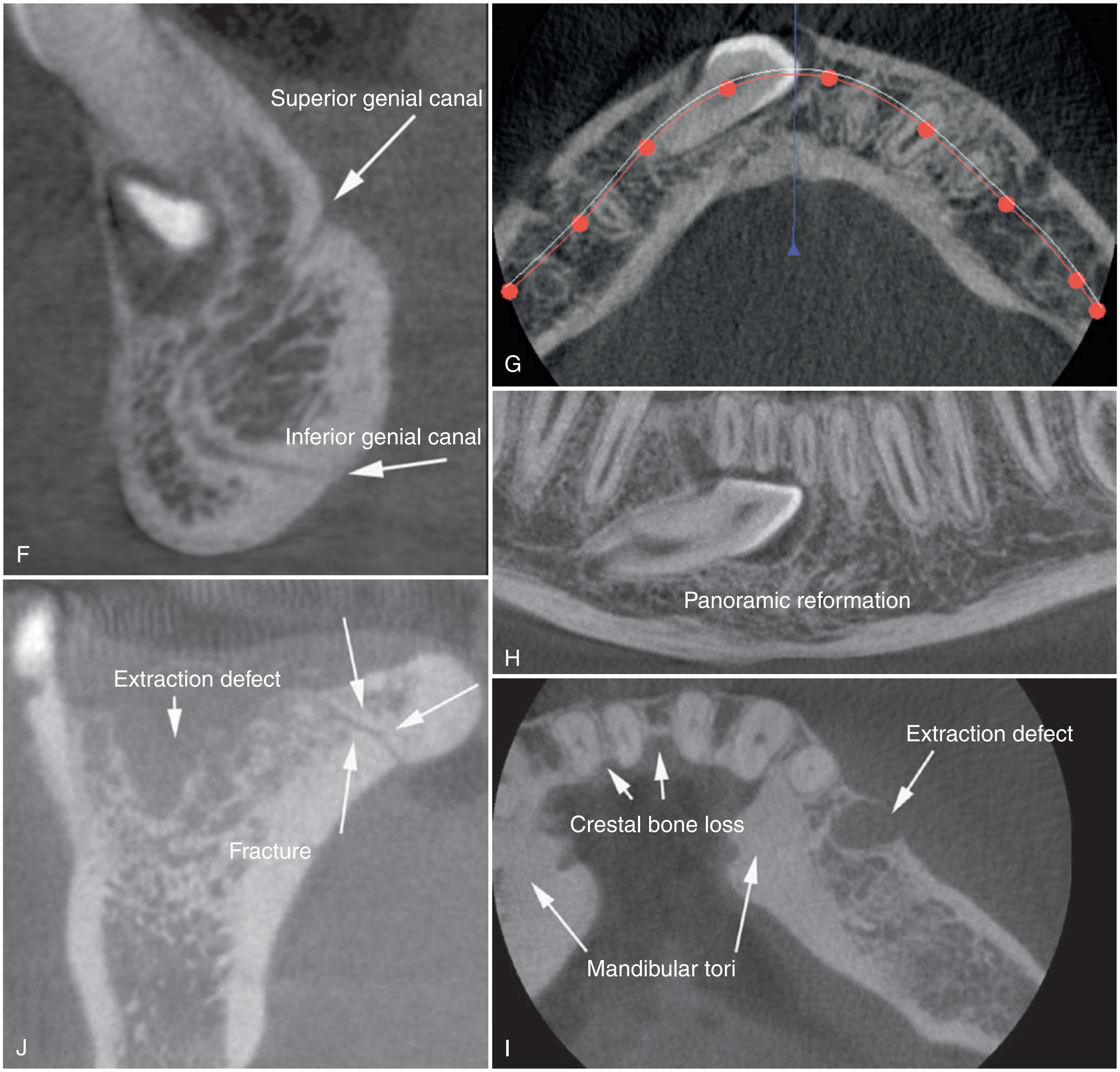

FIG. 2-26, cont'd

this relationship can best be assessed using CBCT.[93] A potential difference in the location of the mandibular canal with respect to age and gender has been reported.[97,167]

Outcomes Assessment

Endodontic treatment outcome predictors using PA radiographs and CBCT imaging have been shown to vary and also are influenced by patient inclusion and exclusion criteria.[104] Historically, PA radiographs and physical examinations were used to determine the success of endodontic treatment, and the absence of posttreatment periradicular radiolucencies and symptoms was considered the criterion for success. However, these planar imaging–based studies have resulted in an overestimation of successful outcomes, compared to CBCT assessments,[192a] because apical periodontitis confined within the cancellous bone or lesions covered by a thick cortex may be undetectable with conventional radiographic assessments.[18] Additional discrepancies between PA radiography and CBCT have resulted from geometric distortion, limiting comparisons of time-based evaluations, even with careful attention to paralleling technique factors.[112] A clinical study comparing the sensitivity, specificity, predictive values, and accuracy of PA and panoramic radiography and CBCT imaging in 888 consecutive patients showed that the prevalence of apical periodontitis in root-treated teeth was 17.6%, 35.3% and 63.3%, respectively. Conventional radiography showed increased accuracy when the evaluation of larger lesions was assessed.[53]

Outcome predictors identified with PA radiographs and CBCT scans may be different depending on the research performed. Liang et al.[104] retrospectively evaluated 115 endodontically treated teeth with vital pulps 2 years after treatment.

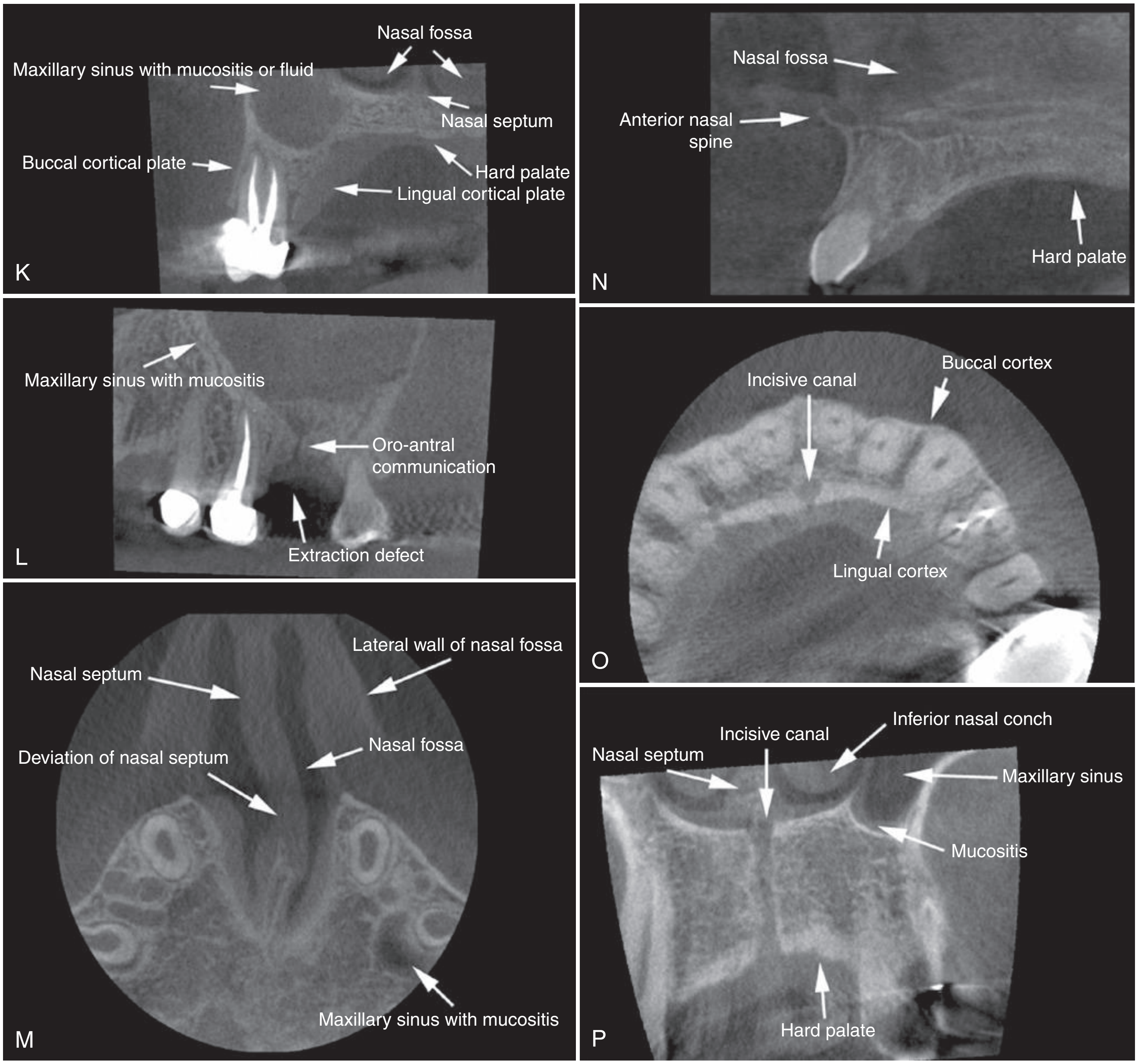

FIG. 2-26, cont'd

Continued

The authors noted that the recall rate of 36% was comparable to that in other studies, but the result may have been affected because patients with symptomatic or already extracted teeth may not have responded. This lost-to-follow-up cohort significantly reduced the level of evidence.[59a] PA radiography identified periapical lesions in only 12.6% of teeth compared to CBCT images, which identified 25.9% of teeth with periapical lesions. In multivariate logistic regression analysis, the extent of root fillings and density were outcome predictors when using PA imaging, whereas density of root fillings and quality of the coronal restoration were outcome predictors when using CBCT scans. The use of cross-sectional tomography in endodontic treatment is not yet supported by high-level studies that show improved outcomes for patients.

The predictive value and diagnostic accuracy of radiologic assessments are critical to the practice of dentistry, and the diagnostic value of radiographs depends on the radiograph's ability to show the histology of apical periodontitis (AP). De Paula-Silva et al.[43] evaluated the periapex of 83 root-treated and untreated dogs' teeth using PA radiography, CBCT scans, and histopathologic analysis. PA radiography detected AP in 71% of roots; CBCT scans detected AP in 84%; and histologic analysis detected AP in 93%. These findings, corroborated by other studies,[27,70,150] emphasized the low negative predictive value (NPV) of PA radiography at 0.25, showing that when the periapical tissues had a normal appearance, 75% actually had AP. CBCT scans resulted in an NPV almost two times higher than that for PA radiography; however, CBCT scans were not able to detect some AP that was confined to the apical foramen or had little volumetric bone loss. The positive predictive value was the same for PA radiography and CBCT scans compared with histologic examination, but true positive and true

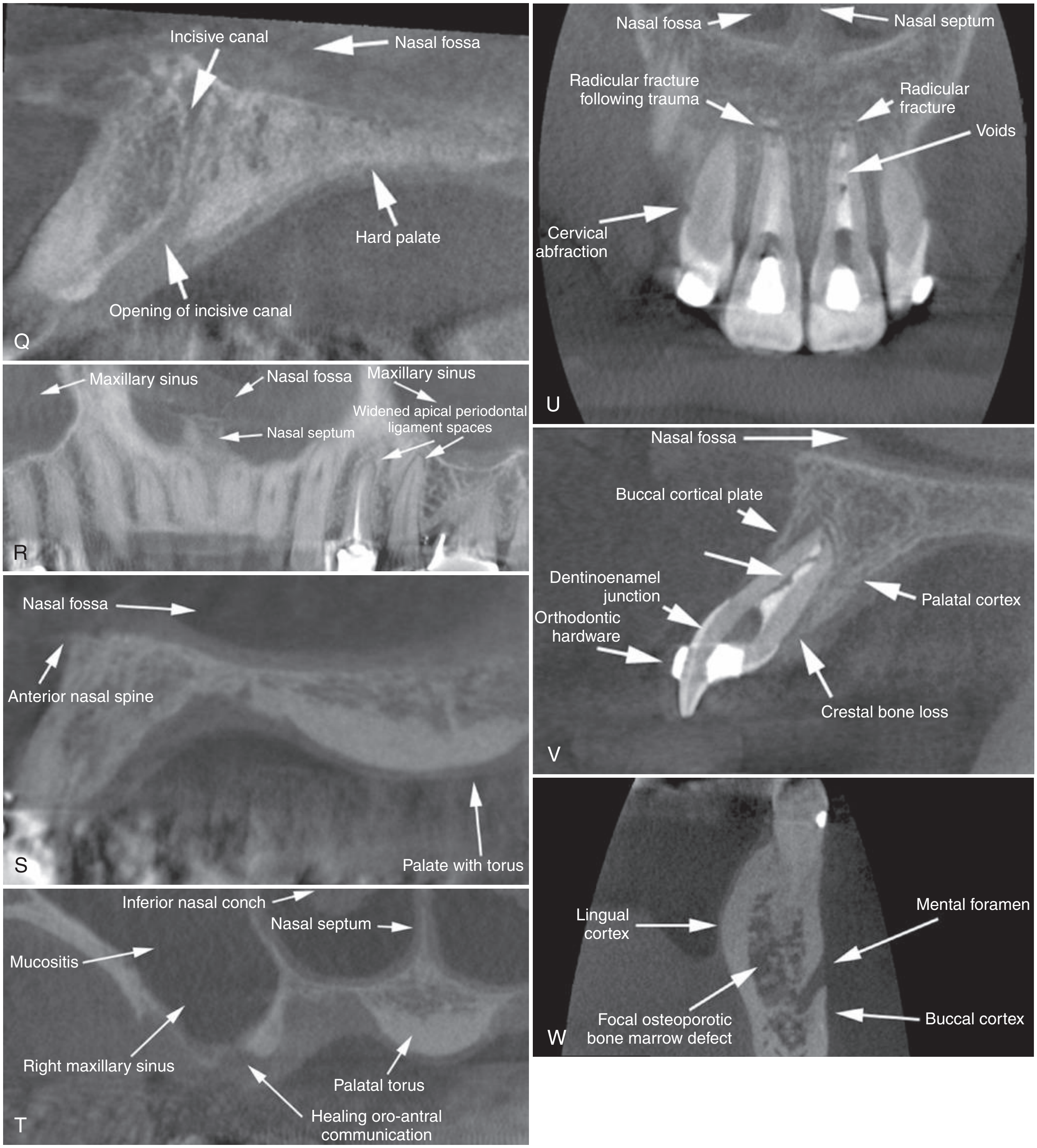

FIG. 2-26, cont'd

negative diagnosis of AP using CBCT scans occurred in 92% of cases.

Determination of healing or nonhealing in individual cases should depend on the clinical and radiographic findings, adjusted for risk factors for the patient, radiation dose, and cost (Fig. 2-27). For patients who are medically complex and subject to possible increased detriment from apical periodontitis (i.e., patients with altered immune systems, such as those undergoing chemotherapy or anti-HIV protocols or who have risk factors associated with prosthetic joints and/or infective endocarditis), these factors should be considered in the decision on whether to use CBCT. The American Academy of Periodontology has published a position paper stating that periodontal disease might contribute to adverse systemic health conditions.[156] The scientific basis for the relationship of AP and adverse systemic health conditions has not been

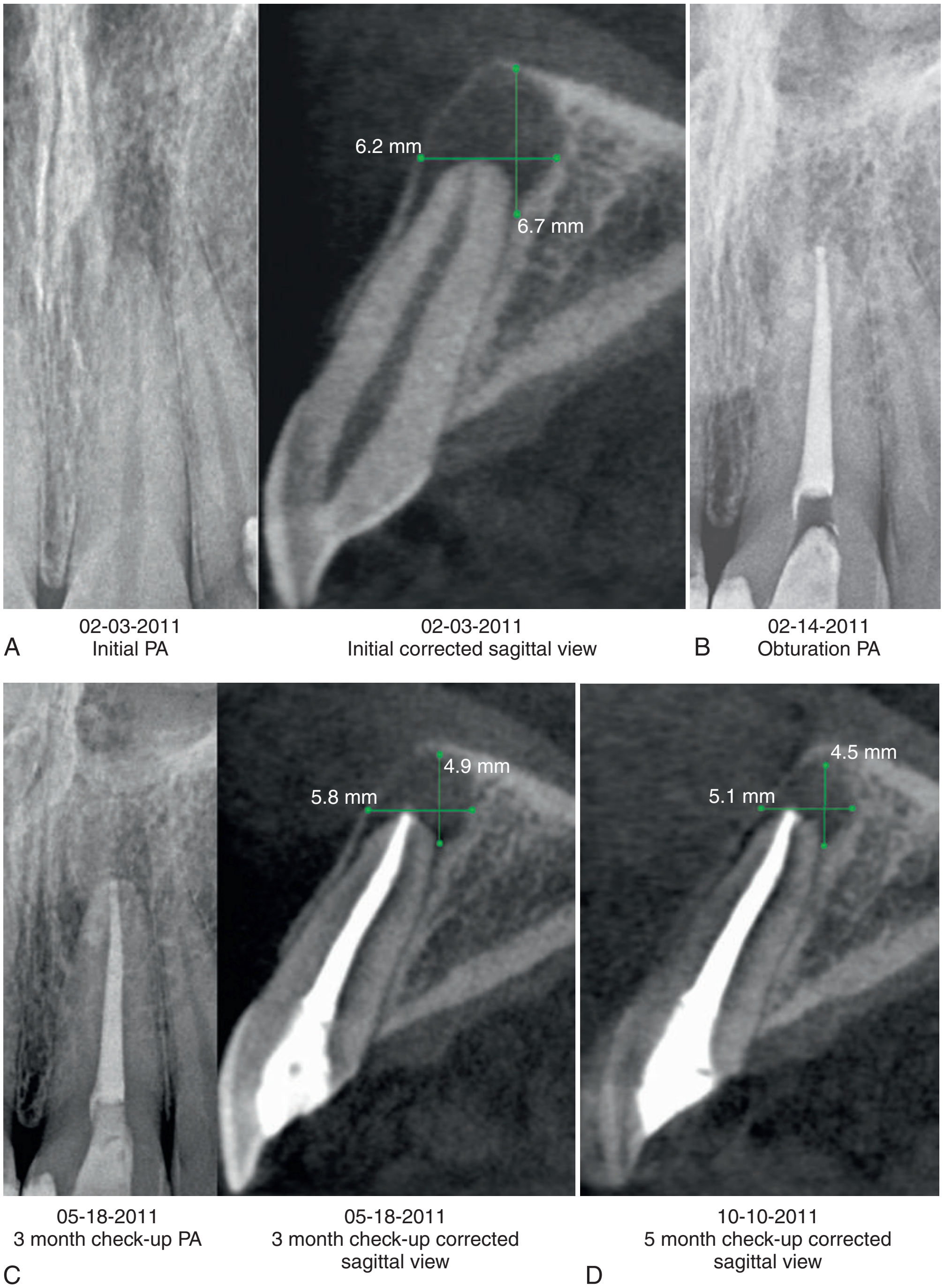

FIG. 2-27 This series of radiographs shows a maxillary left central incisor several months after a bicycle accident. The patient complained of significant discomfort and mobility with slight swelling in the periapical region. The preoperative PA radiograph (**A**, *left*) and contemporaneous CBCT image (**A**, *right,* corrected sagittal view) showed an approximately 6 mm, well-defined periapical radiolucency with a noncorticated diffuse border, centered over the apex, consistent with a periradicular periodontitis. No root or alveolar fractures were observed. A postoperative PA radiograph (**B**) showed satisfactory canal obturation. At a 3-month checkup visit, the patient complained of continued sensitivity to touch and mobility. There was excessive contact with the opposing incisor, which was adjusted. Because the 3-month checkup PA radiograph (**C**, *left*) showed no change in the periradicular radiolucency, a CBCT image (**C**, *right,* corrected sagittal view) was required to assess healing. The periradicular radiolucency was smaller, consistent with progress in healing. A subsequent 5-month CBCT image (**D**, corrected sagittal view) showed continued healing. Consistent with the as low as reasonably achievable (ALARA) principle, no PA radiograph was exposed. (Data acquired and reformatted at 0.076 mm voxel size using a CS 9000 3D unit [Carestream Dental, Atlanta, Ga].)

established[33]; however, new associations between AP and systemic health should be predicated on research that uses CBCT in the detection of endodontic disease.[193]

IMPLANT SITE ASSESSMENTS

Successful endosseous implant site assessment requires the development of a prosthetically driven approach,[130b] with special emphasis on the evaluation of bone volume, the osseous topography, and the location of anatomic structures in relation to positioning of the implant. The AAOMR has published advisory recommendations suggesting all radiographic studies should interface with the dental and medical histories, clinical examinations, and treatment planning. Panoramic radiography, which may be supplemented by PA radiography, should be used for initial imaging assessments. Cross-sectional imaging, including CBCT, should not be used as an initial imaging examination. The AAOMR affirms the need for cross-sectional imaging in the preoperative diagnostic phase, recommending CBCT because it provides the highest diagnostic yield at an acceptable radiation dose risk. CBCT should be used at the smallest FOV necessary, with optimized technique factors, to minimize radiation dose in accordance with the ALARA principle.[177a]

CBCT allows for precise planning and delivery of implants that can reproduce the anatomy with submillimetric accuracy, leading to improved outcomes.[171] The use of CBCT to assess linear measurements, proximity to vital anatomic structures, mapping of the alveolar ridge topography, and fabrication of surgical guides is supported by the dental literature. The use of CBCT to gauge bone density, provide intraoperative surgical navigation, and assess implant integration is generally considered an area that requires further research.[17]

Virtual implant planning using CBCT data allows clinicians to visualize the result before the commencement of treatment, facilitating the virtual investigation of multiple treatment scenarios until the best plan is attained. The evaluation of bone dimensions, bone quality, the long axis of the alveolar bone, internal anatomy, and jaw boundaries; the detection of pathologic features; and the transfer of radiographic information are the main imaging goals. Pathoses of the jaws, such as retained root tips, inflammatory lesions, cysts, and tumors, in addition to extraoral structures, such as the sinuses and temporomandibular joints (TMJs), must also be assessed.[80] CBCT imaging should be considered to evaluate implant sites in the region of teeth with a high likelihood of periradicular pathosis.[200]

IMAGE PERCEPTION AND VIEWING ENVIRONMENT

Medical image perception is an important area of knowledge, and ongoing research relies on an understanding of perceptual issues, such as psychological factors, dwell time, visual search physiology, search tactics, appreciation for the reading environment, and fatigue factors, to increase search satisfaction. Understanding these issues may improve the ability to interpret and report on dental radiographic findings.[155a]

The increasing use of digital radiography in the dental environment has led to a sea change in workflow and the necessity for new ways to view and document radiographic images. Simple to accomplish, but important to improve, are the viewing conditions for softcopy interpretation, including moderately reduced ambient lighting, ranging from 25 to 40 lux.[110a]

FUTURE OF CBCT

The first decade of the twenty-first century saw the development of a wide range of CBCT applications, especially in dentistry. Lower radiation dose, higher spatial resolution, smaller FOV, and relatively lower cost may contribute to CBCT becoming the standard of care in 3D dentomaxillofacial imaging in selected cases. CBCT systems are increasingly being used in medical applications, such as operating rooms, emergency departments, intensive care units, and private otolaryngology offices. Operating room–based C-arm systems have been in use for a number of years, with applications in interventional angiography, cancer surgery, vascular surgery, orthopedic surgery, neurosurgery, and radiotherapy.[55] Applications in otolaryngology and mammography are common, and imaging of extremities in weight-bearing scenarios is under development. Many of these applications rely on systems that use task-specific protocols that benefit from CBCT's 2D flat panel detectors, which allow for a single rotation of the source to generate a study of the region of interest, as opposed to complex MDCTs that use redundant imaging via multiple slice acquisitions to generate a 3D volume.[164]

The introduction of new, high-performance, flat-panel detectors and software algorithms centering on improving the noise-power spectrum and noise-equivalent quanta will continue to increase the utility of CBCT systems in the future. Areas of research include (1) image perception and image quality assessment, to better understand how physicians and dentists analyze radiographic images and thereby improve diagnostic decision making[172]; (2) iterative reconstruction that uses sophisticated algorithms to reduce artifacts; (3) known-component reconstructions that use a model-based 3D image reconstruction and iterative software to reduce image artifacts in the presence of metallic devices such as screws and implants; (4) image registration to align tissues for image-guided surgery and outcomes assessment,[120] (5) image-guided procedures that provide up-to-the-minute surgical navigation; and (6) segmentation to allow discrimination between normal and diseased tissues and permit volumetric measurements (Fig. 2-28).

CONCLUSIONS

Digital radiography has several advantages and has become an indispensable diagnostic tool for many dentists in daily practice. Once the digital image appears on the monitor, the dental x-ray software allows image enhancement, which should be used with caution and based on the diagnostic task. Inappropriate use of enhancement has been shown to adversely affect diagnosis.[121] If digital radiographs are exported using various software packages created for graphic design and image manipulation, digital information can be altered, added, or removed. The DICOM standard has been accepted as the universal standard for image transmission and archiving, so that each image can be transmitted and stored without the use of proprietary software that would seriously limit its distribution. DICOM ensures that all images are readable in any viewing software without loss of fidelity or diagnostic information. Image enhancement features of digital radiography allow

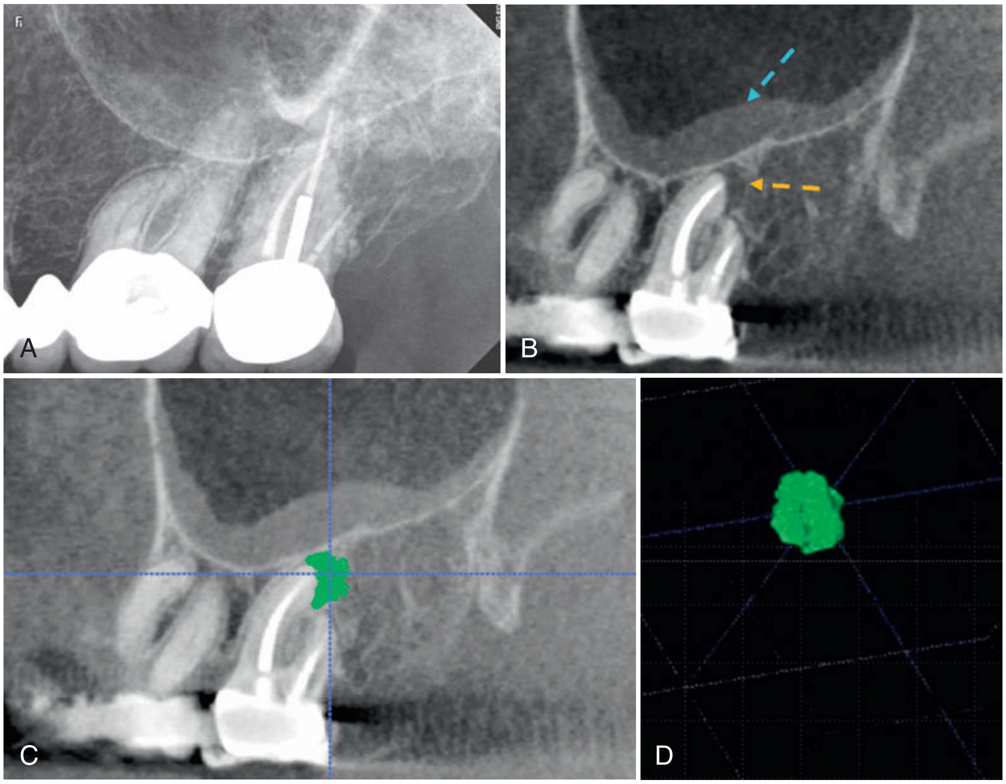

FIG. 2-28 The problem of superimposition of unrelated structures onto the features of interest is reduced when tomographic slices are used instead of images in which an entire volume of data is compressed into a planar image. This PA radiographic image **(A)** of the maxillary left second molar shows no radiographic indicators of pathosis. A contemporaneously exposed CBCT image (**B**, corrected sagittal view) shows a 4.3 × 1.9 mm, well-defined unilocular, noncorticated area of low attenuation centered over the apex of the mesiobuccal root, consistent with a periradicular periodontitis *(yellow arrow).* There is a moderate mucositis in the region of the maxillary sinus adjacent to this tooth *(blue arrow).* Experimental semiautomated segmentation of this image using active contour methods (ITK-SNAP) allowed for measurement of the true volume of the lesion **(C)** and for future temporal comparisons based on volumetric measurements **(D).** This lesion measured 85,112 voxels and 38.1044 cubic mm. (Data acquired and reformatted at 0.076 mm voxel size using a CS 9000 3D unit [Carestream Dental, Atlanta, Ga]; volumetric segmentation and measurement using ITK-SNAP [Radiology Department, School of Medicine, University of Pennsylvania].)

mishandling of images, leading to potential abuse. Published studies illustrate the potential for fraudulent use of digital radiography.[31]

There is a dearth of studies related to the diagnostic performance of the different sensor types currently available on the market. Slight to moderate differences in spatial resolution capabilities exist. With rapid advancement in sensor technology and frequent software upgrades, selection of one system over another for a specific diagnostic task may appear challenging. A review of the most commonly used solid-state sensors notes that most systems perform comparably with intraoral film and also allow for postprocessing of images, which is not possible with film-based images. Other factors that assume significance in this context are the availability of technical and customer support, frequency of both hardware and software upgrades, dimensions of the sensor and its active area, number of sensors needed in a practice (and thus cost issues), the detector quantum efficiency (DQE), and conformance to the DICOM standard for seamless integration with other systems. CCD/CMOS sensors appear to offer the best contrast and spatial resolution, in addition to facilitating instantaneous image capture, and therefore are recommended for endodontic applications. Careful and appropriate image processing further helps tease out the signal of interest. In an enterprise-wide setting or in larger private practices that have multiple specialty areas, PSP-based sensors may be more cost effective for large volume imaging (e.g., full mouth series of radiographs). However, at least one or two CCD/CMOS-based systems should be available for faster image acquisition, such as for endodontic purposes and intraoperative procedures.

It is recommended that the literature be constantly reviewed for updates on digital radiography and advanced imaging modalities for specific endodontic applications because hardware and software upgrades continue to make rapid progress. Previous studies have shown that most digital images performed comparably to conventional intraoral film for a variety of diagnostic tasks. Most of these studies were done with earlier generation sensors. The advances in sensor technology have resulted in greatly enhanced image quality, and this trend is expected to continue. Also of interest in the future will be the use of task-based, appropriate image processing parameters that result in a reduced radiation dose and significant enhancement of the diagnostic information. Automation of this process will result in faster and more consistent image processing based on the diagnostic task. Such procedures are routinely carried out in medical radiology.

Three-dimensional imaging will continue to be used extensively as sensor characteristics improve and more user-friendly software is introduced. As bit-depth and spatial resolution of images increase, CBCT will continue to be explored for more applications in endodontics. Image interpretation also is important. Occult pathology and incidental findings in adjacent regions can be easily missed or go unrecognized by those who have not received specific training in the interpretation of regional anatomy. Image processing can greatly alter signal characteristics, thus rendering the task fairly challenging. Besides, if other pathoses are discovered, additional imaging may be necessary, including MRI, nuclear medicine studies, or even MDCT for evaluation of soft tissues, with and without the use of contrast.

The advent of 3D imaging has provided the endodontist with tools that were not available until now, facilitating interactive image manipulation and enhancement and thus significantly increasing the amount of information that can be gleaned from a volume. Lack of distortion, magnification, artifacts associated with conventional radiography, and the relative low radiation dose compared to medical-grade CT will result in more clinicians adopting such technology to enable accurate diagnoses and treatment planning, in addition to long-term follow-up and the evaluation of healing. Judicious use of CBCT and all other imaging modalities using ionizing radiation is advocated. The AAE/AAOMR position paper provides recommendations for the use of CBCT in endodontics.[34] That position paper is presented at the end of this chapter.

When the clinician works with different vendor products, it is important to have a quality assurance program in place. This is not being done currently. Additionally, accreditation of stand-alone imaging laboratories is now a requirement for reimbursement of medical and dental diagnostic procedures from government agencies and some major third-party insurance providers. Several states are considering enforcing this requirement to prevent abuse of CBCT.

Likewise, definitive referral criteria are lacking. Indications, contraindications, and choice of alternate imaging modalities need to be considered before CBCT is used. There is a learning curve to this technology, and appropriate positioning, choice of exposure parameters (and thus the effective dose), reconstruction schemes, choice of postprocessing algorithms based on diagnostic task, voxel sizes, and cost must be considered. The literature contains few studies to help us formulate definitive guidelines for the use of CBCT in dentistry.

It is equally important to record the doses associated with each study. Accreditation criteria have been developed by the Intersocietal Accreditation Commission for cone beam CT in dentistry that are useful for ensuring the safe use of these units. The lowest possible dose must be imparted to the patient as part of a radiologic examination to minimize stochastic effects that have no known threshold for expression. No dose can be considered a "safe dose." The benefits of any radiographic study must outweigh the risks. All studies must be interpreted fully because signals from adjacent areas may appear in the volume of interest, including small FOV studies. Retakes can be avoided by adhering to protocol selection based on the task at hand. The ALARA principle must be followed, regardless of the dose values reported by the vendor, to optimize the dose for the specific examination. Use of thyroid collars and lead aprons is recommended in the NCRP guidelines, as long as they do not interfere with image acquisition.

Joint Position Statement of the American Association of Endodontists and the American Academy of Oral and Maxillofacial Radiology on the Use of Cone Beam Computed Tomography in Endodontics: 2015 Update

This statement was prepared by the Special Committee to Revise the Joint AAE/AAOMR Position Statement on Use of CBCT in Endodontics, and approved by the AAE Board of Directors and AAOMR Executive Council in May 2015.

INTRODUCTION

This updated joint position statement of the American Association of Endodontists (AAE) and the American Academy of Oral and Maxillofacial Radiology (AAOMR) is intended to provide scientifically-based guidance to clinicians regarding the use of cone beam computed tomography (CBCT) in endodontic treatment and reflects new developments since the 2010 statement.[1] The guidance in this statement is not intended to substitute for a clinician's independent judgment in light of the conditions and needs of a specific patient.

Endodontic disease adversely affects quality of life and can produce significant morbidity in afflicted patients. Radiography is essential for the successful diagnosis of odontogenic and non-odontogenic pathoses, treatment of the root canal systems of a compromised tooth, biomechanical instrumentation, evaluation of final canal obturation, and assessment of healing.

Until recently, radiographic assessments in endodontic treatment were limited to intraoral and panoramic radiography. These radiographic technologies provide two-dimensional representations of three-dimensional anatomic structures. If any element of the geometric configuration is compromised, the image may demonstrate errors.[2] In more complex cases, radiographic projections with different beam angulations can allow parallax localization. However, complex anatomy and surrounding structures can render interpretation of planar images difficult.

The advent of CBCT has made it possible to visualize the dentition, the maxillofacial skeleton, and the relationship of anatomic structures in three dimensions.[3] CBCT, as with any technology, has known limitations, including a possible higher radiation dose to the patient. Other limitations include potential for artifact generation, high levels of scatter and noise, and variations in dose distribution within a volume of interest.[4]

CBCT should be used only when the patient's history and a clinical examination demonstrate that the benefits to the patient outweigh the potential risks. CBCT should not be used routinely for endodontic diagnosis or for screening purposes in the absence of clinical signs and symptoms. Clinicians should use CBCT only when the need for imaging cannot be met by lower dose two-dimensional (2D) radiography.

VOLUME SIZE(S)/FIELD OF VIEW

There are numerous CBCT equipment manufacturers, and several models are available. In general, CBCT is categorized into large, medium and limited-volume units based on the size of their "field of view" (FOV). The size of the FOV describes the scan volume of CBCT machines. That volume determines the extent of anatomy included. It is dependent on the detector size and shape, beam projection geometry, and the ability to collimate the beam. To the extent practical, FOV should only slightly exceed the dimensions of the anatomy of interest.

Generally, the smaller the FOV, the lower the dose associated with the study. Beam collimation limits the radiation exposure to the region of interest and helps ensure that an optimal FOV can be selected based on disease presentation. Smaller scan volumes generally produce higher resolution images. Because endodontics relies on detecting small alterations such as disruptions in the periodontal ligament space, optimal resolution should be sought.[5]

The principal limitations of large FOV CBCT imaging are the size of the field irradiated and the reduced resolution compared to intraoral radiographs and limited volume CBCT units with inherent small voxel sizes.[5] The smaller the voxel size, the higher is the spatial resolution. Moreover, the overall scatter generated is reduced due to the limited size of the FOV. Optimization of the exposure protocols keeps doses to a minimum without compromising image quality. If a low-dose protocol can be used for a diagnostic task that requires lower resolution, it should be employed, absent strong indications to the contrary.

In endodontics, the area of interest is limited and determined prior to imaging. For most endodontic applications, limited FOV CBCT is preferred to medium or large FOV CBCT because there is less radiation dose to the patient, higher spatial resolution, and shorter volumes to be interpreted.

DOSE CONSIDERATIONS

Selection of the most appropriate imaging protocol for the diagnostic task must be consistent with the ALARA principles that every effort should be made to reduce the effective radiation dose to the patient "as low as reasonably achievable." Because radiation dose for a CBCT study is higher than that for an intraoral radiograph, clinicians must consider overall radiation dose over time. For example, will acquiring a CBCT study now eliminate the need for additional imaging procedures in the future? It is recommended to use the smallest possible FOV, the smallest voxel size, the lowest mA setting (depending on the patient's size), and the shortest exposure time in conjunction with a pulsed exposure-mode of acquisition.

If extension of pathoses beyond the area surrounding the tooth apices or a multifocal lesion with possible systemic etiology is suspected, and/or a non-endodontic cause for devitalization of the tooth is established clinically, appropriate larger field of view protocols may be employed on a case-by-case basis.

There is a special concern with overexposure of children (up to and including 18 year-olds) to radiation, especially with the increased use of CT scans in medicine. The AAE and the AAOMR support the Image Gently Campaign led by the Alliance for Radiation Safety in Pediatric Imaging. The goal of the campaign is, "to change practice; to raise awareness of the opportunities to lower radiation dose in the imaging of children." Information on use of CT is available at http://www.imagegently.org/Procedures/ComputedTomography.aspx

INTERPRETATION

If a clinician has a question regarding image interpretation, it should be referred to an oral and maxillofacial radiologist.[6]

RECOMMENDATIONS

The following recommendations are for limited FOV CBCT scans.

Diagnosis

Endodontic diagnosis is dependent upon thorough evaluation of the patient's chief complaint, history, and clinical and radiographic examination. Preoperative radiographs are an essential part of the diagnostic phase of endodontic therapy. Accurate diagnostic imaging supports the clinical diagnosis.

Recommendation 1: Intraoral radiographs should be considered the imaging modality of choice in the evaluation of the endodontic patient.

Recommendation 2: Limited FOV CBCT should be considered the imaging modality of choice for diagnosis in patients who present with contradictory or non-specific clinical signs and symptoms associated with untreated or previously endodontically-treated teeth.

Rationale:

- In some cases, the clinical and planar radiographic examinations are inconclusive. Inability to confidently determine the etiology of endodontic pathosis may be attributed to limitations in both clinical vitality testing and intraoral radiographs to detect odontogenic pathoses. CBCT imaging has the ability to detect periapical pathosis before it is apparent on 2D radiographs.[7]
- Preoperative factors such as the presence and true size of a periapical lesion play an important role in endodontic treatment outcome. Success, when measured by radiographic criteria, is higher when teeth are endodontically treated before radiographic signs of periapical disease are detected.[8]
- Previous findings have been validated in clinical studies in which primary endodontic disease detected with intraoral radiographs and CBCT was 20% and 48%, respectively. Several clinical studies had similar findings, although with slightly different percentages.[9,10] Ex vivo experiments in which simulated periapical lesions were created yielded similar results.[11,12] Results of in vivo animal studies, using histologic assessments as the gold standard also showed similar results observed in human clinical and ex-vivo studies.[13]
- Persistent intraoral pain following root canal therapy often presents a diagnostic challenge. An example is persistent dentoalveolar pain also known as atypical odontalgia.[14] The diagnostic yield of conventional intraoral radiographs and CBCT scans was evaluated in the differentiation between patients presenting with suspected atypical odontalgia vs. symptomatic apical periodontitis, without radiographic evidence of periapical bone destruction.[15] CBCT imaging detected 17% more teeth with periapical bone loss than conventional radiography.

Initial Treatment

Preoperative:

Recommendation 3: Limited FOV CBCT should be considered the imaging modality of choice for initial treatment of teeth with the potential for extra canals and suspected complex morphology, such as mandibular anterior teeth, and maxillary and mandibular premolars and molars, and dental anomalies.

Intraoperative:

Recommendation 4: If a preoperative CBCT has not been taken, limited FOV CBCT should be considered as the imaging modality of choice for intra-appointment identification and localization of calcified canals.

Postoperative:

Recommendation 5: Intraoral radiographs should be considered the imaging modality of choice for immediate postoperative imaging.

Rationale:

- Anatomical variations exist among different types of teeth. The success of non-surgical root canal therapy depends on identification of canals, cleaning, shaping and obturation of root canal systems as well as quality of the final restoration.

- 2D imaging does not consistently reveal the actual number of roots and canals. In studies, data acquired by CBCT showed a very strong correlation between sectioning and histologic examination.[16,17]
- In a 2013 study, CBCT showed higher mean values of specificity and sensitivity when compared to intraoral radiographic assessments in the detection of the MB2 canal.[18]

Non-Surgical Retreatment

Recommendation 6: Limited FOV CBCT should be considered the imaging modality of choice if clinical examination and 2D intraoral radiography are inconclusive in the detection of vertical root fracture (VRF).

Rationale:

- In non-surgical retreatment, the presence of a vertical root fracture significantly decreases prognosis. In the majority of cases, the indication of a vertical root fracture is more often due to the specific pattern of bone loss and periodontal ligament space enlargement than direct visualization of the fracture. CBCT may be recommended for the diagnosis of vertical root fracture in unrestored teeth when clinical signs and symptoms exist.
- Higher sensitivity and specificity were observed in a clinical study where the definitive diagnosis of vertical root fracture was confirmed at the time of surgery to validate CBCT findings, with sensitivity being 88% and specificity 75%.[19] Several case series studies have concluded that CBCT is a useful tool for the diagnosis of vertical root fractures. In vivo and laboratory studies[20,21] evaluating CBCT in the detection of vertical root fractures agreed that sensitivity, specificity, and accuracy of CBCT were generally higher and reproducible. The detection of fractures was significantly higher for all CBCT systems when compared to intraoral radiographs. However, these results should be interpreted with caution because detection of vertical root fracture is dependent on the size of the fracture, presence of artifacts caused by obturation materials and posts, and the spatial resolution of the CBCT.

Recommendation 7: Limited FOV CBCT should be the imaging modality of choice when evaluating the non-healing of previous endodontic treatment to help determine the need for further treatment, such as non-surgical, surgical or extraction.

Recommendation 8: Limited FOV CBCT should be the imaging modality of choice for non-surgical re-treatment to assess endodontic treatment complications, such as overextended root canal obturation material, separated endodontic instruments, and localization of perforations.

Rationale:

- It is important to evaluate the factors that impact the outcome of root canal treatment. The outcome predictors identified with periapical radiographs and CBCT were evaluated by Liang et al.[22] The results showed that periapical radiographs detected periapical lesions in 18 roots (12%) as compared to 37 on CBCT scans (25%). 80% of apparently short root fillings based on intraoral radiographs images appeared flush on CBCT. Treatment outcome, length and density of root fillings and outcome predictors determined by CBCT showed different values when compared with intraoral radiographs.
- Accurate treatment planning is an essential part of endodontic retreatment. Incorrect, delayed or inadequate endodontic diagnosis and treatment planning places the patient at risk and may result in unnecessary treatment. Treatment planning decisions using CBCT versus intraoral radiographs were compared to the gold standard diagnosis.[23] An accurate diagnosis was reached in 36%-40% of the cases with intraoral radiographs compared to 76%-83% with CBCT. A high level of misdiagnosis was noted in invasive cervical resorption and vertical root fracture. In this study, the examiners altered their treatment plan after reviewing the CBCT in 56%-62.2% of the cases, thus indicating the significant influence of CBCT.

Surgical Retreatment

Recommendation 9: Limited FOV CBCT should be considered as the imaging modality of choice for pre-surgical treatment planning to localize root apex/apices and to evaluate the proximity to adjacent anatomical structures.

Rationale:

The use of CBCT has been recommended for treatment planning of endodontic surgery.[24,25] CBCT visualization of the true extent of periapical lesions and their proximity to important vital structures and anatomical landmarks is superior to that of periapical radiographs.

Special Conditions

a. Implant Placement:

Recommendation 10: Limited FOV CBCT should be considered as the imaging modality of choice for surgical placement of implants.[26]

b. Traumatic Injuries:

Recommendation 11: Limited FOV CBCT should be considered the imaging modality of choice for diagnosis and management of limited dento-alveolar trauma, root fractures, luxation, and /or displacement of teeth and localized alveolar fractures, in the absence of other maxillofacial or soft tissue injury that may require other advanced imaging modalities.[27]

c. Resorptive Defects:

Recommendation 12: Limited FOV CBCT is the imaging modality of choice in the localization and differentiation of external and internal resorptive defects and the determination of appropriate treatment and prognosis.[28,29]

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CHAPTER 3

Case Selection and Treatment Planning

PAUL A. ROSENBERG | MATTHEW MALEK

CHAPTER OUTLINE

The process of case selection and treatment planning begins after a clinician has diagnosed an endodontic problem. The clinician must determine whether the patient's oral health needs are best met by providing endodontic treatment and maintaining the tooth or by advising extraction. The use of rotary instruments, ultrasonics, and microscopy as well as new materials has made it possible to predictably retain teeth that previously would have been extracted. In addition, even teeth that have failed initial endodontic treatment can often be successfully retreated using nonsurgical or surgical procedures.

Increased knowledge concerning the importance of anxiety control, premedication with a nonsteroidal anti-inflammatory drug (NSAID) or acetaminophen, profound local anesthesia, appropriate occlusal adjustment, and biology-based clinical procedures enables clinicians to complete endodontic procedures without intraoperative or posttreatment pain.

Questions concerning tooth retention and possible referral can be answered only after a complete patient evaluation. The evaluation must include assessment of medical, psychosocial, and dental factors as well as consideration of the relative complexity of the endodontic procedure. Although most medical conditions do not contraindicate endodontic treatment, some can influence the course of treatment and require specific modifications. A number of valuable texts are available that review the subject of dental care for the medically compromised patient.[14,48,110] The American Academy of Oral Medicine (Edmonds, WA) has an excellent website (www.aaom.com) that can be used to elicit information about medically compromised patients.

Perhaps the most important advice for a clinician who plans to treat a medically compromised patient is to be prepared to communicate with the patient's physician. The proposed treatment can be reviewed, and medical recommendations should be documented. Fig. 3-1 depicts a sample medical consultation letter that can be modified as necessary.

The American Society of Anesthesiologists (ASA; Park Ridge, IL) Physical Status Classification system is commonly used to express medical risk (Box 3-1). The ASA classification system remains the most widely used assessment method for preanesthetic patients despite some inherent limitations to its use as a peritreatment risk predictor. This classification system is a generally accepted and useful guide for pretreatment assessment of relative risk but does not advise appropriate treatment modifications. The clinician should go beyond the classification system and gather more information from the patient and physician, including the patient's compliance with suggested medication, frequency of physician visits, and most recent visit.

Typical questions include the following: *Do you take medication as prescribed by your physician?* Or, *when was the last time you were examined by your physician?* Other systems have been proposed that would better reflect the increasing number of

Michael White, MD
1 Walker Street
Brown City, OK

Dear Dr. White,

Your patient, Ms. Mary Smith, presented for consultation on August 10, 2009, concerning tooth #19. The tooth is asymptomatic at this time, but a small (4 mm x 3 mm), well-circumscribed periradicular radiolucency associated with the palatal root was noted on radiographic examination. The tooth was tested for vitality using thermal and electrical modalities and found to be nonvital, indicating an odontogenic cause for the lesion. The tooth will require endodontic treatment in order to be maintained. The prognosis for nonsurgical endodontic treatment in this case is good. I anticipate that her dental medication plan would include lidocaine with epinephrine for anesthesia and ibuprofen for postoperative pain control.

In a review of the patient's medical history she noted that she is being treated for a malignancy of the thyroid gland and is undergoing radiation therapy. She was unable to provide more specific information about her treatment.

I would appreciate information regarding her ability to undergo endodontic treatment at this time. Please call me if there is further information that you would require concerning the dental treatment to be provided. Thank you.

Yours truly,

Peter Jones, DDS

FIG. 3-1 Sample medical consultation letter.

BOX 3-1

American Society of Anesthesiologists Physical Status Classification System

P1: Normal, healthy patient; no dental management alterations required

P2: Patient with mild systemic disease that does not interfere with daily activity or who has a significant health risk factor (e.g., smoking, alcohol abuse, gross obesity)

P3: Patient with moderate to severe systemic disease that is not incapacitating but may alter daily activity

P4: Patient with severe systemic disease that is incapacitating and a constant threat to life

From: www.asahq.org/clinical/physicalstatus.htm.

medically complex patients treated by clinicians as Americans live longer.[35] Regardless of the classification system used, these generalized guidelines need to be individualized for the patient under care.

An alternative means of considering risk assessment is to review the following issues:

- History of allergies
- History of drug interactions, adverse effects
- Presence of prosthetic valves, joints, stents, pacemakers, and so on
- Antibiotics required (prophylactic or therapeutic)
- Hemostasis (normal expected, modification to treatment)
- Patient position in chair
- Infiltration or block anesthesia with or without vasoconstrictor
- Significant equipment concerns (radiographs, ultrasonics, electrosurgery)
- Emergencies (potential for occurrence, preparedness)
- Anxiety (past experiences and management strategy)

A review of these areas provides the clinician with essential background data before initiating treatment.

COMMON MEDICAL FINDINGS THAT MAY INFLUENCE ENDODONTIC TREATMENT PLANNING

Cardiovascular Disease

Patients with some forms of cardiovascular disease are vulnerable to physical or emotional stress that may be encountered during dental treatment, including endodontics. Patients may be confused or ill informed concerning the specifics of their particular cardiovascular problem. In these situations, consultation with the patient's physician is mandatory before the initiation of endodontic treatment. "For patients with symptoms of unstable angina or those who have had an MI [myocardial infarction] within the past 30 days (major risk category), elective care should be postponed."[48] One study found "no significant increase in the risk of experiencing a second vascular event after dental visits, including those that involved invasive procedures, in periods up to 180 days after a first recorded ischemic stroke, transient ischemic attack (TIA) or acute MI."[94]

The use of vasoconstrictors in local anesthetics poses potential problems for patients with ischemic heart disease. In these patients, local anesthetics without vasoconstrictors may be used as needed. If a vasoconstrictor is necessary, patients with intermediate clinical risk factors (i.e., a past history of MI without ischemic symptoms) and those taking nonselective beta-blockers can safely be given up to 0.036 mg epinephrine (two cartridges containing 1:100,000 epinephrine) at one appointment. For patients at higher risk (i.e., those who have had an MI within the past 7 to 30 days and unstable angina), the use of vasoconstrictors should be discussed with the physician.[48]

Vasoconstrictors may interact with some antihypertensive medications and should be used only after consultation with the at-risk patient's physician. Local anesthetic agents with minimal or no vasoconstrictors are usually adequate for nonsurgical endodontic procedures[48] (see also Chapter 4). A systematic review of the cardiovascular effects of epinephrine concluded that the increased risk for adverse events among uncontrolled hypertensive patients was low, and the reported adverse events associated with epinephrine use in local anesthetics was minimal.[4] Another review highlighted the advantages of including a vasoconstrictor in the local anesthesia and stated that "pain control was significantly impaired in those patients receiving the local anesthetic without the vasoconstrictor as compared to those patients receiving the local anesthetic with vasoconstrictor."[13]

A patient who has specific heart conditions may be susceptible to an infection of the heart valves, induced by a bacteremia. This infection is called *infective* or *bacterial endocarditis* and is potentially fatal. In 2008, the American College of Cardiology and American Heart Association (AHA) Task Force on Practice Guidelines published an update on their previous guidelines, which focused on infectious endocarditis. This guideline stated that "prophylaxis against infective endocarditis is reasonable for the following patients at highest risk for adverse outcomes from infective endocarditis who undergo dental procedures that involve manipulation of either gingival tissue or the periapical region of teeth or perforation of the oral mucosa: patients with prosthetic cardiac valves or prosthetic material used for cardiac valve repair . . . , patients with previous infective endocarditis . . . [and] patients with congenital heart disease."[71]

The specific recommendations are summarized in a reference guide by the American Association of Endodontists (AAE; Chicago, IL), found online at www.aae.org/uploadedfiles/publications_and_research/guidelines_and_position_statements/antibioticprophylaxsisquickrefguide.pdf). Because the AHA periodically revises its recommended antibiotic prophylactic regimen for dental procedures, it is essential that the clinician stay current concerning this important issue. There is a low compliance rate among at-risk patients regarding their use of the suggested antibiotic coverage before dental procedures. Therefore, the clinician must question patients concerning their compliance with the prescribed prophylactic antibiotic coverage before endodontic therapy. If a patient has not taken the antibiotic as recommended, it may be administered up to 2 hours after the procedure.[71]

Patients with artificial heart valves are considered susceptible to bacterial endocarditis. Consulting the patient's physician in such cases regarding antibiotic premedication is essential. Some physicians elect to administer parenteral antibiotics in addition to or in place of the oral regimen.

A dentist may be the first to detect elevated blood pressure if he or she routinely evaluates blood pressure before treatment. Furthermore, patients receiving treatment for hypertension may not be controlled adequately because of poor compliance or inappropriate drug therapy. Abnormal blood pressure readings may be the basis for physician referral.

Some patients may be disposed to serious life-threatening complications due to stress. Acute heart failure during a stressful dental procedure in a patient with significant valvular disease and heart failure or the development of infectious endocarditis represent two such life-threatening disorders.[91] Careful evaluation of patients' medical histories including the cardiac status of patients, the use of appropriate prophylactic antibiotics, and stress reduction strategies will minimize the risk of serious cardiac sequelae.

There is a widespread belief among dentists and physicians that oral anticoagulation therapy in which patients receive drugs such as warfarin (Coumadin) must be discontinued before dental treatment to prevent serious hemorrhagic complications, especially during and after surgical procedures. Aspirin is a drug commonly used as an anticoagulant on a daily basis without the supervision of a physician. Clinical studies do not support the routine withdrawal of anticoagulant therapy before dental treatment for patients who are taking such medications.[10,39,48]

When patients report they are receiving an anticoagulant medication, they can benefit from the clinician using the following guidelines:

- Identify the reason why the patient is receiving anticoagulant therapy.
- Assess the potential risk versus benefit of altering the drug regimen.
- Know the laboratory tests used to assess anticoagulation levels (i.e., the international normalized ratio [INR] value should be 3.5 or less for patients who are taking warfarin to safely undergo dental or surgical endodontic procedures).[48] Be familiar with methods used to obtain hemostasis both intraoperatively and postoperatively.
- Be familiar with the potential complications associated with prolonged or uncontrolled bleeding.
- Consult the patient's physician to discuss the proposed dental treatment and to determine the need to alter the anticoagulant regimen.

Another cardiac complication may occur in patients with Hodgkin disease or breast cancer, who often receive irradiation to the chest as an element of treatment. Although the therapy often cures the malignancy, it has been implicated in causing late-onset heart disease that may influence the development of a treatment plan and subsequent treatment. Dentists must identify patients who have received irradiation to the chest and consult with patients' physicians to determine whether that therapy has damaged the heart valves or coronary arteries. Patients with radiation-induced valvular disease may require prophylactic antibiotics when undergoing specific dental procedures that are known to cause a bacteremia and a heightened risk of developing endocarditis. Patients with radiation-induced coronary artery disease should be administered only limited amounts of local anesthetic agents containing a vasoconstrictor. They may require the administration of sedative agents and cardiac medications to preclude ischemic episodes. Consultation with the patient's physician is an appropriate response when a patient presents with a history that includes prior radiation to the chest.[29]

Diabetes

The Centers for Disease Control and Prevention (CDC, Atlanta, GA) in 2011 reported that 25.8 million people, or 8.3% of the U.S. population, have diabetes. There were also about 1.9 million people aged 20 years or older newly diagnosed with diabetes in 2010. (See Centers for Disease Control and

Prevention *Diabetes Fact Sheet*, available at http://cdc.gov/diabetes/pubs/estimates11.htm#2, 2011.) Diabetes is the seventh leading cause of death in the United States,[61] and, according to the *Diabetes Fact Sheet*, the risk for death among people with diabetes is about twice that of people of similar age but without diabetes. It is likely that patients with diabetes who require endodontic treatment will be increasingly common.

Diabetes mellitus appears to have multiple causes and several mechanisms of pathophysiology.[48] It can be thought of as a combination of diseases that share the key clinical feature of glucose intolerance. Patients with diabetes, even those who are well controlled, require special consideration during endodontic treatment. The patient with well-controlled diabetes, who is free of serious complications such as renal disease, hypertension, or coronary atherosclerotic disease, is a candidate for endodontic treatment. However, special considerations exist in the presence of acute infections. The non–insulin-controlled patient may require insulin, or the insulin dose of some insulin-dependent patients may have to be increased.[79] When surgery is required, consultation with the patient's physician is advisable in order to consider adjustment of the patient's insulin dosage, antibiotic prophylaxis, and dietary needs during the posttreatment period.

The clinician should ask patients with diabetes who self-monitor their glucose levels to bring a glucometer to each visit. If pretreatment glucose levels are below normal fasting range (80 to 120 mg/dl), it may be appropriate to take in a carbohydrate source.[100] A source of glucose (e.g., glucose tablets, orange juice, or soda) should be available if signs of insulin shock (hypoglycemic reaction caused by overcontrol of glucose levels) occur.[48] Signs and symptoms of hypoglycemia include confusion, tremors, agitation, diaphoresis, and tachycardia.[100] The clinician can avoid a hypoglycemic emergency by taking a complete, accurate history of the time and amount of the patient's insulin and meals. When questions arise concerning the appropriate course to follow, the patient's physician should be contacted or treatment deferred.

Appointments should be scheduled with consideration given to the patient's normal meal and insulin schedule.[79] Usually, a patient with diabetes who is well managed medically and is under good glycemic control without serious complications such as renal disease, hypertension, or coronary atherosclerotic heart disease can receive any indicated dental treatment.[57] However, patients with diabetes who have serious medical complications may need a modified dental treatment plan. For instance, although prophylactic antibiotics generally are not required, it "may be prescribed a patient with brittle (very difficult to control) diabetes for whom an invasive procedure is planned but whose oral health is poor and the fasting plasma glucose exceeds 200 mg/dL."[48] Local anesthesia would not be an issue in the presence of well-controlled diabetes, "but for patients with concurrent hypertension or history of recent myocardial infarction, or with a cardiac arrhythmia, the dose of epinephrine should be limited to no more than two cartridges containing 1 : 100,000 epinephrine."[48]

Inadequate diabetic control may predispose such patients to several oral infections, including dental pulp infection.[45] One study determined that although apical periodontitis may be significantly more prevalent in untreated teeth in patients with type 2 diabetes, the disease does not seem to influence the response to root canal treatment.[52] However, other studies suggest that diabetes is associated with a decrease in the success of endodontic treatment in cases with pretreatment periradicular lesions.[12,28] In a prospective study on the impact of systemic diseases on the risk of tooth extraction, it has been also shown that an increased risk of tooth extraction after nonsurgical root canal treatment was significantly associated with diabetes mellitus, hypertension, and coronary heart disease.[103] Patients with diabetes and other systemic diseases may be best served by referral to an endodontist for treatment planning.

Pregnancy

Although pregnancy is not a contraindication to endodontics, it does modify treatment planning. Protection of the fetus is a primary concern when administration of ionizing radiation or drugs is considered. Of all the safety aids associated with dental radiography, such as high-speed film, digital imaging, filtration, and collimation, the most important is the protective lead apron with thyroid collar.[5,107] Although drug administration during pregnancy is a controversial subject, Box 3-2 presents commonly used dental drugs usually compatible with both pregnancy and breast-feeding. Based on U.S. Food and Drug Administration pregnancy risk factor definitions,[35] local anesthetics administered with epinephrine generally are considered safe for use during pregnancy and are assigned to the pregnancy risk classification categories B and C. (See www.fda.gov/Drugs/DevelopmentApprovalProcess/DevelopmentResources/Labeling/ucm093310.htm.) Few anxiolytics are considered safe to use during pregnancy. However, a single, short-term exposure to nitrous oxide–oxygen (N_2O-O_2) for less than 35 minutes is not thought to be associated with any human fetal anomalies, including low birth weight.[48] If a need exists for antibiotic therapy, penicillins, cephalosporins, and macrolides are considered first-line agents.

The analgesic of choice during pregnancy had been acetaminophen (category B).[78] However, a link between acetaminophen and childhood asthma has been suggested. Research has found that "the use of acetaminophen in middle to late but not early pregnancy may be related to respiratory symptoms in the first year of life."[74] This finding, although not completely validated, should be discussed with pregnant patients when an analgesic is being considered. Aspirin and nonsteroidal anti-inflammatory drugs also convey risks for constriction of the ductus arteriosus, as well as for postpartum hemorrhage and delayed labor.[78]

A major concern is that a drug may cross the placenta and be toxic or teratogenic to the fetus. In addition, any drug that is a respiratory depressant can cause maternal hypoxia, resulting in fetal hypoxia, injury, or death. Ideally, no drug should be administered during pregnancy, especially during the first trimester. If a specific situation makes adherence to this rule

BOX 3-2

Partial List of Drugs Usually Compatible with Both Pregnancy and Breast-Feeding

- Local anesthetics including lidocaine, etidocaine, and prilocaine
- Many antibiotics including penicillins, clindamycin, and azithromycin
- Acetaminophen
- Acyclovir
- Prednisone
- Antifungals including fluconazole and nystatin

difficult, then the clinician should review the appropriate current literature and discuss the case with the physician and patient.[11,55,60]

Further considerations exist during the postpartum period if the mother breast-feeds her infant. A clinician should consult the responsible physician before using any medications for the nursing mother. Alternative considerations include using minimal dosages of drugs, having the mother bank her milk before treatment, having her feed the child before treatment, or suggesting the use of a formula for the infant until the drug regimen is completed. Limited data are available on drug dosages and the effects on breast milk.[48]

In terms of treatment planning, elective dental care is best avoided during the first trimester because of the potential vulnerability of the fetus. The second trimester is the safest period in which to provide routine dental care. Complex surgical procedures are best postponed until after delivery.

Malignancy

Some malignancies may metastasize to the jaws and mimic endodontic pathosis, whereas others can be primary lesions (Fig. 3-2). The most common malignancies metastasize to the jaws are breast, lung, thyroid, and prostate.[53] A panoramic radiograph and a cone-beam computer tomography image are useful in providing an overall view of all dental structures. When a clinician begins an endodontic procedure on a tooth with a well-defined apical radiolucency, it might be assumed to result from a nonvital pulp. Pulp testing is essential to confirm a lack of pulp vitality in such cases. A vital response in such cases indicates a nonodontogenic lesion.

Careful examination of pretreatment radiographs from different angulations is important because lesions of endodontic origin would not be expected to be shifted away from the radiographic apex in the various images. Alternative methods, such a cone-beam computed tomography (CBC), may provide important diagnostic information (see Chapter 2).

A useful website for the differential diagnosis of radiographic lesions (Oral Radiographic Differential Diagnosis [ORAD] II) is available online at www.orad.org/index.html. A definitive diagnosis of periradicular lesions can be made only after biopsy. When a discrepancy exists between the initial diagnosis and clinical findings, consultation with an endodontist is advisable.

Patients undergoing chemotherapy or radiation to the head and neck may have impaired healing responses.[48] Treatment should be initiated only after the patient's physician has been

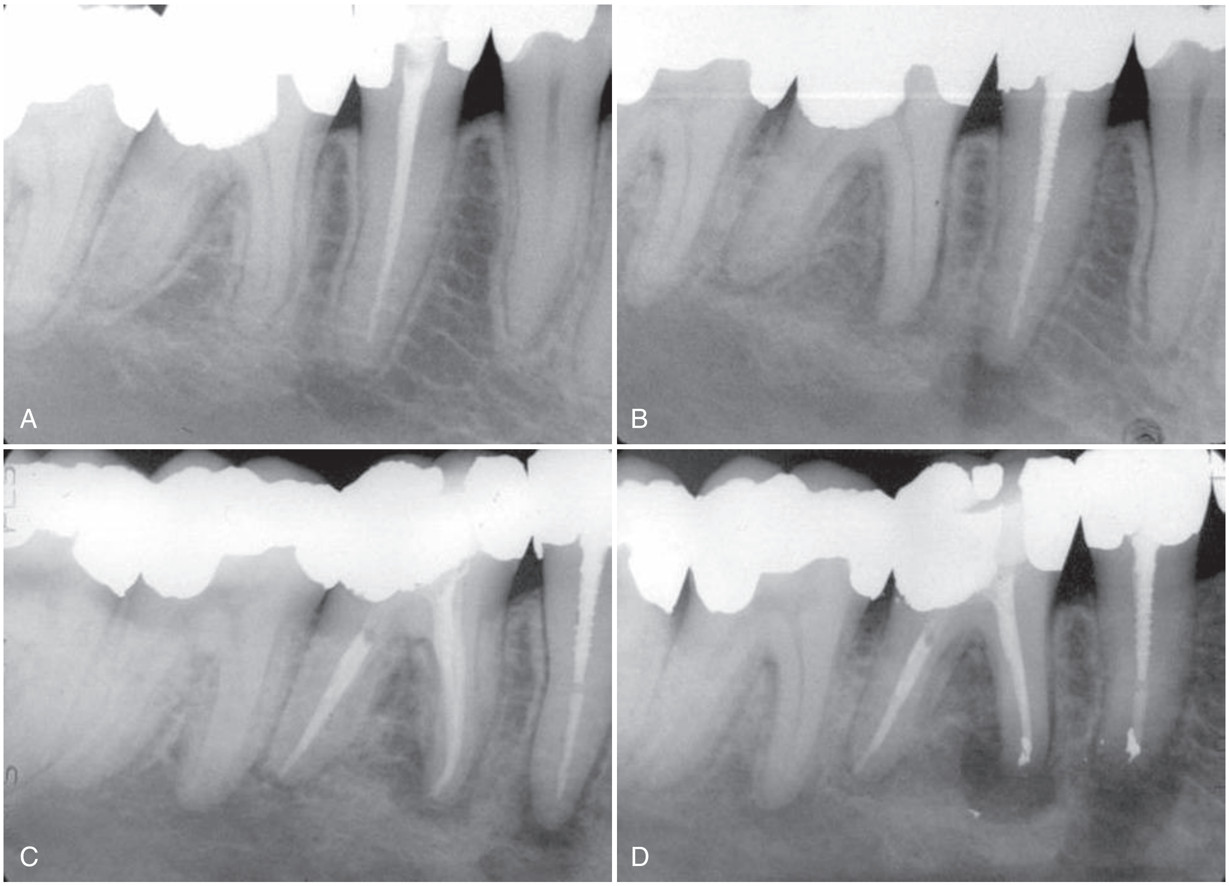

FIG. 3-2 A, Periapical view of tooth #29 after endodontic treatment by a general dental clinician. The diagnosis was irreversible pulpitis. B, Patient was referred to an endodontist 4 months later to evaluate radiolucencies of teeth #29 and #30. Symptoms indicated irreversible pulpitis of tooth #30, with concurrent lower right lip and chin paresthesia. Past medical history revealed breast cancer in remission. C, Nonsurgical endodontics was performed on tooth #30. Immediate referral was made to an oncologist/oral surgeon for biopsy to rule out nonodontogenic origin of symptoms. D, Surgical posttreatment radiograph of teeth #29 and #30. The biopsy report confirmed metastatic breast cancer. (Courtesy Dr. R. Sadowsky, Dr. L. Adamo, and Dr. J. Burkes.)

consulted. A dialogue among the dentist, physician, and patient is required prior to determining whether a tooth or teeth should be extracted or endodontically treated prior to radiation.

The effect of the external beam of radiation therapy on normal bone is to decrease the number of osteocytes, osteoblasts, and endothelial cells, thus decreasing blood flow. Pulps may become necrotic from this impaired condition.[48] Toxic reactions during and after radiation and chemotherapy are directly proportional to the amount of radiation or dosage of cytotoxic drug to which the tissues are exposed. Delayed toxicities can occur several months to years after radiation therapy.

Oral infections and any potential problems should be addressed before initiating radiation. It is advised that symptomatic nonvital teeth be endodontically treated at least 1 week before initiating radiation or chemotherapy, whereas treatment of asymptomatic nonvital teeth may be delayed.[48] The outcome of endodontic treatment should be evaluated within the framework of the toxic results of radiation and drug therapy. The white blood cell (WBC) count and platelet status of a patient undergoing chemotherapy should also be reviewed before endodontic treatment. In general, routine dental procedures can be performed if the granulocyte count is greater than 2000/mm^3 and the platelet count is greater than 50,000/mm^3. If urgent care is needed and the platelet count is below 50,000/mm^3, consultation with the patient's physician is required.[48]

Medication-Related Osteonecrosis of the Jaws (MRONJ)

Bisphosphonates offer great benefits to patients at risk of bone metastases and in the prevention and treatment of osteoporosis, although this and other drugs (e.g., denosumab) are associated with a rare occurrence of osteonecrosis.

To distinguish medication-related osteonecrosis of the jaws (MRONJ) from other delayed healing conditions, the following working definition of MRONJ has been adopted by the American Association of Oral and Maxillofacial Surgeons (AAOMS): Patients may be considered to have MRONJ if all of the following three characteristics are present (see American Association of Oral and Maxillofacial Surgeons: Position paper on Bisphosphonate-Related Osteonecrosis of the Jaw—2014 update, available at www.aaoms.org/docs/position_papers/mronj_position_paper.pdf?pdf=MRONJ-Position-Paper):

1. Current or previous treatment with an antiresorptive drug such as a bisphosphonate or an antiangiogenic drug (e.g., sunitinib [Sutent], sorafenib [Nexavar], bevacizumab (Avastin), or sirolimus (Rapamune)
2. Exposed, necrotic bone in the maxillofacial region that has persisted for more than 8 weeks
3. No history of radiation therapy to the jaws

A patient's risk of developing osteonecrosis of the jaw while receiving oral bisphosphonates appears to be low, but there are factors known to increase the risk for MRONJ (Box 3-3). According to the American Association of Endodontists (available at www.aae.org/uploadedFiles/Publications_and_Research/Guidelines_and_Position_Statements/bisphosonatesstatement.pdf, 2012), such risks include a history of taking bisphosphonates, especially intravenous (IV) formulations, previous history of cancer, and a history of a traumatic dental procedure. In addition to the usual risk factors, patients receiving high-dose IV bisphosphonates for more than 2 years are at most risk for developing osteonecrosis of the jaw.

BOX 3-3

Risk Factors for Development of Bisphosphonate-Associated Osteonecrosis

- History of taking bisphosphonates for more than 2 to 3 years, especially with intravenous therapy
- History of cancer, osteoporosis, or Paget disease
- History of traumatic dental procedure
- Patient more than 65 years of age
- History of periodontitis
- History of chronic corticosteroid use
- History of smoking
- History of diabetes

It has been reported that patients with multiple myeloma and metastatic carcinoma to the skeleton who are receiving intravenous, nitrogen-containing bisphosphonates are at greatest risk for osteonecrosis of the jaws. These patients represent 94% of published cases. The mandible is more commonly affected than the maxilla (2:1 ratio), and 60% of cases are preceded by a dental surgical procedure.[108] Treatment outcomes of MRONJ are unpredictable, and prevention strategies are extremely important.

Management of high-risk patients might include nonsurgical endodontic treatment of teeth that otherwise would be extracted. The combination of orthodontic extrusion and bloodless extraction—exfoliation of the extruded roots after their movement—has also been suggested with the aim of minimizing trauma and enhancing the health of the surrounding tissues in patients at risk of developing MRONJ or when a patient refuses to undergo conventional tooth extraction.[95]

For patients at higher risk of MRONJ, surgical procedures such as extractions, endodontic surgery, or placement of dental implants should be avoided. (See www.aae.org/uploadedFiles/Publications_and_Research/Guidelines_and_Position_Statements/bisphosonatesstatement.pdf, 2012.) Sound oral hygiene and regular dental care may be the best approach to lowering the risk of MRONJ. Patients taking bisphosphonates and undergoing endodontic therapy should sign an informed consent form, inclusive of the risks, benefits, and alternative treatment plans. The following recommendations have been suggested to reduce the risk of MRONJ associated with endodontic treatment[58]:

- Apply a 1-minute mouth rinse with chlorhexidine prior to the start of the treatment with the aim of lowering the bacterial load of the oral cavity.
- Avoid the use of anesthetic agents with vasoconstrictors in order to prevent impairment of tissue vascularization.
- Work under aseptic conditions, including removing of all caries and placement of rubber dam prior to intracanal procedures.
- Avoid damage to the gingival tissues during the placement of rubber dam.
- Avoid maintaining patency of the apical foramen to prevent bacteremia.
- Use techniques that reduce the risk of overfilling and overextension.

Aggressive use of systemic antibiotics is indicated in the presence of an infection in a patient taking bisphosphonates.[48] Discontinuing bisphosphonate therapy may not eliminate any risk of developing MRONJ.[51,54,56] Some clinicians have proposed use of the CTX (C-terminal telopeptide of type I collagen α_1 chain) test (Quest Diagnostics, Madison, NJ) for assessing the risk of developing bone osteonecrosis (BON). For patients who have developed MRONJ, close coordination with an oral maxillofacial surgeon or oncologist is highly recommended.

An astute awareness of the potential risk of MRONJ in patients receiving bisphosphonate therapy is critical. Increased attentiveness to the prevention, recognition, and management of MRONJ will allow the clinician to make the best treatment decisions. Our knowledge of MRONJ is developing rapidly and it is essential that the clinician monitor the literature for changes in treatment protocols.[51,54,56]

Human Immunodeficiency Virus (HIV) and Acquired Immunodeficiency Syndrome (AIDS)

From 1987 through 1994, HIV disease mortality increased and reached a plateau in 1995. Subsequently, the mortality rate for this disease decreased an average of 33% per year from 1995 through 1998, and 5.5% per year from 1999 through 2009.[61] This dramatic improvement seems to be due to the use of a combination of highly active antiretroviral therapy (HAART) and improved preventive strategies.[48]

It is important, when treating patients with AIDS, that the clinician understand the patient's level of immunosuppression, drug therapies, and the potential for opportunistic infections. Although the effect of HIV infection on long-term prognosis of endodontic therapy is unknown, it has been demonstrated that clinicians may not have to alter their short-term expectations for periapical healing in patients infected with HIV.[77] The clinical team must also minimize the possibility of transmission of HIV from an infected patient, and this is accomplished by adherence to universal precautions. (See Universal Precautions for Prevention of Transmission of HIV and Other Bloodborne Infections, available at www.cdc.gov/niosh/topics/bbp/universal.html.)

Although saliva is not the main route for transmission of HIV, the virus has been found in saliva and its transmission through saliva has been reported.[33] Infected blood can transmit HIV, and during some procedures it may become mixed with saliva. Latex gloves and eye protection are essential for the clinician and staff. HIV can be transmitted by needlestick or via an instrument wound, but the frequency of such transmission is low, especially with small-gauge needles. Nevertheless, "Patients at high risk for AIDS and those in whom AIDS or HIV has been diagnosed should be treated in a manner identical to that for any other patient—that is, with standard precautions."[48]

A vital aspect of treatment planning for the patient with HIV/AIDS is to determine the current $CD4^+$ lymphocyte count and level of immunosuppression. In general, patients having a $CD4^+$ cell count exceeding 350 cells/mm^3 may receive all indicated dental treatments. Patients with a $CD4^+$ cell count of less than 200 cells/mm^3 or severe neutropenia (neutrophil count lower than 500/μL) will have increased susceptibility to opportunistic infections and may be effectively medicated with prophylactic drugs. White blood cell and differential counts, as well as a platelet count, should be ordered before any surgical procedure is undertaken. Patients with severe thrombocytopenia may require special measures (platelet replacement) before surgical procedures. Care in prescribing medications must also be exercised with any medications after which the patient may experience adverse drug effects, including allergic reactions, toxic drug reactions, hepatotoxicity, immunosuppression, anemia, serious drug interactions, and other potential problems. The practitioner should also be aware of oral manifestations of the disease as far as it concerns diagnosis and treatment planning. For instance, candidiasis of the oral mucosa, Kaposi sarcoma, hairy leukoplakia of the lateral borders of the tongue, herpes simplex virus (HSV), herpes zoster, recurrent aphthous ulcerations, linear gingival erythema, necrotizing ulcerative periodontitis, necrotizing stomatitis, oral warts, facial palsy, trigeminal neuropathy, salivary gland enlargement, xerostomia, and melanotic pigmentation are all reported to be associated with HIV infection. It is essential that consultation with the patient's physician occurs before performing surgical procedures or initiating complex treatment plans.[48,86]

End-Stage Renal Disease and Dialysis

Consultation with the patient's physician is important before dental care is initiated for patients being treated for end-stage renal disease. Depending on the patient's status and the presence of other diseases common to renal failure (e.g., diabetes mellitus, hypertension, and systemic lupus erythematosus), dental treatment may be best provided in a hospital setting. The goal of dental care for patients being treated for end-stage renal disease is to slow the progression of dental disease and preserve the patient's quality of life.[48,76]

The most recent American Heart Association guidelines do not include a recommendation for prophylactic antibiotics before invasive dental procedures for patients receiving dialysis with intravascular access devices, unless an abscess is being incised and drained.[3,48] Because controversy exists about the need for prophylactic antibiotics, consultation with the physician is important for patients receiving hemodialysis and those who have known cardiac risk factors. When prophylaxis is used, the standard regimen of the American Heart Association is recommended.[3]

Some drugs frequently used during endodontic treatment are affected by dialysis. Drugs metabolized by the kidneys and nephrotoxic drugs should be avoided. Both aspirin and acetaminophen are removed by dialysis and require a dosage adjustment in patients with renal failure. Amoxicillin and penicillin also require dosage adjustment as well as a supplemental dosage subsequent to hemodialysis.[76] It is advisable to consult the patient's physician concerning specific drug requirements during endodontic treatment. Endodontic treatment is best scheduled on the day after dialysis. On the day of dialysis, patients are generally fatigued and could have a bleeding tendency.[48]

Chronic renal failure is a disorder that may stimulate secondary hyperparathyroidism that can cause a variety of bone lesions. In some instances, these lesions appear in the periapical region of teeth and can lead to a misdiagnosis of a lesion of endodontic origin.[50]

Prosthetic Implants

Patients with prosthetic implants are frequently treated in dental practices. The question concerning the need for antibiotic prophylaxis to prevent infection of the prosthesis has been debated for many years. A statement was issued jointly in 2003 by the American Dental Association (ADA; Chicago, IL) and the American Academy of Orthopaedic Surgeons (AAOS; Rosemont, IL) in an attempt to clarify the issue.[1] The statement concluded that scientific evidence does not support the need for antibiotic prophylaxis for dental procedures to prevent prosthetic joint infections. It went on to state that antibiotic prophylaxis is not indicated for dental patients with pins, plates, and screws, nor is it routinely indicated for most patients with total joint replacements. However, the statement indicated that some "high-risk patients" who are at increased risk for infection and undergoing dental procedures likely to cause significant bleeding should receive antibiotic prophylactic treatment. Such patients would include those who are immunocompromised or immunosuppressed, who have insulin-dependent (type 1) diabetes, who are in the first 2 years following joint replacement, or who have previous joint infections, malnourishment, or hemophilia.[1] The advisory statement concludes that the final decision on whether to provide antibiotic prophylaxis is the responsibility of the clinician, who must consider potential benefits and risks.[1] It should be noted that although endodontics has been shown to be a possible cause of bacteremia,[19,90] the risk is minimal in comparison with extractions, periodontal surgery, scaling, and prophylaxis.[72] In February 2009, the AAOS published a statement entitled "Antibiotic Prophylaxis for Bacteremia in Patients with Joint Replacements." In this updated publication it was stated: "Given the potential adverse outcomes and cost of treating an infected joint replacement, the AAOS recommends that clinicians consider antibiotic prophylaxis for all total joint replacement patients prior to any invasive procedure that may cause bacteremia." (See American Academy of Orthopaedic Surgeons: AAOS releases new statement on antibiotics after arthroplasty, www.aaos.org/news/aaosnow/may09/cover2.asp, 2012.)

However, the American Academy of Oral Medicine's (AAOM) position on this statement is that the "2009 information statement is more an opinion than an official guideline, AAOM believes that it should not replace the 2003 joint consensus statement prepared by the relevant organizations: the ADA, the AAOS and the Infectious Disease Society of America (IDSA)."[49] In 2012, an evidenced-based guideline was published that included recommendations of the AAOS-ADA clinical practice guideline for Prevention of Orthopaedic Implant Infection in Patients Undergoing Dental Procedures. This guideline stated that there is limited evidence for discontinuing the practice of routinely prescribing prophylactic antibiotics for patients with hip and knee prosthetic joint implants undergoing dental procedures. (See American Academy of Orthopaedic Surgeons: Prevention of orthopaedic implant infection in patients undergoing dental procedures, available at www.aaos.org/research/guidelines/PUDP/PUDP_guideline.pdf, 2012.)

Consultation with the patient's physician on a case-by-case basis is advisable to assess the need for prophylaxis.

Behavioral and Psychiatric Disorders

Stress reduction is an important factor in the treatment of patients with behavioral and psychiatric disorders. Sensitivity to the patient's needs must be part of the dental team's approach. Significant drug interactions and side effects are associated with tricyclic antidepressants, monoamine oxidase inhibitors, and antianxiety medications.[48] Consultation with physicians in such cases is essential before using sedatives, hypnotics, antihistamines, or opioids.

Psychosocial Evaluation

The initial visit, during which medical and dental histories are gathered, provides an opportunity to consider the patient's psychosocial status. Although some patients may want to maintain a tooth with a questionable prognosis, others may lack the ability to comprehend the potential risks and benefits. It would be a mistake to lead patients beyond what they can appreciate, and patients should not be allowed to dictate treatment that has a poor prognosis.

The clinician should also assess the patient's level of anxiety as an important part of preparation for the procedure to follow. It is reasonable to assume that most patients are anxious to some degree, especially when they are about to undergo endodontic treatment. A conversation describing the procedure and what the patient can expect is an important part of an anxiety-reduction protocol. It is well documented that a high level of anxiety is a predictor of poor anesthesia and posttreatment pain.[15,62] More than 200 studies indicate that behavioral intervention for the highly anxious patient before treatment decreases anxiety before and after surgery, reduces posttreatment pain, and accelerates recovery.[15]

DEVELOPMENT OF THE ENDODONTIC TREATMENT PLAN

The strategic value of a tooth in question should be considered before presenting alternative treatment plans to the patient. Although some decisions may be straightforward, considering alternative treatment options can be challenging as the clinician weighs multiple factors that will play a role in determining the ultimate success or failure of the case. Referral of the patient to a specialist should be considered when the complexity of a procedure is beyond the ability of a clinician. Factors that affect endodontic prognosis, including periodontal and restorative considerations, must be considered. The alternative of a dental implant is another choice when the endodontic prognosis is poor.

ENDODONTIC PROGNOSIS

Prognostic studies have identified a number of preoperative factors affecting the outcome of primary endodontic treatment. In a systematic review, it was determined that the absence of periapical radiolucency improves the outcome of root canal treatment significantly. The same study also showed that tooth vitality does not have an impact on the endodontic prognosis, as long as the periapex is healthy.[70] Studies have shown that the size of the radiolucency may also affect the outcome of endodontic treatment.[31,70] Another study found that the existence of sinus tract, narrow but deep periodontal probing depth, pain, and discharging sinus have a significant effect on the outcome of nonsurgical root canal treatment.[67] Preoperative pain is not only one of the most important predictors for postoperative pain,[64] it also has an impact on tooth survival after endodontic treatment.[68]

These findings suggest that all preexisting signs and symptoms that could affect the prognosis of treatment, along with the prognostic factors associated with other disciplines—which will be discussed in the next segment—should be taken into consideration when developing a treatment plan. It is of utmost importance that the prognosis and risks and benefits of the treatment be relayed to the patient before the initiation of the treatment as well.

There is a general belief that the prognoses for retreatment cases are less than those for primary treatment, but this is not universally supported. In a systematic review it was suggested that the outcome of retreatment cases should be similar to treatment cases as long as access to the apical infection can be reestablished.[65] However, there is some evidence indicating that the incidence of postoperative pain and flare-up is higher in retreatment cases in comparison to treatments.[36] The presence of preoperative periapical lesion, apical extent of root filling, and quality of coronal restoration has been proved to significantly affect the outcome of retreatment cases.[65]

Retreatment cases offer a particular set of challenges to the clinician (Figs. 3-3 and 3-4), and this topic is covered extensively in Chapter 8. Important questions to be considered before retreatment include the following:

- Why did the treatment fail?
- Can the point of bacterial entry to the canal space be identified?
- Are prior radiographs available for review?
- Is there an obvious procedural problem that can be corrected?
- Is the canal system readily accessible for reentry?
- Are there additional factors (other than endodontic) that may have contributed to the failure?
- Is the tooth critical to the treatment plan?
- Does the patient understand the prognosis for the tooth and want to attempt retreatment?

A retreatment plan should be developed after the clinician has determined the cause of failure and weighed other factors that may affect the prognosis (e.g., root fracture, defective restoration) (Figs. 3-5 to 3-8). Retreatment cases may require surgical endodontics in combination with nonsurgical retreatment. Referral to a specialist is often helpful when planning treatment for complex cases. If retreatment (with or without surgery) on a tooth with a new restoration is being considered, it must be weighed against the possibility of an implant. Many variables must be considered before a reasonable conclusion can be reached.

Single-Visit versus Multiple-Visit Treatment

Some vital cases are suitable for single-visit treatment. The number of roots, time available, and the clinician's skills are factors to be considered. Severity of the patient's symptoms is

FIG. 3-3 Incision and drainage should be performed on this fluctuant swelling *(arrow)* in conjunction with canal instrumentation.

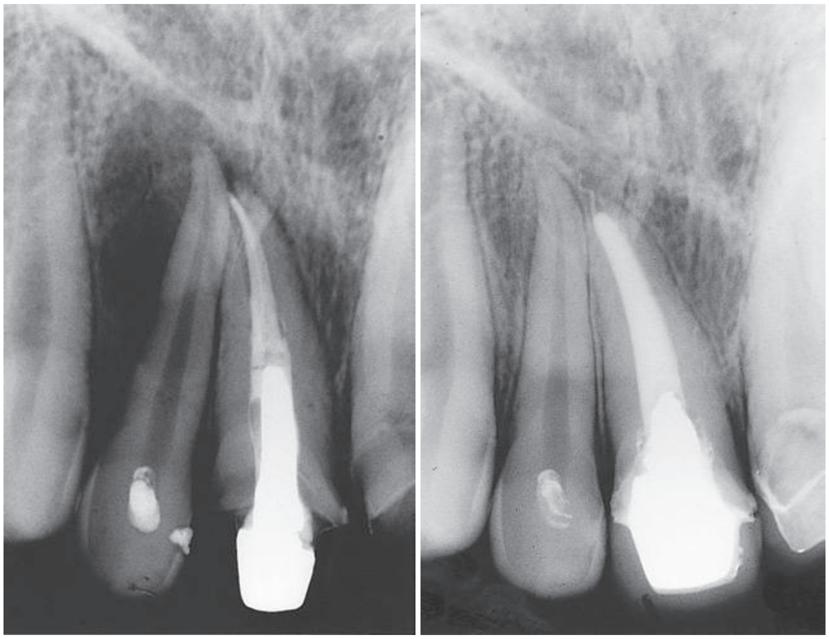

FIG. 3-4 Two years after endodontic therapy of tooth #8, the patient returned with pain and swelling. A clinician mistakenly began endodontic access on tooth #7, without confirming the apparent radiographic diagnosis by sensibility testing. Tooth #7 was vital, and tooth #8 was successfully retreated after removal of the post. (Courtesy Dr. Leon Schertzer.)

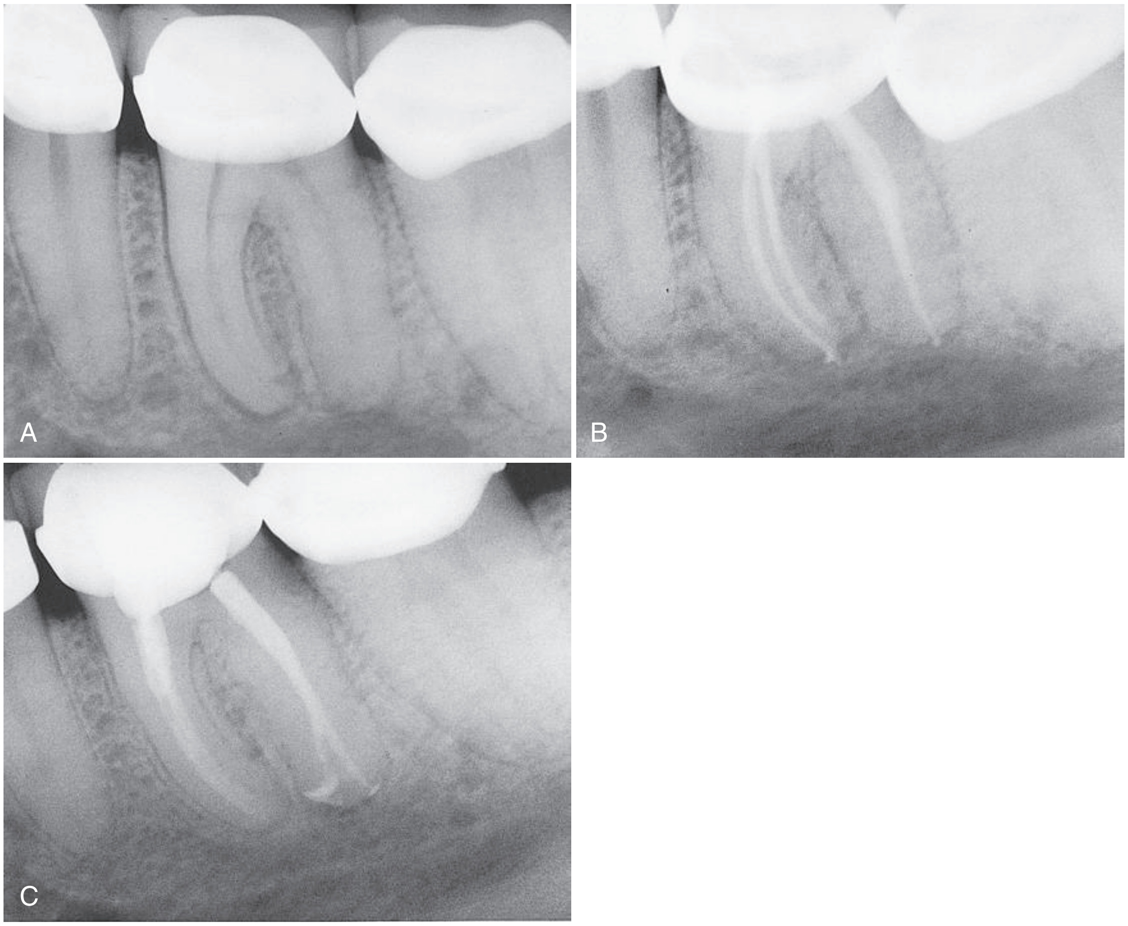

FIG. 3-5 Many years after endodontic treatment of tooth #19, the patient returned with a chief complaint of pain and an inability to chew with the tooth. Despite the radiographic appearance of excellent endodontic treatment, the tooth was retreated and the patient's pain disappeared. Note the unusual distal root anatomy, which was not apparent during the initial procedure. A, Initial radiograph. B, Completion of initial endodontic therapy. C, Retreatment.

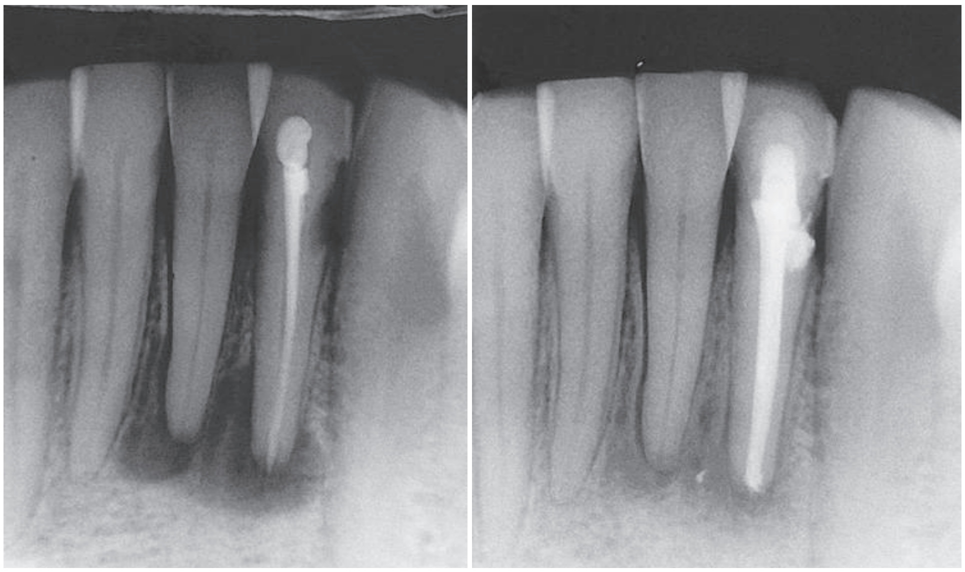

FIG. 3-6 Initial radiograph was misleading and implicated tooth #23 and tooth #24. Pulp testing indicated a vital pulp in tooth #24, and it was not treated. Retreatment of #23 resulted in healing of the periradicular lesion. (Courtesy Dr. Leon Schertzer.)

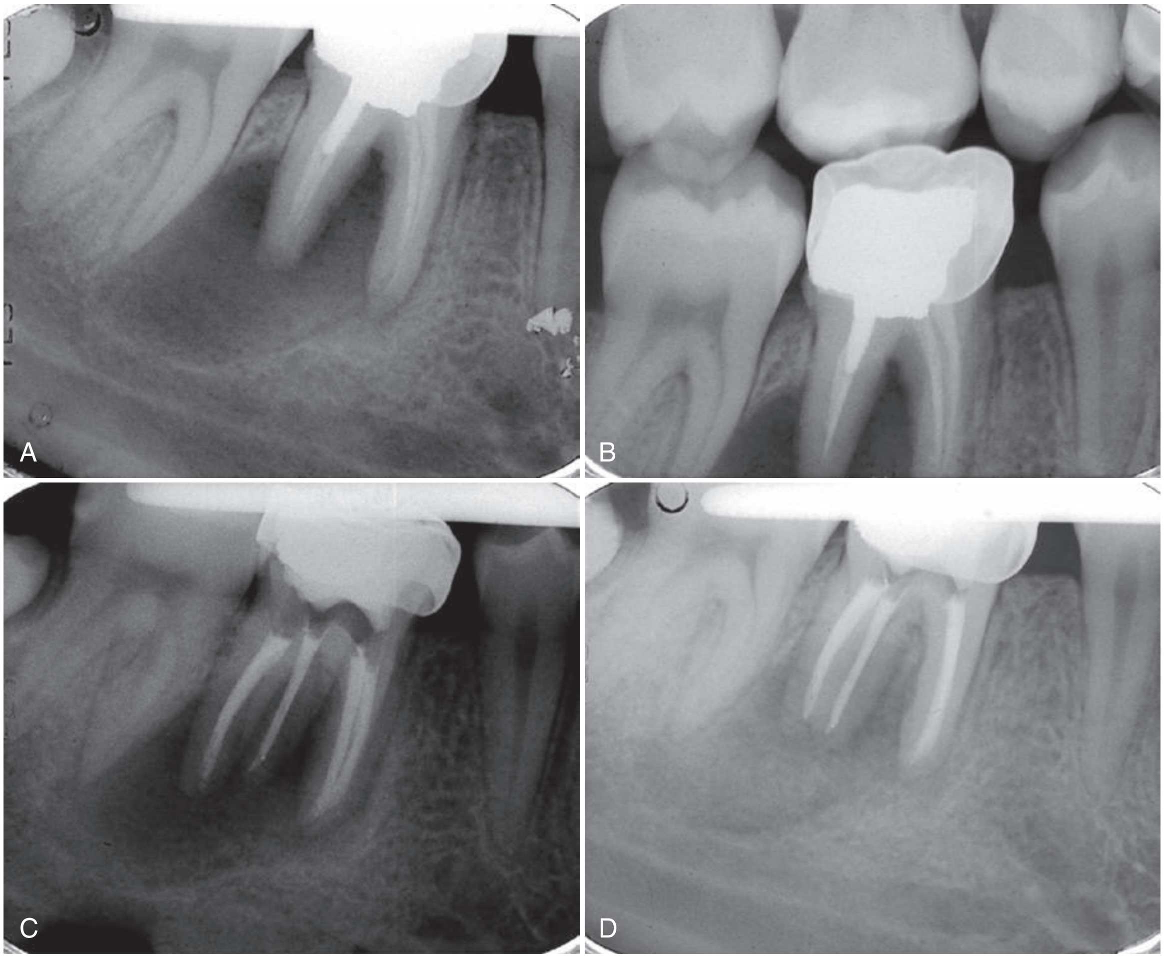

FIG. 3-7 Nonsurgical retreatment of tooth #30. An additional root was located and treated. **A,** Note inadequate endodontic treatment and large periapical lesion. **B,** Bitewing radiograph. **C,** Retreatment after post removal. **D,** Eighteen-month recall radiograph indicates periapical healing.

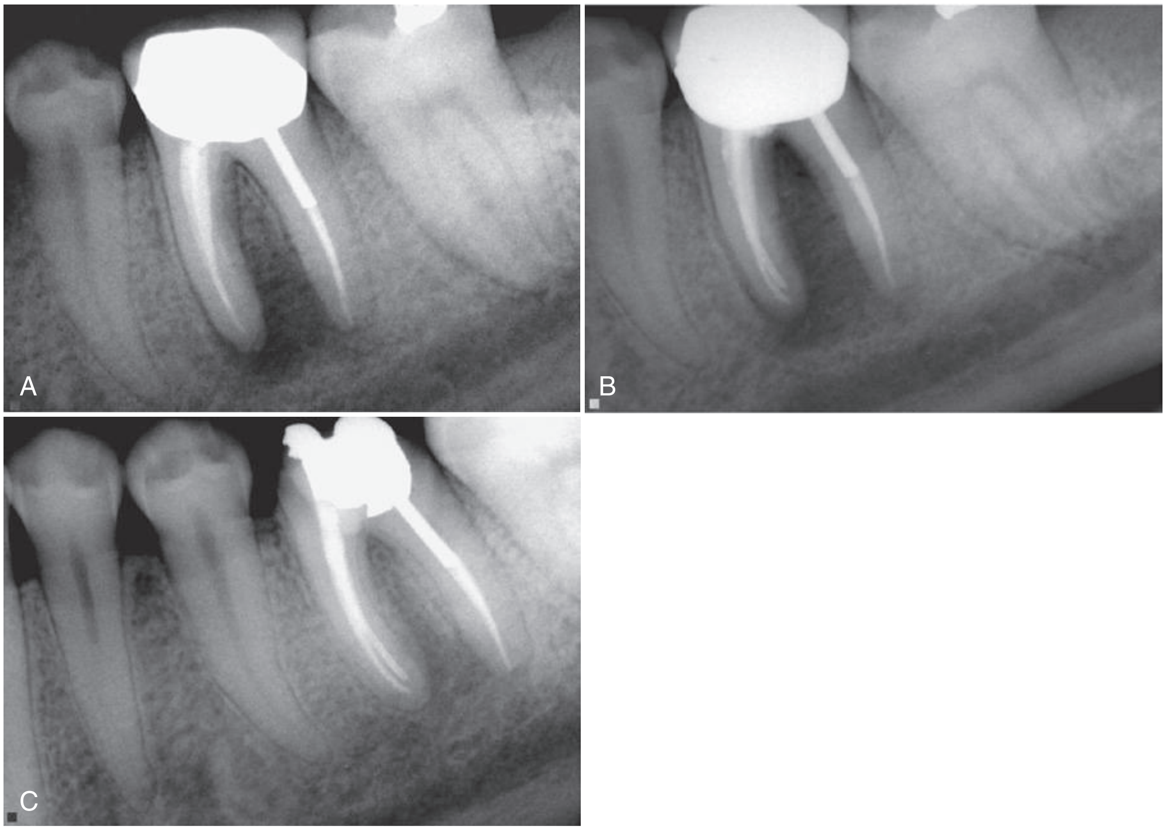

FIG. 3-8 Despite several exacerbations during endodontic retreatment, this case responded rapidly after the completion of therapy. Radiographic evaluation indicates a good periapical response after only 4 months.

another important consideration. For example, a patient in severe pain, with or without swelling, should not experience a long visit including access, instrumentation, and obturation. Treatment in such cases should be directed at alleviating pain, with filling of the canal postponed until a later visit. The clinician's judgment of what the patient can comfortably tolerate (regarding duration of the visit) is made on a case-by-case basis.

There are advantages in having a patient return for a second visit, after initially presenting with an endodontic emergency due to pain or swelling with or without a stoma. The second visit allows the clinician to determine the effect of the treatment on inflamed and infected tissues. Deferring the filling of the canal(s) leads to a shorter initial visit for the emergency patient.

Although some studies have reported less posttreatment pain in single-visit cases,[26,80,96] a systematic review found that the incidence of postobturation discomfort was similar in the single- and multiple-visit approaches.[27] In another systematic review it was concluded that there was a lack of compelling evidence indicating a significantly different prevalence of post-treatment pain/flare-up with either single- or multiple-visit root canal treatment.[85] Differences in research methodology explain the conflict in these findings.

Regarding the healing rate of single- and multiple-visit cases, a systematic review found that there was no detectable difference in the effectiveness of root canal treatment in terms of radiologic success between single and multiple visits.[27] A more recent systematic review also found that the healing rate of single- and multiple-visit root canal treatment is similar for infected teeth.[96]

Teeth with nonvital pulps and apical periodontitis pose a microbiologic problem. It is important to avoid pushing bacterial debris into the periapical tissues. Agreement is lacking concerning the appropriateness of single-visit endodontics for treating these patients. Some have postulated that the intervisit use of an antimicrobial dressing is essential to thoroughly disinfect the root canal system.[92,93,99] In contrast, other researchers have found no statistically significant difference in success when using the single-visit or multiple-visit approach to the nonvital tooth with apical periodontitis.[27,31,59,73,75,106] A systematic review found that, single-visit root canal treatment appeared to be slightly more effective than multiple-visit treatment (6.3% higher healing rate). However, the difference between these two treatment regimens was not statistically significant.[84] This is a complicated issue because the inability to detect differences between groups might also be due to variations in research methodology, including sample size, duration of follow-up, and treatment methods.

It is possible that total elimination of bacteria may not be absolutely necessary for healing. Perhaps maximal reduction of bacteria, effective root canal filling, and a timely satisfactory coronal restoration can result in a high level of clinical success. However, regardless of the number of appointments, effective bacteriologic disinfection of the root canal system is critical.[46]

Treatment planning for an endodontic case should be based on biologic considerations. Patients who present with acute symptoms present a different set of biologic issues than those with an asymptomatic tooth. Swelling associated with an abscess, cellulitis, or presence of a stoma represent signs of pathologic processes. The biologic significance of these conditions should be considered before determining specific goals for each visit.

Developing specific goals at each visit helps to organize the treatment. For example, for an uncomplicated molar or premolar, some clinicians will set a specific goal for the first visit that includes access and thorough instrumentation while deferring the obturation to a second visit. Uncomplicated single-rooted, vital teeth may be planned for a single-visit approach. It is important that ample time be allowed so that the procedure can be adequately completed without undue stress.

These recommendations have a biologic basis. Biologically, it is not reasonable to partially instrument root canal systems, thereby leaving residual inflamed pulpal remnants or necrotic debris in the canal, because such remnants may cause pain and be susceptible to infection. The clinician would be well advised to begin canal instrumentation only if time permits the extirpation of all pulp tissue and debridement of the root canal system.

Although in most cases the clinical procedures required to complete endodontic treatment can be accomplished in a single visit, that does not mean it is the better course of treatment. What can be done and what should be done represent two very different approaches to endodontic treatment planning. The patient's systemic health, level of anxiety, and symptoms, as well as the complexity of the root canal system, are factors that must be considered.

A study concerning the outcome of initial treatment noted the complexity of treating apical periodontitis.[31] The author commented:

Treatment of this disease cannot be improved merely by changing treatment techniques. Because apical periodontitis results from interactions between microorganisms, their environment and the host immune system, only use of effective modifiers of any of these three factors might significantly improve the outcome of treatment.

INTERDISCIPLINARY TREATMENT PLANNING

Periodontal Considerations

Extensive periodontal lesions may complicate endodontic prognosis. Lesions with endodontic and periodontal components may necessitate consultation with an endodontist or periodontist in order to gather more information about the tooth's prognosis.

A 4-year retrospective study found that attachment loss and periodontal status affected endodontic prognosis of endodontically treated molars.[87] It is crucial that the dental practitioner be aware of the periodontal factors that may influence the prognosis of endodontic treatment, such as root perforations, bone loss, and clinical attachment loss.

When establishing the prognosis of a tooth with an endodontic/periodontal lesion, there are essential factors to be considered. Determination of pulp vitality and the extent of the periodontal defect are central to establishing the prognosis and developing a treatment plan for a tooth with an endodontic/periodontal lesion (see also Chapter 25).

In primary endodontic disease, the pulp is nonvital (Figs. 3-9 and 3-10), whereas in primary periodontal disease, the pulp retains vitality. True combined endodontic-periodontal disease occurs less frequently. The combined lesion is found

FIG. 3-9 **A**, Inflamed, edematous interproximal tissue *(arrow)* caused by acute endodontic pathosis. **B**, Soft tissue healing *(arrow)* 3 days after initiation of endodontic treatment. **C**, Periradicular pathosis. **D**, Completed endodontic therapy. **E**, Periradicular healing at 1-year recall.

when the endodontic disease process advances coronally and joins with a periodontal pocket progressing apically. There is significant attachment loss with this type of lesion, and the prognosis is guarded.[81] The radiographic appearance of combined endodontic-periodontal lesions may be similar to that of a vertically fractured tooth. Therapy for true combined lesions requires both endodontic and periodontal therapy. Sequencing of treatment is based on addressing the initial chief complaint.

The prognosis and treatment of each type of endodontic-periodontal disease vary. Primary endodontic disease should be treated solely by endodontic therapy, and the prognosis is usually good. Primary periodontal disease should be treated only by periodontal therapy, and the prognosis varies depending on the seventy of the disease and patient's response to treatment.[81]

Pathogenesis of the lesion can be better understood after sensibility testing, periodontal probing, radiographic assessment, and evaluation of dental history. When extensive prostheses are planned, the potential risk of including a tooth with a questionable prognosis must be considered. It is not prudent to incorporate a chronic problem into a new complex prosthesis (Fig. 3-11).

Surgical Considerations

Surgical evaluation is particularly valuable in the diagnosis of lesions that may be nonodontogenic. Biopsy is the definitive means of diagnosing osseous pathosis, which may mimic a lesion of endodontic origin. When retreatment is being considered, the clinician must determine whether nonsurgical, surgical, or combined treatment is appropriate. This decision is influenced by the presence of complex restorations, posts, and the radiographic assessment of prior endodontic therapy.

Endodontic surgery is most often performed in an attempt to improve the apical seal and correct failure of nonsurgical therapy. Bacteria are the essential cause of failure. It is important that the clinician determine the bacterial path of ingress. For example, a deficient restoration or recurrent decay will result in microleakage into the root canal space. Unless that issue is addressed, apical surgery may not be predictable (Fig. 3-12).

When a deficient restoration is identified, it must be replaced to prevent continued bacterial penetration. Endodontic surgery (see Chapter 9) may also be performed as a primary procedure when there are complications such as calcific metamorphosis. In those cases, by using surgery as primary therapy, an apical seal can be established while preserving the crown of the tooth.

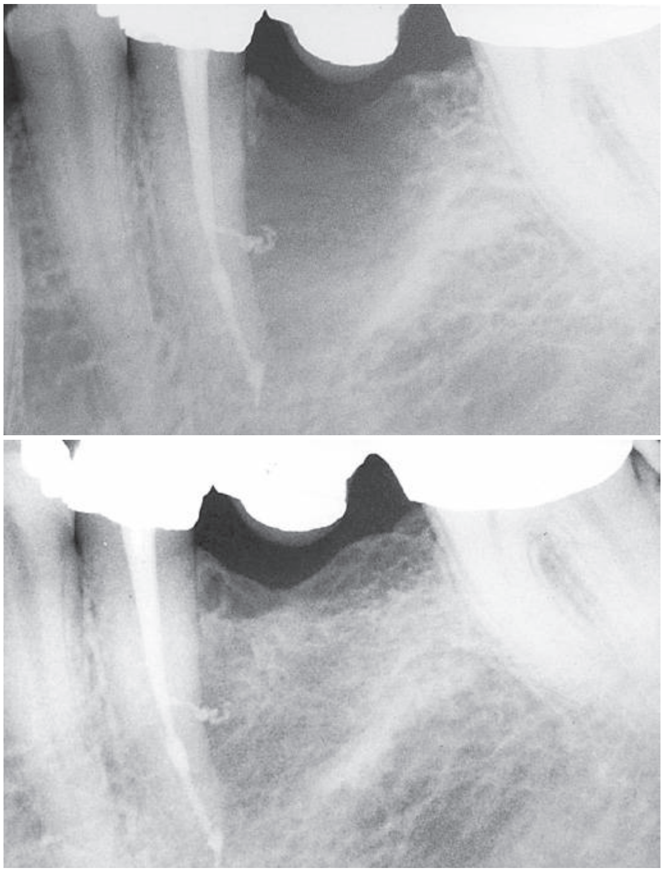

FIG. 3-10 A large, bony defect associated with tooth #20 healed after endodontic therapy. The tooth was nonvital, and no significant periodontal probing depth indicated pulpal disease.

The treatment plan for these cases is determined after reviewing multiple radiographs and considering the possibility of completing nonsurgical therapy without destroying an otherwise functional crown or natural tooth. Endodontic surgery without prior nonsurgical therapy should be a treatment of last resort and only when nonsurgical treatment is not possible.

Reviewing the best available evidence for alternative treatments is an important aspect of treatment planning for a tooth with failed endodontics. Evidence concerning healing potential after endodontic surgery is an important consideration in the management of posttreatment disease.[30] Numerous studies

FIG. 3-11 Tooth #30 has a poor prognosis. Periodontal probing reached the apex of the distal root. Extraction is indicated and should be done as soon as possible to prevent further damage to the mesial bone associated with tooth #31. Implant site preservation is another consideration in treatment planning for this case.

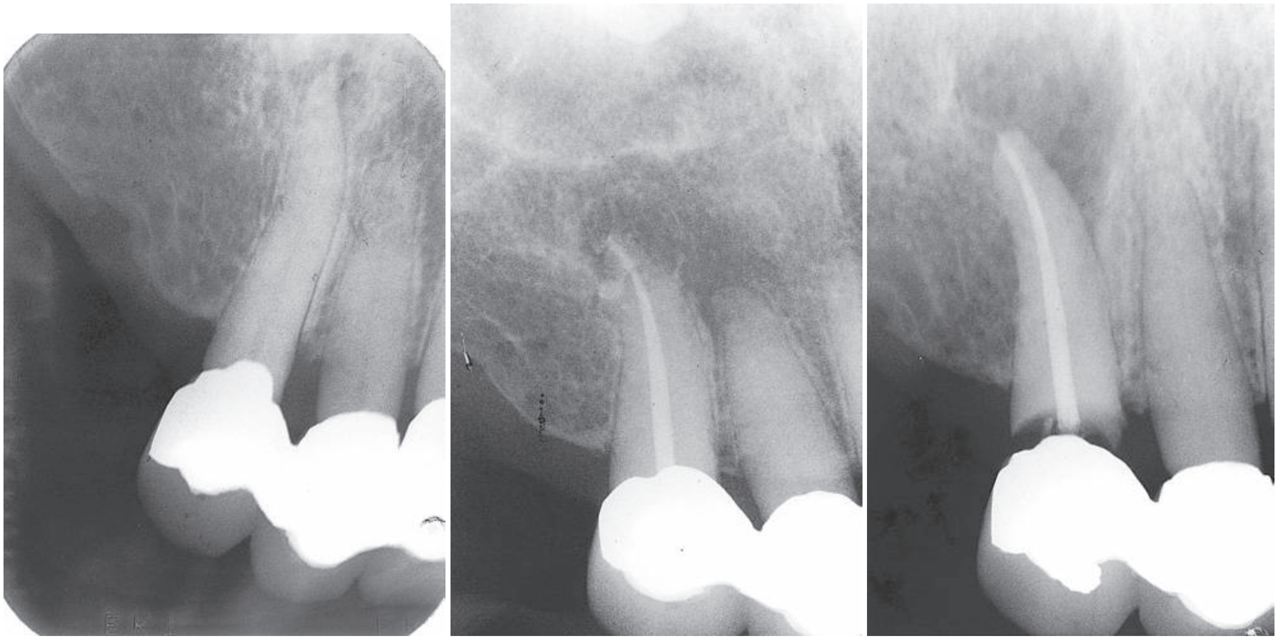

FIG. 3-12 Four years after endodontic therapy, the patient complained of pain and swelling associated with tooth #6. The initial impression was that apical surgery was indicated. However, further radiographs revealed the true cause of the endodontic failure. The initial endodontic access through the crown or caries damaged the coronal seal and recurrent decay followed.

have examined the outcome of apical surgery and the results vary considerably.[101,104,112] This variability may reflect actual outcome differences or reflect variations in case selection techniques, recall periods, and methodology.

One prospective study indicated that there is an increased odds ratio for disease persistence for teeth with larger pretreatment lesions and pretreatment root canal filling of adequate length.[104] Another study found that patients presenting with pain at the initial examination before surgery had a significantly lower rate of healing at the 1-year follow-up compared with patients who did not have pain at the initial examination.[101]

It should also be noted that the periodontal condition of the tooth, including the interproximal bone levels and the amount of marginal bone loss, has been shown to significantly affect the long-term prognosis of periapical surgery.[102,105] Moreover, it has been shown that isolated endodontic lesions have much higher success rates at the 1- to 5-year follow-up (95.2%) in comparison with endodontic-periodontal combined lesions (77.5%).[40]

Dramatic changes in surgical technique and materials have occurred: The advent of microscopy, endoscopy, and ultrasonics, as well as improved retrograde filling materials, represents important modifications of surgical technique. An outcome study comparing traditional root-end surgery (TRS) and endodontic microsurgery (EMS) found that the probability of success for EMS was 1.58 times greater than the probability of success for TRS.[89] Another study comparing the EMS techniques with and without the use of higher magnification found that the difference of probability of success between the groups was statistically significant for molars, but no significant difference was found for the premolar or anterior teeth.[88] Cone-beam computed tomography has proved to be of value in some surgical cases. It produces three-dimensional images of a tooth, pathosis, and adjacent anatomic structures. It is beneficial for localizing the mandibular canal,[42] mental foramen, maxillary sinus, and nasal cavity.[16]

Restorative and Prosthodontic Considerations

A satisfactory restoration may be jeopardized by a number of factors. Subosseous root caries (perhaps requiring crown lengthening), poor crown-to-root ratio, and extensive periodontal defects or misalignment of teeth may have serious effects on the final restoration. These problems must be recognized before endodontic treatment is initiated. For complex cases, a restorative treatment plan should be in place before initiating endodontic treatment (see Chapter 22). Some teeth may be endodontically treatable but nonrestorable, or they may represent a potential restorative complication because of a large prosthesis. Reduced coronal tooth structure under a full-coverage restoration makes endodontic access more difficult because of reduced visibility and lack of radiographic information about the anatomy of the chamber. It is not unusual for restorations to be compromised during endodontic access (see Fig. 3-12). Whenever possible, restorations should be removed before endodontic treatment.

Full coverage restorations are usually suggested after endodontic treatment. In a systematic review on tooth survival following nonsurgical root canal treatment, four factors were found to be of significance in tooth survival[66]:

- A crown restoration after root canal treatment
- Tooth having both mesial and distal proximal contacts
- Tooth not functioning as an abutment for removable or fixed prosthesis
- Tooth type or specifically nonmolar teeth

Another systematic review found that the odds for healing of apical periodontitis increase with both adequate root canal treatment and adequate restorative treatment. However, poorer clinical outcomes may be expected with adequate root filling/inadequate coronal restoration and inadequate root filling/adequate coronal restoration, with no significant difference in the odds of healing between these two combinations.[34] These findings suggest that the quality of the coronal restoration is as important as the quality of the root canal treatment. Therefore, to increase the success of the treatment, it is strongly suggested that the clinician discuss the restorative plan of the tooth with both the patient and—if it is a referred patient—with the referring dentists before initiation of treatment.

Endodontic Therapy or Dental Implant

The successful evolution of dental implants as a predictable replacement for missing teeth has had a positive impact on patient care. A clinician now has an additional possibility to consider when developing a treatment plan for a patient with a missing tooth or teeth. More challenging is the decision concerning whether or not to provide endodontic therapy for a tooth with a questionable prognosis or extract and use a single-tooth implant as a replacement. Numerous studies have evaluated both nonsurgical endodontic therapy[18,69,70,82,97,98] and endosseous dental implants.[2,17,37,47]

It is not possible to compare outcome studies because of variations in research methodologies, follow-up periods, and criteria associated with determining success or failure. A review of outcome studies points to the need for randomized controlled trials with standardized or similar methodologies that could provide a higher level of evidence to use in answering important clinical prognostic questions.

A synthesis of available evidence indicates that both primary root canal treatment and single-tooth implants are highly predictable procedures when treatment is appropriately planned and implemented. A study assessed clinical and radiographic success of initial endodontic therapy of 510 teeth over a 4- to 6-year period. It was found that 86% of teeth healed and 95% remained asymptomatic and functional.[18] Another study considered the outcomes of endodontic treatment on 1,462,936 teeth. More than 97% of teeth were retained after 8 years.[82] In a similar study it was found that overall, 89% of the 4744 teeth were retained in the oral cavity 5 years after the endodontic retreatment.[83] A study concerning the outcome of endodontic therapy on 1312 patients in general practice with a mean follow-up time of 3.9 years found a combined failure rate of 19.1%, concluding that "failure rates for endodontic therapy are higher than previously reported in general practices, according to results of studies based on dental insurance claims data."[7]

The American Dental Association's Council on Scientific Affairs has reported high survival rates for endosseous implants. An evaluation of 10 studies with more than 1400 implants demonstrated survival rates ranging from 94.4% to 99% with a mean survival rate of 96.7%.[2] With such high survival rates reported for endodontics and single-tooth implants, a clinician must consider a multiplicity of factors within the context of the best available evidence. Most current studies indicate no significant difference in the long-term prognosis between restored endodontically treated teeth and single-tooth implants.[37]

In a retrospective cross-sectional comparison of initial nonsurgical endodontic treatment and single-tooth implants, it was suggested that restored endodontically treated teeth and single-tooth implant restorations have similar survival rates, although the implant group showed a longer average and median time to obtain function and a higher incidence of posttreatment complications requiring subsequent treatment intervention.[20] A review summarized the best available evidence concerning factors influencing treatment planning involving preservation of a tooth with endodontic therapy or replacement by a single-tooth implant. Factors considered included prosthetic restorability of the natural tooth, quality of bone, aesthetic concerns, cost-to-benefit ratio, systemic factors, potential for adverse effects, and patient preferences.[37] The authors concluded that "endodontic treatment of teeth represents a feasible, practical and economical way to preserve function in a vast array of cases and that dental implants serve as a good alternative in selected indications in which prognosis is poor."[37]

Aside from treatment outcome, there are other factors involved in any treatment that the practitioner has to consider when making a treatment planning decision. In a study evaluating the quality of life of endodontically treated versus implant treated patients, the results showed a high rate of satisfaction with both treatment modalities.[32] One study found that comparing to endodontic molar retreatment and fixed partial dentures, implant-supported restoration, despite its high survival rate, has been shown to be the least cost-effective treatment option.[41] Another study found that "endodontically treated natural teeth may provide more effective occlusal contact during masticatory function compared with implant-supported restorations, leading to more efficient mastication."[109]

Another important factor is the patient's health status. Implants require a surgical procedure that may not be possible due to the patient's medical status. One area of concern is diabetes mellitus. However, it has been shown that dental implant osseointegration can be accomplished in these subjects as long as they have good glycemic control.[38]

It seems clear that patients are best served by retaining their natural dentition as long as the prognosis for long-term retention is positive. It is not reasonable to extract a tooth if endodontics with a good prognosis can be completed. It is also not reasonable for a patient to invest in root canal therapy, a post, and a crown if the prognosis is highly questionable and an implant with a good prognosis can be placed. An important advantage of providing endodontic therapy is to allow rapid return of the patient's compromised dentition to full function and aesthetics. This rapid return is in marked contrast to the use of provisional restorations associated with dental implants while waiting for osseous integration. The challenge is to weigh all pretreatment variables and reach a reasonable conclusion concerning the prognosis for tooth retention or implant placement.

Interestingly, some endodontic advanced education programs are now including implant training in their curricula. This training will enable the endodontist to provide more value to the patient and referring the dental clinician as treatment plans are determined. Such dually trained endodontists will be well positioned to provide endodontic therapy or place an implant as best serves the patient.

OTHER FACTORS THAT MAY INFLUENCE ENDODONTIC CASE SELECTION

A variety of factors may complicate proposed endodontic therapy. Calcifications, dilacerations, or resorptive defects may compromise endodontic treatment of a tooth with potentially strategic value (Fig. 3-13). The inability to isolate a tooth is also a problem and may result in bacterial contamination of the root canal system. Extra roots and canals pose a particular

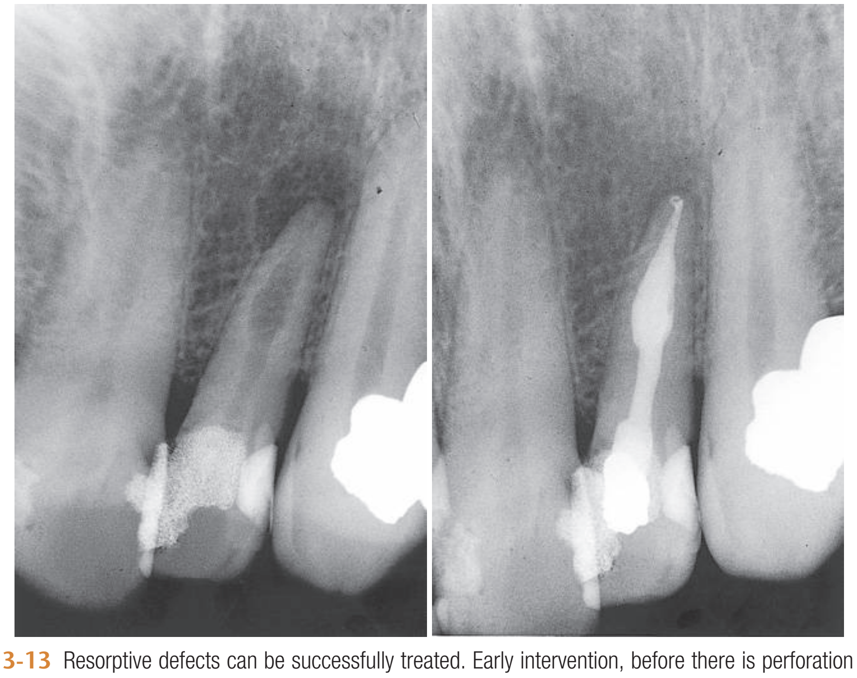

FIG. 3-13 Resorptive defects can be successfully treated. Early intervention, before there is perforation of the root, increases the chance of success. (Courtesy Dr. Leon Schertzer.)

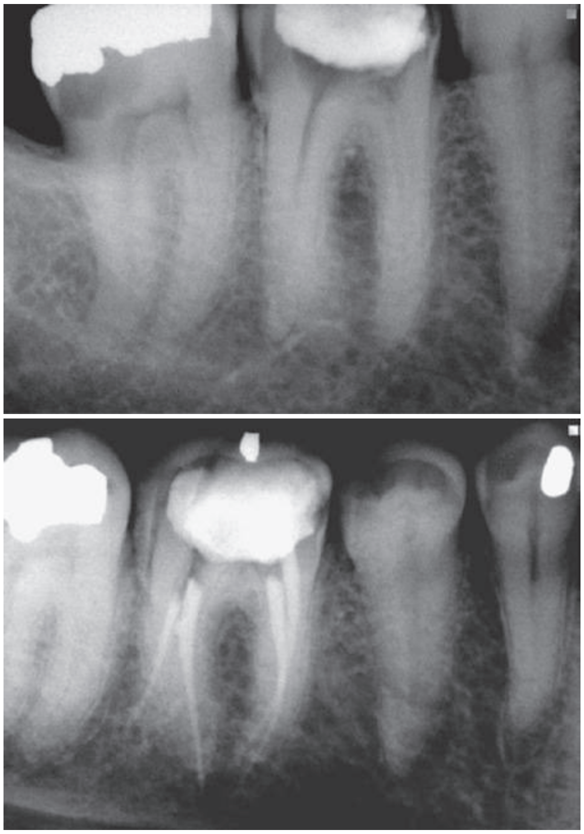

FIG. 3-14 The presence of curved roots and multiple canals is a complicating factor.

anatomic challenge that radiographs do not always reveal (Fig. 3-14). A bitewing radiograph is useful in providing an accurate image of the pulp chambers of posterior teeth. The clinician should recognize these potential problems and be able to manage and factor them into the decision concerning the tooth's prognosis, including the possibility that the patient should be referred to a specialist.

Another consideration is the stage of maturity of the tooth. Primary and immature permanent teeth may have a pulpal pathosis caused by caries or trauma; preserving these young teeth is essential. Premature loss of an anterior tooth can lead to malocclusion, predispose the patient to tongue habits, impair aesthetics, and damage the patient's self-esteem. (See Chapters 20 and 24 for further information.)

Some clinicians use a simple formula for determining which endodontic cases they treat and which they refer to a specialist. The number of roots may be the determining factor in a decision concerning referral, or the key factor may be the chronic or acute status of the case. Others consider the complexity of the ultimate prosthesis as a factor in considering an endodontic referral. The most important variables in determining whether to refer a patient to a specialist are the skills of the clinician and the complexity of the case.

The American Association of Endodontists (AAE) developed guidelines for assessing endodontic case difficulty (available at www.aae.org/uploadedFiles/Publications_and_Research/Guidelines_and_Position_Statements/2006CaseDifficultyAssessmentFormB_Edited2010.pdf) (see Fig. 2-1). The AAE Endodontic Case Difficulty Assessment Form enables a clinician to assign a level of difficulty to a particular case. The form describes cases with minimal, moderate, and high degrees of difficulty. This form lists criteria that can be used to identify cases that should be referred to a specialist. The use of surgical operating microscopes, endoscopes, and ultrasonics enables the specialist to predictably treat teeth that would not previously have been treatable.

Anxiety

Anxiety presents a problem at many levels of dental care (see also Chapter 28). Avoidance of dental treatment due to anxiety appears to be associated with significant deterioration of oral and dental health.[111] Even at the diagnostic stage, severe anxiety may confuse the process.[23] Several studies support the hypothesis that pain or fear of pain is a primary source of anxiety as well as an obstacle to seeking dental care.[44,111] Also, highly anxious patients appear to be more sensitive to pain.[24,43] High levels of anxiety have been found to negatively affect clinical procedures including local anesthesia.[62] In 2009, Binkley tested the hypothesis that having natural red hair color, which is caused by variants of the melanocortin-1 receptor (*MC1R*) gene, could predict a patient's experiencing dental care–related anxiety and dental care avoidance.[8] She found that participants with *MC1R* gene variants reported significantly more dental care–related anxiety and fear of dental pain than did participants with no *MC1R* gene variants. A more recent study confirmed the relationship between the red hair phenotype and anxiety. However, this study found no association between the red hair phenotype and the success of local anesthesia.[21]

It has been demonstrated that dental anxiety and expectation of pain had a profound effect on a patient's ability to understand information provided.[25] A person's cognitive ability to process information is significantly affected by stress.[25] A study found that 40% of patients who had minor oral surgery did not remember receiving both written and verbal instructions, contributing to 67% noncompliance with antibiotic prescriptions.[9] Patients' anxiety can compromise their understanding of complex treatment plans. Decisions made by a patient concerning options involving tooth retention or loss may be markedly affected by anxiety.

Unfortunately, the impact that a high level of anxiety can have on patient's cognition, local anesthesia, and intraoperative and postoperative experiences is not always recognized. A landmark medical study found that pretreatment discussion of surgical treatments and associated discomfort reduced by 50% the need for posttreatment morphine and reduced the time to discharge.[22] Existing research has focused primarily on the effect of pretreatment information on reducing anxiety and stress during surgery.[25]

More than 200 studies indicate that preemptive behavioral intervention decreases anxiety before and after surgery, reduces posttreatment pain intensity and intake of analgesics, and accelerates recovery.[15] A calm setting, reassurance by the clinician and explanation of the treatment plan, as well as a discussion about pain prevention strategies are all important steps even before treatment starts.[63] A written description as well as a verbal description of the proposed treatment are helpful. It may also be of value to have a family member or friend accompany the patient for a discussion of the treatment plan.

Scheduling Considerations

If a vital case is to be treated by a multivisit approach, it is suggested that the clinician allow 5 to 7 days between canal instrumentation and obturation to allow periradicular tissues to recover. When a vital case is to be treated in a single visit, adequate time must be scheduled so that the clinician can comfortably complete the procedure. Because profound inferior alveolar nerve block anesthesia can require approximately 15 to 20 minutes, it is wise to include that time when scheduling a patient's appointment (see also Chapter 4).

Appointments to fill nonvital cases should be scheduled approximately 1 week after instrumentation to maximize the antimicrobial effect of the intracanal dressing when calcium hydroxide is used.[6,92,93] Acute (pain or swelling) nonvital cases should be seen every 24 to 48 hours to monitor the patient's progress and bring the acute symptoms under control. Further cleaning and shaping are important components of the treatment as the clinician seeks to eliminate persistent microbes in the canal system. Long delays between visits contribute to the development of resistant microbial strains and should be avoided.

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CHAPTER 4

Pain Control

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CHAPTER OUTLINE

I. LOCAL ANESTHESIA FOR RESTORATIVE DENTISTRY AND ENDODONTICS

Effective local anesthesia is the bedrock of pain control in endodontics and restorative dentistry. Regardless of the clinician's skills, both treatment and patient management are difficult or impossible to deliver without effective pain control. This chapter reviews the pharmacology of local anesthetics and the relative advantages and limitations of various anesthetics and routes of administration. Other chapters in this book provide complementary information on the use of local anesthetics in diagnosis (see Chapter 1) and the treatment of emergency patients (see Chapter 18). The authors assume that the reader is familiar with various anesthetic injection techniques; several excellent texts are available for review regarding this point.[195,262,353]

MECHANISMS OF ACTION FOR ANESTHETICS

Most dental pharmacology courses teach that local anesthetics block sodium channels by partitioning into two types, the uncharged basic form of the molecule (RN), which crosses cell membranes, and the charged acid form of the molecule (RNH^+), which binds to the inner pore of the sodium channel. As a first approximation, this model is reasonably accurate. However, molecular research has demonstrated the existence of at least nine subtypes of voltage-gated sodium channels (VGSCs) that differ in their expression pattern, biophysical properties, and roles in mediating peripheral pain (Table 4-1). These channels have a clear clinical relevance.[39,170,241] Indeed, several groups of patients have been described with genetic mutations to a VGSC, with significant reported effects on pain sensitivity.

The broad class of VGSCs can be divided into channels that are blocked by a toxin (tetrodotoxin [TTX]) and those that are resistant to the toxin (TTX-R). Most TTX-R channels are found primarily on nociceptors (e.g., Na_v 1.8 and Na_v 1.9).[433] These channels also are relatively resistant to local anesthetics and are sensitized by prostaglandins.[148] As is explained later in the chapter, the presence of TTX-R sodium channels may explain why local anesthetics are less effective when administered to patients with odontalgia. Many of the adverse effects of local anesthetics are attributed to their ability to block other VGSCs expressed in the central nervous system (CNS) or heart (see Table 4-1).

VGSCs consist of an alpha and a beta subunit. The alpha subunit serves as a voltage sensor, leading to channel activation and sodium ion passage when the channel detects an electrical field. The biologic basis for an electrical pulp tester, therefore, is the generation of a small electrical field across the dental pulp that can activate VGSCs.[170] Interestingly, sensitization of TTX-R channels by prostaglandins lowers the activation threshold and increases the number of sodium ions that flow through the channel.[148] Put another way, an inflammation-induced elevation in prostaglandin levels sensitizes TTX-R channels, leading to greater activation with weaker stimuli. This may explain the increased responsiveness to electrical pulp testing seen in patients with irreversible pulpitis.

TABLE 4-1

Voltage-Gated Sodium Channels and Pain

Channel Subtype	Tissue Expression	Tetrodotoxin Sensitive	Peripheral Role in Pain
Na_v 1.1	Central nervous system (CNS), sensory neurons	Yes	?
Na_v 1.2	CNS	Yes	No
Na_v 1.3	CNS	Yes	No
Na_v 1.4	Muscle	Yes	No
Na_v 1.5	Heart	Somewhat	No
Na_v 1.6	CNS, sensory neurons	Yes	?
Na_v 1.7	CNS, sensory neurons	Yes	?
Na_v 1.8	Sensory neurons	No	Yes
Na_v 1.9	Sensory neurons	No	Yes

Local anesthetics have other mechanisms that may contribute to their pharmacology for treating odontogenic pain. For example, local anesthetics modulate certain G protein–coupled receptors (GPCRs). The GPCRs are a major class of cell membrane receptors, and many classes of dental drugs (e.g., opioids, catecholamines) and endogenous mediators produce their effects by activating specific GPCRs and their related second messenger pathways. Studies suggest that local anesthetics inhibit the G-alpha-q ($G_{\alpha q}$) class of GPCRs, which includes receptors activated by inflammatory mediators such as bradykinin.[183] Local anesthetics may therefore block the actions of a major hyperalgesic agent.

Other studies have indicated that local anesthetics potentiate the actions of the G-alpha-i ($G_{\alpha i}$) class of GPCRs.[32] This could have a major effect in potentiating the actions of vasoconstrictors, including the newly recognized analgesic role that vasoconstrictors play in inhibiting pulpal nociceptors.[43,169] Prolonged alteration of GPCR function might explain why analgesia obtained with long-acting local anesthetics persists well beyond the period of anesthesia.[78,104,300] More research is needed on this exciting aspect of local anesthetic pharmacology.

CLINICALLY AVAILABLE LOCAL ANESTHETICS

The most common forms of injectable local anesthetics are in the amide class. In 2003, the American Dental Association specified a uniform color code for dental cartridges to prevent confusion among brands (Table 4-2). Local anesthetics can be divided roughly into three types: short duration (30 minutes of pulpal anesthesia), intermediate duration (60 minutes of pulpal anesthesia), and long duration (over 90 minutes of pulpal anesthesia). However, clinical anesthesia does not always follow these guidelines, depending on whether the local anesthetic is used as a block or for infiltration. For example, bupivacaine is classified as a long-acting agent, and when it is used in an inferior alveolar nerve (IAN) block, this is true.[112] However, when it is used for infiltration for anterior teeth, it

TABLE 4-2

Local Anesthetics Available in the United States*

Anesthetic	Vasoconstrictor	Dental Cartridge Color Codes†	Maximum Allowable Dose	Typical Maximum Dose
2% Lidocaine	1:100,000 epinephrine	Red	13	8
2% Lidocaine	1:50,000 epinephrine	Green	13	8
2% Lidocaine	Plain (no vasoconstrictor)	Light blue	8	8
2% Mepivacaine	1:20,000 levonordefrin	Brown	11	8
3% Mepivacaine	Plain (no vasoconstrictor)	Tan	7	5½
4% Prilocaine	1:200,000 epinephrine	Yellow	5½	5½
4% Prilocaine	Plain (no vasoconstrictor)	Black	5½	5½
0.5% Bupivacaine	1:200,00 epinephrine	Blue	10	10
4% Articaine	1:100,000 epinephrine	Gold	7	7
4% Articaine	1:200,000 epinephrine	Silver	7	7

*This table provides the maximum dosage in two formats. The maximum allowable dose generally is approached only with complex oral and maxillofacial surgical procedures. The typical maximum dose is the usual outer envelope of drug dosage for most endodontic, surgical, and restorative dental procedures. Both columns show the number of cartridges that would be required for an adult weighing 67.5 kg (150 pounds).
†Uniform dental cartridge color codes were mandated by the American Dental Association in June, 2003.

has a shorter duration of anesthetic action than 2% lidocaine with 1:100,000 epinephrine[81,156] (this is discussed in more detail later in the chapter).

SELECTION OF A LOCAL ANESTHETIC: POSSIBLE ADVERSE EFFECTS, MEDICAL HISTORY, AND PREOPERATIVE ANXIETY

Possible Adverse Effects

Possible adverse reactions to local anesthetics can be divided into six major categories: cardiovascular reactions, systemic effects, methemoglobinemia, peripheral nerve paresthesia, allergic reactions to the anesthetic and/or latex, and reactions to anesthetics containing a sulfite antioxidant. These reactions range from fairly common (e.g., tachycardia after intraosseous injection of 2% lidocaine with 1:100,000 epinephrine) to extremely rare (e.g., allergic reactions to lidocaine).

Cardiovascular Reactions

Although classic research studies have reported that large dosages or intravenous (IV) injections of local anesthetics were required to produce cardiovascular effects,[192,419] it now is well recognized that even comparatively small amounts of epinephrine can induce measurable tachycardia after nerve block or intraosseous injection.[113,150,358] Several authors have reported increases in heart rate with infiltration injections and nerve blocks using 2% lidocaine with 1:100,000 epinephrine[2,172,236,375,418]; others have reported that no significant changes in heart rate occurred or that the changes were clinically insignificant.[282,413,422] When specific information was given on dosing and heart rate increases, several studies found mean heart rate increases.[2,172,235,418] Two studies found increases on average of about 4 beats/min with approximately 20 μg of epinephrine[172,235]; three studies recorded increases of 10 to 15 beats/min with 45 to 80 μg of epinephrine[2,235,375]; and one study found increases of approximately 21 beats/min using 144 μg.[418] Increasing the amount of epinephrine in an infiltration or block injection, therefore, increases the likelihood of an elevated heart rate.

Tachycardia after injection is primarily a pharmacologic effect. The cardiovascular effects are the result of alpha-adrenoceptor stimulation by systemic distribution of the vasoconstrictor throughout the vascular compartment. The patient may also report heart palpitations associated with anxiety or fear and may experience transient tachycardia and changes in blood pressure. Large doses or inadvertent IV injection may lead to lidocaine toxicity and CNS depression.[115,308] To reduce this risk, the clinician should always aspirate before making the injection, inject slowly, and use dosages within accepted guidelines. The maximal dosages for local anesthetics are listed in Table 4-2.

Systemic Effects

Acute toxicity from an overdose of a local anesthetic often is the result of inadvertent IV administration or of a cumulative large dose (e.g., repeated injections). As shown in Table 4-1, VGSCs are found in the CNS and the myocardium, the two major sites of anesthetic-induced toxicity. Although systemic effects from a local anesthetic are rare, they can include an initial excitatory phase (e.g., muscle twitching, tremors, grand mal convulsions) and a subsequent depressive phase (e.g., sedation, hypotension, and respiratory arrest).[86,115] It should be noted that symptomatic management (possibly including cardiopulmonary resuscitation [CPR], airway support, and supplemental oxygen) is the primary response to this adverse event.[229,233] An acute hypotensive crisis with respiratory failure also has been interpreted as the result of hypersensitivity to local anesthetics[62]; these patients should be evaluated with allergy testing. To reduce the risk of systemic effects from anesthetics, the clinician must always aspirate before giving the injection and must use dosages within accepted guidelines (see Table 4-2). Finder and Moore[115] proposed a “rule of 25” as a simple means of remembering maximal local anesthetic dosages: with currently formulated local anesthetic cartridges, it generally is safe to use one cartridge of local anesthetic for every 25 pounds of patient weight (e.g., six cartridges for a patient weighing 150 pounds [67.5 kg]).

Methemoglobinemia

Metabolism of certain local anesthetics (e.g., prilocaine, benzocaine, articaine, and to a lesser extent lidocaine) can produce a metabolite that causes methemoglobinemia; this effect often occurs several hours after injection of the local anesthetic.[265,439] Typical signs and symptoms include cyanosis, dyspnea, emesis, and headache. In a study on benzocaine-induced methemoglobinemia, 67% of reported adverse effects of benzocaine were associated with methemoglobinemia; of these events, 93% occurred with spray formulations of benzocaine, and only one case involved the gel formulation.[301] To reduce the risk of methemoglobinemia, clinicians should take care to refrain from giving excessive dosages of local anesthetics.

Peripheral Nerve Paresthesia

Postinjection paresthesia is a rare adverse effect of local anesthetics.[161,265,453] The incidence of paresthesia (which involved the lip and/or tongue) associated with articaine and prilocaine was higher than that found with either lidocaine or mepivacaine.[132,140,161] Another study evaluated patients referred with a diagnosis of damage to the inferior alveolar and/or lingual nerve that could only have resulted from an IAN block.[345] In 35% of these cases, the paresthesia was caused by a lidocaine formulation, and in 30%, it was caused by an articaine formulation. The conclusion was that there was not a disproportionate nerve involvement from articaine, although this interpretation does not account for large differences in clinical usage of the two local anesthetics. However, with any paresthesia, documentation of the patient’s reported area of altered sensation, the type of altered sensation (e.g., anesthesia, paresthesia, dysesthesia), and regular follow-up are important.[463]

Allergic Reactions to Local Anesthetics and Latex

The amide local anesthetics appear to have little immunogenicity and therefore have an extremely low rate of allergic reactions.[382] One study included more than 140 patients specifically referred for allergy testing because of adverse effects after injection of a local anesthetic; none of these patients had hypersensitivity reactions to intradermal local anesthetics,[368] but case reports of hypersensitivity reactions after administration of local anesthetics have been published.[41,62,302,382] Some concern has been raised that the rubber latex stopper in dental anesthetic cartridges might be a source of allergen to patients allergic to latex. In a review of this literature (1966 to 2001), Shojaei and Haas[385] concluded that some evidence for exposure to the latex allergen exists, although no causal study has been published.

Local anesthetic formulations that contain vasoconstrictors also contain sulfite to prevent oxidation of this agent. Sulfite-induced reactions came to prominence with the report of six deaths after exposure to salad bars or homemade wine.[20] Common reported signs and symptoms include allergic-like reactions, such as urticaria, bronchospasm, and anaphylaxis. Risk factors include an active history of asthma (perhaps 5% of asthmatics are at risk) and atopic allergy. The use of local anesthetics without vasoconstrictors is a possible alternative with these patients. No sulfite reaction in dental practice has ever been documented, possibly because the amount of sulfite in local anesthetic cartridges is relatively small.

EFFECTS OF SYSTEMIC DISEASES OR CONDITIONS ON LOCAL ANESTHETICS

It has been stated that vasoconstrictors should be avoided in patients with high blood pressure (higher than 200 mmHg systolic or 115 mmHg diastolic), cardiac dysrhythmias, unstable angina, less than 6 months since myocardial infarction or cerebrovascular accident, or severe cardiovascular disease.[262] However, these conditions are contraindications to routine dental treatment. Patients taking antidepressants, nonselective beta-blocking agents, medicine for Parkinson disease, and cocaine have a potential for problems.[262,353] In patients taking these medications, plain mepivacaine (3% Carbocaine) can be used for the inferior alveolar nerve block.

Alcoholics have been found to be more sensitive to painful stimulation.[406] Alcoholics with a history of depression/unhappiness may also have reduced pulpal anesthesia.[116] In contrast, alcoholics in recovery may not be at increased risk for inadequate pain control with local anesthesia.[116]

Any of the commonly available local anesthetics are safe for use in pregnant or lactating women.[162] The most important aspect of care with pregnant patients is to eliminate the source of pain by performing the indicated endodontic treatment; this reduces the need for systemic medications.[162]

Local anesthetics may interact with a patient's medications, so a thorough review of the medical history is an absolute requirement. Potential drug-drug interactions occur primarily with the vasoconstrictors in local anesthetic formulations (Table 4-3). Judicious use of local anesthetic solutions without vasoconstrictors (e.g., 3% mepivacaine) is a reasonable alternative for adult patients.

Studies have found that women try to avoid pain more than men, accept it less, and fear it more.[99,114,249,303] One study found that women find postsurgical pain more intense than males, but men are more disturbed than women by low levels of pain that lasts several days.[303] Another study found gender differences in analgesia for postoperative endodontic pain.[374] Anxiety

TABLE 4-3
Possible Drug Interactions with Vasoconstrictors

Drugs	Possible Adverse Effects	Recommendations
Tricyclic Antidepressants		
Amitriptyline, doxepin	Increased cardiovascular responses	Reduce or eliminate vasoconstrictors
Nonselective Beta-Blockers		
Nadolol, propranolol	Hypertension, bradycardia	Reduce or eliminate vasoconstrictors
Recreational Drugs		
Cocaine	Hypertension, myocardial infarction, dysrhythmias	Instruct patient to abstain from drug use for 48 hours before procedure; do not use vasoconstrictors
COMT Inhibitors		
Entacapone, tolcapone	Increased cardiovascular responses	Reduce or eliminate vasoconstrictors
Antiadrenergic Drugs		
Guanadrel, guanethidine	Increased cardiovascular responses	Reduce or eliminate vasoconstrictors
Nonselective Alpha-Adrenergic Blockers		
Chlorpromazine, clozapine, haloperidol	Increased cardiovascular responses	Reduce or eliminate vasoconstrictors
Digitalis		
Digoxin	Dysrhythmias (especially with large dosage of vasoconstrictor)	Reduce or eliminate vasoconstrictor
Hormone		
Levothyroxine	Dysrhythmias (especially with large dosage of vasoconstrictor)	*Euthyroid:* No precaution *Hyperthyroid:* Reduce or eliminate vasoconstrictors
Monoamine Oxidase Inhibitors		
Furazolidone, linezolid, selegiline, tranylcypromine	No interaction	None

Modified from Naftalin L, Yagiela JA: Vasoconstrictors: indications and precautions, *Dent Clin North Am* 46:733, 2002.
COMT, Catecholamine *O*-methyl transferase.

may also modulate differences in pain responses between males and females. In addition, pain threshold response varies greatly at different stages of the menstrual cycle.[42] Other studies have shown that women report greater pain relief from kappa opioid agonists (e.g., pentazocine) after endodontic treatment.[420] We should be aware that women might react differently to pain than men.[114]

CLINICAL ANESTHESIA AND ROUTES OF ANESTHETIC ADMINISTRATION

Recognition is growing that evidence-based therapeutics offers an excellent source of information that should become an aspect of treatment in conjunction with the practitioner's clinical skills and the patient's particular needs. In many areas of dentistry, this is a limited concept because few randomized, placebo-controlled, double-blind clinical trials have been conducted. However, this is not the case with dental pharmacology. The astute clinician can make informed decisions on various local anesthetics and routes of injection based on a large collection of well-designed clinical trials. The following discussion focuses on the clinical aspects of local anesthesia, with special emphasis on restorative dentistry and endodontics.

IMPORTANT CLINICAL FACTORS IN LOCAL ANESTHESIA

Traditional Methods of Confirming Anesthesia

Traditional methods of confirming anesthesia usually involve questioning the patient ("Is your lip numb?"), soft tissue testing (e.g., lack of mucosal responsiveness to a sharp explorer), or simply beginning treatment. However, these approaches may not be effective for determining pulpal anesthesia.[60,179,277,424]

Determining Pulpal Anesthesia in Asymptomatic Vital Teeth

Anesthesia in asymptomatic vital teeth can be measured more objectively by applying a cold refrigerant (Fig. 4-1) or by using an electrical pulp tester (EPT), as described in Chapter 1 (Fig. 4-2). Application of cold or the electrical pulp tester can be used to test the tooth under treatment for pulpal anesthesia before a clinical procedure is started.[56,100,201,257]

FIG. 4-1 A cold refrigerant may be used to test for pulpal anesthesia before the start of a clinical procedure. (Coltène/Whaledent Inc., Cuyahoga Falls, OH.)

FIG. 4-2 An electrical pulp tester also may be used to test for pulpal anesthesia before a clinical procedure is started. (Courtesy SybronEndo, Corporation Orange, CA.)

Determining Pulpal Anesthesia in Symptomatic Vital Teeth

In symptomatic (painful) vital teeth and after administration of a local anesthetic, testing with a cold refrigerant or an electrical pulp tester can be used to evaluate pulpal anesthesia before an endodontic procedure is started.[68,100,323,355] If the patient responds to the stimulus, pulpal anesthesia has not been obtained, and supplemental anesthetic should be administered. However, in patients presenting for an emergency appointment with a painful vital tooth (e.g., symptomatic irreversible pulpitis), the lack of a response to pulp testing may not guarantee pulpal anesthesia.[100,323,355] Therefore, if a patient experiences pain when the endodontic procedure is started, supplemental anesthetic is indicated, regardless of the responsiveness to pulpal testing. If the chamber is necrotic and the canals are vital, no objective test can predict the level of clinical anesthesia.

Patient Who Has Had Previous Difficulty with Anesthesia

Anesthesia is more likely to be unsuccessful in patients who report a history of previous difficulty with anesthesia.[214] These patients generally make comments such as, "Novocaine doesn't work on me" or "It takes a lot of shots to get my teeth numb." A good clinical practice is to ask the patient if dentists previously have had difficulty obtaining anesthesia. If the answer is yes, supplemental injections should be considered.

Failure to Achieve Anesthesia in Patients with Pain

Obtaining anesthesia is often difficult in patients with endodontic pain of pulpal origin. A number of explanations have been proposed for this.[170] One is that conventional anesthetic techniques do not always provide profound pulpal anesthesia, and patients with preexisting hyperalgesia may be unable to tolerate any noxious input. Another explanation relates to the theory that inflamed tissue has a lower pH, which reduces the amount of the base form of anesthetic that penetrates the nerve membrane. Consequently, less of the ionized form is available in the nerve to achieve anesthesia. However, this explanation does not account for the mandibular molar with pulpitis that is not readily blocked by an inferior alveolar injection administered at some distance from the area of inflammation. Correlating localized inflammatory changes with failure of the IAN block is difficult.

Another explanation for failure is that nerves arising from inflamed tissue have altered resting potentials and decreased excitability thresholds.[51,427] Two studies demonstrated that local anesthetics were unable to prevent impulse transmission because of these lowered excitability thresholds.[292,427] Another factor might be the TTX-R sodium channels, which are resistant to the action of local anesthetics,[373] are increased in inflamed dental pulp,[399,431,433] and are sensitized by prostaglandins.[148] A related factor is the increased expression of sodium channels.[399,431,433]

Finally, patients in pain are often apprehensive, which lowers the pain threshold. Therefore, practitioners should consider supplemental techniques (e.g., intraosseous injections[320,323,332,355] or periodontal ligament injections[68]) if an IAN block fails to provide pulpal anesthesia for patients with irreversible pulpitis.

Use of Topical Anesthetics

Fear of needle insertion is a major cause of apprehension in dental patients.[234,289,290] Although some studies have demonstrated the effectiveness of topical anesthetics,[146,175,186,312,372] others have shown no significant pain reduction.[146,222,270] Interestingly, one study showed that patients who thought they were receiving a topical anesthetic anticipated less pain regardless of whether they actually received the anesthetic.[270] The most important aspect of a topical anesthetic may not be its clinical effectiveness, but rather its psychological effect on the patient, who believes the practitioner is doing everything possible to prevent pain.

Reversing the Action of Local Anesthetics

Phentolamine mesylate (0.4 mg in a 1.7-ml cartridge [OraVerse, Novalar Pharmaceuticals, San Diego, California]) is a recently developed agent that shortens the duration of soft tissue anesthesia. The duration of soft tissue anesthesia is longer than pulpal anesthesia and is often associated with difficulty eating, drinking, and speaking.[176,245] The best use of OraVerse is after dental procedures when postoperative pain is not a concern. Asymptomatic endodontic patients may benefit from the use of a reversal agent when they have speaking engagements or important meetings or must perform in musical or theatrical events.[121] Therefore, OraVerse may be used to shorten the duration of soft tissue anesthesia if the patient presents with an asymptomatic tooth and little postoperative pain is anticipated.[121]

INFERIOR ALVEOLAR NERVE BLOCK FOR RESTORATIVE DENTISTRY

2% Lidocaine and 1:100,000 Epinephrine

Because failure occurs most often with the IAN block,[214] factors that modify mandibular anesthesia must be carefully reviewed. The technique for administering an IAN block can be reviewed in available textbooks.[195,262] The following discussion reviews the expected outcomes after administration of a conventional IAN block to asymptomatic patients using 1.8 ml of 2% lidocaine with 1:100,000 epinephrine (Xylocaine, Lignospan, Octocaine). Although anesthesia requirements vary among dental procedures, the following discussion concentrates on *pulpal* anesthesia in asymptomatic patients and thus is directly relevant to endodontic therapy.

Anesthetic Success

One way to define anesthetic success for nerve blocks is the percentage of subjects who achieve two consecutive nonresponsive readings on electrical pulp testing within 15 minutes and continuously sustain this lack of responsiveness for 60 minutes. In other words, the objective is to achieve anesthesia within 15 minutes and to have it last 1 hour. This endpoint is as important for restorative dentistry as it is for endodontic treatment, so it is used as a benchmark for clinically significant information from research on local anesthetics. Using this criterion, the percentage of cases in which anesthesia was obtained after IAN block injections ranged from 10% (central incisor) to 65% (second molar).* It is important to note that all patients from these studies reported a positive lip sign (e.g., profound lip numbness); therefore, profound lip numbness *does not* predict pulpal anesthesia. However, lack of soft tissue anesthesia is a useful indicator that the block injection was not administered accurately for that patient. Missed blocks occur in about 5% of cases, and the clinician should readminister the nerve block before continuing with treatment.

Anesthetic Failure

Anesthetic failure can be defined as the percentage of subjects who never achieved two consecutive nonresponsive EPT readings at any time during a 60-minute period. Using this criterion, anesthetic failure rates ranged from 17% (second molar) to 58% (central incisor).†

Noncontinuous Anesthesia

Another measure of mandibular anesthesia is noncontinuous anesthesia, which may be related to the action of the anesthetic solution on the nerve membrane (blocking and unblocking the sodium channels). This occurs in about 12% to 20% of patients.‡

Slow Onset

After a conventional IAN block injection, the onset of pulpal anesthesia occurs within 10 to 15 minutes in most cases (Fig. 4-3).§ Slow onset can be defined as the percentage of

*References 60, 165, 179, 277, 322, 353, and 424.
†References 60, 112, 165, 179, 277, 322, 353, 388, 424, and 425.
‡References 60, 158, 165, 179, 277, 322, 353, and 424.
§References 60, 112, 165, 179, 277, 322, 353, 388, 424, and 425.

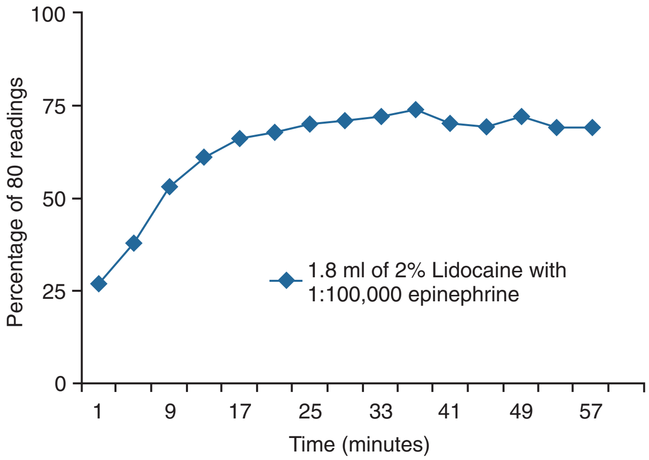

FIG. 4-3 Incidence of first mandibular molar anesthesia as determined by lack of response to electrical pulp testing at the maximum setting (percentage of 80 readings) across time for 60 minutes.

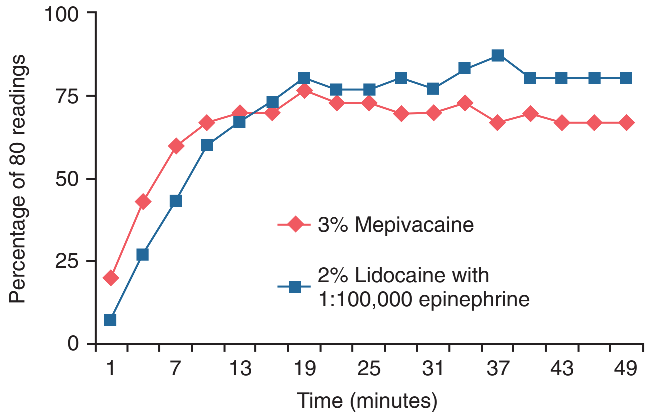

FIG. 4-4 **Incidence of first mandibular molar anesthesia: comparison of 3% mepivacaine to 2% lidocaine with 1:100,000 epinephrine.** Results were determined by lack of response to electrical pulp testing at the maximum setting (percentage of 80 readings) across time for 50 minutes. No significant difference between the two solutions was noted.

subjects who achieved a nonresponsive EPT reading after 15 minutes. In mandibular teeth, slow onset occurs in 12% to 20% of patients.

Duration

The duration of action for pulpal anesthesia in the mandible is very good.* If patients are anesthetized initially, anesthesia usually persists for approximately 2½ hours.[112] Figure 4-3 depicts the time course for complete pulpal anesthesia for an asymptomatic first molar, as defined by the percentage of patients who did not respond to a stimulus (EPT) across time for 60 minutes. Most patients achieved pulpal anesthesia within 15 minutes and had a duration of anesthesia of at least 1 hour, but the success rate was not 100% for the population.

ALTERNATIVE ANESTHETIC SOLUTIONS FOR THE INFERIOR ALVEOLAR NERVE BLOCK

Plain Solutions: 3% Mepivacaine (Carbocaine, Polocaine, Scandonest) and 4% Prilocaine (Citanest Plain)

In a study of volunteers without dental pathosis, anesthesia from IAN injection of 3% mepivacaine plain and 4% prilocaine plain was as effective as that from 2% lidocaine with 1:100,000 (Fig. 4-4).[277] A clinical study of patients with irreversible pulpitis also found that 3% mepivacaine and 2% lidocaine with 1:100,000 epinephrine were equivalent for IAN blocks.[68] These findings support the selection of 3% mepivacaine as a local anesthetic when medical conditions or drug therapies suggest caution in the administration of solutions containing epinephrine.

*References 60, 112, 165, 179, 277, 322, 353, 388, 424, and 425.

4% Prilocaine with 1:200,000 Epinephrine (Citanest Forte) and 2% Mepivacaine with 1:20,000 Levonordefrin (Carbocaine with Neo-Cobefrin)

In a study of volunteers without dental pathosis, IAN injection of 4% prilocaine with 1:200,000 epinephrine or 2% mepivacaine with 1:20,000 levonordefrin worked as well as 2% lidocaine with 1:100,000 epinephrine in achieving pulpal anesthesia.[179]

Levonordefrin has 75% alpha activity and only 25% beta activity, making it seemingly more attractive than epinephrine (50% alpha activity and 50% beta activity).[262] However, levonordefrin is marketed as a 1:20,000 concentration in dental cartridges.[262] Clinically, the higher concentration of levonordefrin makes it equipotent to epinephrine in clinical and systemic effects,[158,179] so 1:20,000 levonordefrin offers no clinical advantage over 1:100,000 epinephrine.

Articaine with 1:100,000 Epinephrine (Septocaine, Articadent, Zorcaine)

Articaine has been reported to be a safe and effective local anesthetic.[378] It was approved for use in the United States in April, 2000, and is marketed as a 4% solution with either 1:100,000 or 1:200,000 epinephrine.[265,299] Articaine is classified as an amide. It has a thiophene ring (instead of a benzene ring, as do the other amide local anesthetics) and an extra ester linkage, which results in hydrolysis of articaine by plasma esterases.[271] A number of studies have evaluated articaine and concluded that it is safe when used in appropriate doses.* Lidocaine and articaine have the same maximal dose of 500 mg for adult patients (recommended dose, 6.6 to 7 mg/kg), but the maximum number of cartridges is different because of the differences in drug concentration (see Table 4-2).[262]

*References 82, 178, 193, 263, 265, 293, 328, 389, and 449.

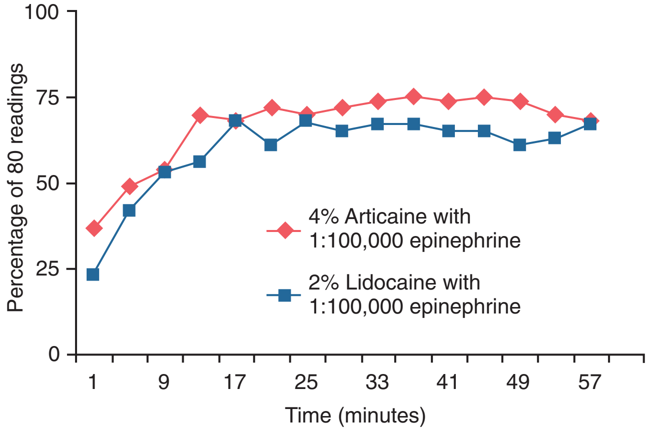

FIG. 4-5 Incidence of first mandibular molar anesthesia: comparison of 4% articaine with 1 : 100,000 epinephrine to 2% lidocaine with 1 : 100,000 epinephrine. Results were determined by lack of response to electrical pulp testing at the maximum setting (percentage of 80 readings) across time for 60 minutes. No significant difference between the two solutions was noted.

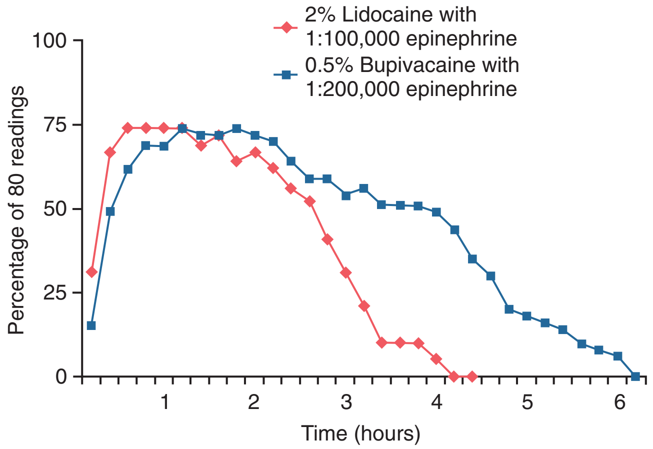

FIG. 4-6 Incidence of first mandibular molar anesthesia: comparison of 0.5% bupivacaine with 1 : 200,000 epinephrine to 2% lidocaine with 1 : 100,000 epinephrine. Results were determined by lack of response to electrical pulp testing at the maximum setting (percentage of 80 readings) across time for 6 hours. The bupivacaine solution showed a longer duration of anesthesia than the lidocaine solution.

Clinical Effectiveness of Articaine for Inferior Alveolar Nerve Blocks

The available literature indicates that articaine is equally effective for IAN blocks when statistically compared to other local anesthetics.* In comparing the anesthetic efficacy of 4% articaine with 1 : 100,000 epinephrine to 2% lidocaine with 1 : 100,000 epinephrine for IAN blocks, one study found that the two solutions were not significantly different (Fig. 4-5).[288] Two studies found no difference in efficacy between 4% articaine with 1 : 100,000 and 1 : 200,000 epinephrine.[299,412] In summary, repeated clinical trials have failed to demonstrate any statistical superiority of articaine over lidocaine for IAN blocks.

Articaine and Uncorroborated Insurance Carrier Warning

A letter was sent to thousands of U.S. dentists in 2006 by insurer Emery and Webb/Ace USA stating, "... we have noticed an increase in reversible and, in some cases, nonreversible paresthesias (with Septocaine) … We are writing you to alert you to these events in hopes that you will not fall victim to one of these incidents."[261] Knowledgeable dentists and educators communicated their concerns, and a Notice of Retraction was issued:

> Unfortunately, we at Emery & Webb discovered upon further review, and subsequent to the mailings, that both documents contained inaccuracies and an alarmist tone, which was not warranted … Emery and Webb has not noted an increase in malpractice claims or lawsuits in connection with articaine … It should be made clear that Emery and Webb has not conducted any scientific investigation, sampling, testing, or other investigation of the articaine anesthetic, and has no independent knowledge or data which would restrict the use of the product.[261]

Astute clinicians should be very careful of Web chat sites and colleagues' clinical endorsements, because they may not accurately reflect the correct information regarding articaine.

Long-Acting Anesthetics

Clinical trials with bupivacaine (Marcaine) and etidocaine (Duranest) have been conducted in patients undergoing oral surgery,[84,371] endodontic treatment,[104,300] and periodontic treatment.[78,254] Etidocaine was withdrawn from the market by Dentsply Pharmaceuticals (York, Pennsylvania). Bupivacaine was found to have a slower onset of pulpal anesthesia than lidocaine for IAN blocks.[112] Generally, bupivacaine provides prolonged analgesia and is indicated when postoperative pain is anticipated, but not all patients want lip numbness for an extended period.[371] Patients should be questioned about their preference. Although bupivacaine has a somewhat slower onset than lidocaine, its duration of pulpal anesthesia in the mandible is almost twice as long (approximately 4 hours; Fig. 4-6).[112]

Ropivacaine (Naropin), a relatively new long-acting local anesthetic, is a structural homolog of bupivacaine.[223] A number of studies have shown that ropivacaine has a lower potential for toxic CNS and cardiovascular effects than bupivacaine but produces equivalent pharmacologic effects.[223] Ropivacaine and levobupivacaine are being developed as potentially new local anesthetics based on their stereochemistry. Both are S-isomers and are thought to cause less toxicity than the racemic mixture of bupivacaine currently marketed.[392] A clinical trial has indicated that levobupivacaine showed significantly better postoperative pain control at 4 and 24 hours after infiltration injection than ropivacaine.[331] Because of their decreased potential for cardiac and CNS toxicity, ropivacaine and levobupivacaine may replace bupivacaine with epinephrine in clinical dental practice.

Buffered Lidocaine

Buffering lidocaine using sodium bicarbonate raises the pH of the anesthetic solution. In medicine there is evidence that buffering lidocaine results in less pain during the injection.[55,164]

*References 64, 95, 159, 160, 263, 264, 288, 421, and 450.

In dentistry, some studies[15,16,44,210] found that buffered lidocaine produced less pain on injection and a faster onset of anesthesia. However, other dental studies[350,435] did not find less pain on injection or a faster onset with buffered lidocaine for IAN block. Using a commercial buffering system (Onpharma, Los Gatos, California) in asymptomatic subjects, one study[266] found a reduction in onset time and injection pain, whereas another study[180] found no difference in these measurements. In symptomatic patients with a diagnosis of pulpal necrosis and associated acute swelling, no significant decrease in pain of infiltrations or significant decrease in pain of an incision and drainage procedure was found when the buffered anesthetic formulation was used.[29] Most patients who had the incision and drainage procedure experienced moderate to severe pain.

Use of Mannitol

An Ohio State University research group studied the use of mannitol to increase the efficacy of nerve blocks. Mannitol, a hyperosmotic sugar solution, is thought to temporarily disrupt the protective covering (perineurium) of sensory nerves, allowing the local anesthetic to gain entry to the innermost part of the nerve.[22] These researchers found that the use of mannitol in combination with lidocaine increased anesthetic success in IAN blocks about 15% to 20% but did not provide complete pulpal anesthesia for restorative or endodontic treatment.[239,398,443] The drug combination may be introduced sometime in the future.

ALTERNATIVE INJECTION SITES

Gow-Gates and Vazirani-Akinosi Techniques

Some clinicians have reported that the Gow-Gates technique[154] has a higher success rate than the conventional IAN block injection,[259,262] but controlled experimental studies have failed to show superiority of the Gow-Gates technique.[11,149,294,411] Neither has the Vazirani-Akinosi technique[12,149,262] been found superior to the standard inferior alveolar injection.[149,271,394,411,460] In a small study of 21 patients, no difference was found between lidocaine (11 patients) and articaine (10 patients) formulations for the Gow-Gates injection in patients with irreversible pulpitis.[384] Another study found the Gow-Gates technique had a higher success rate (52%) than the Vazirani-Akinosi technique (41%) in patients with irreversible pulpitis.[4] Further research is indicated with both techniques in patients presenting with symptomatic irreversible pulpitis. The Vazirani-Akinosi technique is indicated for cases involving a limited mandibular opening (trismus).

Incisive Nerve Block/Infiltration at the Mental Foramen

The incisive nerve block is successful 80% to 83% of the time in anesthetizing the premolar teeth for about 20-30 minutes.[30,202,313,437] It is not effective for the central and lateral incisors.[313]

Lidocaine Infiltrations

Labial or lingual infiltration injections of a lidocaine solution alone are not effective for pulpal anesthesia in the mandible.[118,281,459]

Articaine Infiltrations

Articaine is significantly better than lidocaine for buccal infiltration of the mandibular first molar.[75,203,205,362] However, articaine alone does not predictably provide pulpal anesthesia of the first molar. There is no difference between 4% articaine with 1:100,000 and 1:200,000 epinephrine for buccal infiltration.[275]

In anterior teeth, buccal and lingual infiltrations of articaine provide initial pulpal anesthesia, but the anesthesia declines over 60 minutes.[190,326]

ATTEMPTS TO INCREASE SUCCESS OF THE INFERIOR ALVEOLAR NERVE BLOCK

Increasing the Volume of Anesthetic

One possible method for increasing anesthetic success could be to double the injection volume of local anesthetic solution. However, increasing the volume of 2% lidocaine with epinephrine to 3.6 ml (two cartridges) does not increase the incidence of pulpal anesthesia with the IAN block (Fig. 4-7).[322,455]

Increasing the Epinephrine Concentration

A second approach for increasing the success of the IAN block could be to increase the concentration of epinephrine. However, when this technique was evaluated in clinically normal teeth, no advantage was seen in using a higher concentration (1:50,000 versus 1:100,000) of epinephrine.[80,425]

Addition of Hyaluronidase

Hyaluronidase reduces the viscosity of the injected tissue, permitting a wider spread of injected fluids.[21] Early studies in dentistry found that an IAN block was more easily attained and was more complete when hyaluronidase was added to an anesthetic solution.[230,258] A recent study found that hyaluronidase may increase the duration of the effects of lidocaine.[377] However, a controlled clinical trial found that adding hyaluronidase to a lidocaine solution with epinephrine did not statistically increase the incidence of pulpal anesthesia in IAN blocks.[360] In addition, hyaluronidase increased the occurrence of adverse effects (i.e., increased pain and trismus).[360]

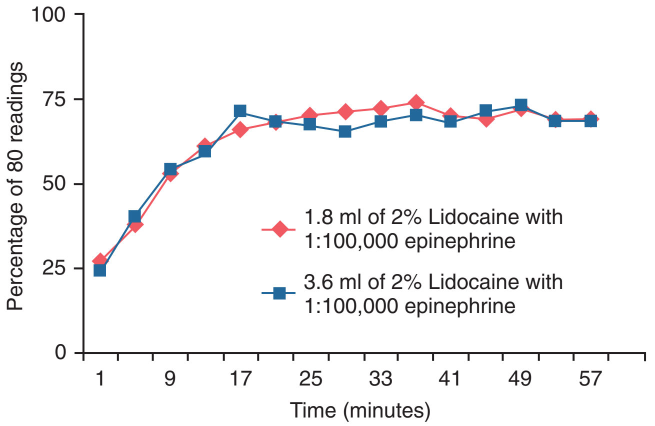

FIG. 4-7 **Incidence of first mandibular molar anesthesia: comparison of 1.8 ml and 3.6 ml of 2% lidocaine with 1:100,000 epinephrine.** Results were determined by lack of response to electrical pulp testing at the maximum setting (percentage of 80 readings) across time for 60 minutes. No significant difference between the two volumes was noted.

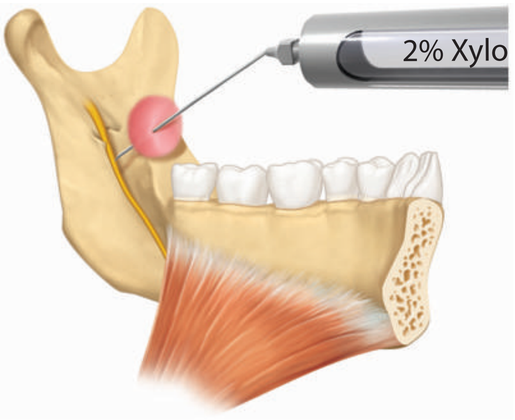

FIG. 4-8 Injection site for the mylohyoid nerve block.

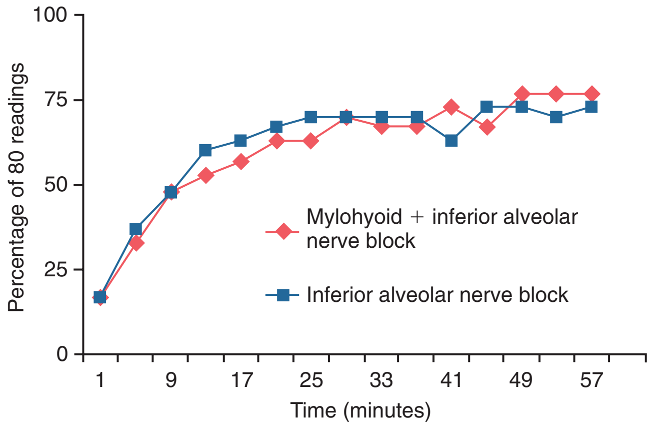

FIG. 4-9 Incidence of first mandibular molar anesthesia: comparison of the combination mylohyoid infiltration plus the inferior alveolar nerve block to the inferior alveolar nerve block alone. Results were determined by lack of response to electrical pulp testing at the maximum setting (percentage of 80 readings) across time for 60 minutes. No significant difference between the two techniques was noted.

CARBONATED ANESTHETIC SOLUTIONS

Experimentally, carbonated anesthetic solutions are more effective because the anesthetic is trapped in the nerve.[60] In addition, carbon dioxide (CO_2) has a synergistic relationship with local anesthetics and a direct depressant action on nerves.[60] However, a controlled clinical study was unable to demonstrate a superior effect of lidocaine hydrocarbonate in IAN blocks.[60]

Diphenhydramine as a Local Anesthetic Agent

Diphenhydramine (Benadryl) has been advocated for patients who are allergic to commonly used local anesthetics. Two studies found that diphenhydramine was less effective than lidocaine for extractions.[286,432] Another study found that the combinations of lidocaine/diphenhydramine with epinephrine, and diphenhydramine with epinephrine, were significantly less effective for pulpal anesthesia than lidocaine with epinephrine for IAN blocks.[440] These researchers also found that the diphenhydramine solutions were more painful on injection and had a high incidence of moderate postoperative pain.

Addition of Meperidine to Lidocaine

Two studies found that the addition of meperidine (Demerol) to a lidocaine formulation did not increase the success of the IAN block.[37,151]

FACTORS IN FAILURE OF THE INFERIOR ALVEOLAR NERVE BLOCK

Accessory Innervation: Mylohyoid Nerve

The mylohyoid nerve is the accessory nerve most often cited as a cause of failure of mandibular anesthesia.[127,441] A controlled clinical trial compared the IAN block alone to a combination of the IAN block and a mylohyoid nerve block using 2% lidocaine with 1:100,000 epinephrine (Fig. 4-8), which was aided by the use of a peripheral nerve stimulator.[66] The investigators found that the mylohyoid injection did not significantly enhance pulpal anesthesia of the IAN block (Fig. 4-9), so the study does not support the hypothesis that the mylohyoid nerve is a major factor in failure of the IAN block.

Accuracy of Injection

It has been theorized that an inaccurate injection contributes to inadequate mandibular anesthesia, but a number of studies determined that the use of ultrasound, a peripheral nerve stimulator, or radiographs to guide needle placement for IAN blocks did not result in more successful pulpal anesthesia.[35,134,165,387] The authors of these studies speculated that the anesthetic solution migrated along the path of least resistance, which was determined by fascial planes and structures encountered in the pterygomandibular space. These studies highlight an important clinical point: Lack of pulpal anesthesia is not necessarily the result of an inaccurate injection.

Needle Deflection

Needle deflection has been proposed as a cause of failure with the IAN block.[70,83,182] Several in vitro studies have shown that beveled needles tend to deflect toward the nonbeveled side (i.e., away from the bevel).* To compensate for this, a bidirectional needle rotation technique using the computer-controlled local anesthetic delivery system (CCLAD) (Milestone Scientific, Livingston, New Jersey) has been proposed in which the CCLAD handpiece assembly and needle are rotated in a fashion similar to the rotation of an endodontic hand file.[182] The technique was found to reduce deflection during insertion of the needle. A controlled clinical trial compared the anesthetic success of the conventional IAN block using two needle insertion methods.[224] However, no significant difference in anesthetic success was seen when the needle bevel was oriented away from the mandibular ramus (so that the needle would deflect toward the mandibular foramen [50% success]) compared with the bidirectional CCLAD needle rotation technique (56% success).[224] Neither technique resulted in an acceptable rate of anesthetic success in patients with symptomatic irreversible pulpitis.

Needle Bevel and Success

In asymptomatic subjects, the orientation of the needle bevel away or toward the mandibular ramus for an IAN block did

*References 13, 70, 83, 182, 199, and 363.

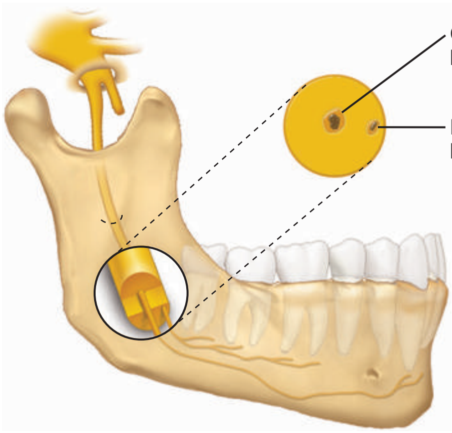

FIG. 4-10 Central core theory. The axons in the mantle bundle supply the molar teeth, and those in the core bundle supply the anterior teeth. The extraneural local anesthetic solution diffuses from the mantle to the core. (Modified and redrawn from De Jong RH: *Local anesthetics,* St Louis, 1994, Mosby.)

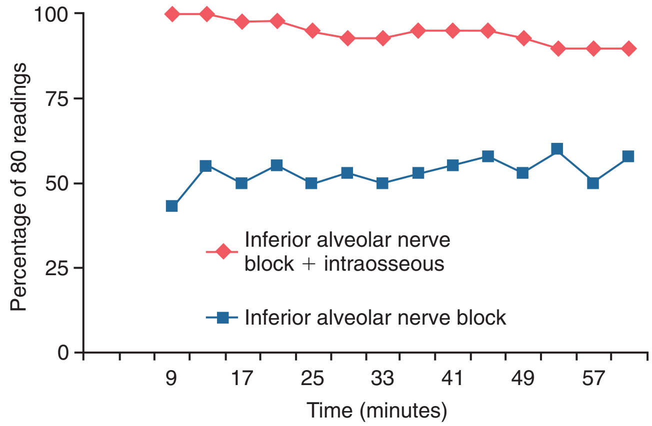

FIG. 4-11 Incidence of first mandibular molar anesthesia: comparison of the combination intraosseous injection of 2% lidocaine with 1:100,000 epinephrine plus the inferior alveolar nerve block to the inferior alveolar nerve block alone. Results were determined by lack of response to electrical pulp testing at the maximum setting (percentage of 80 readings) across time for 60 minutes. The combination technique was significantly better at all postinjection times.

not affect anesthetic success or failure.[405] Therefore, the use of commercial needles with markers to indicate the needle bevel is not necessary.

Speed of Injection and Success

A slow inferior alveolar nerve block increases success over a fast injection[204] but not for patients diagnosed with irreversible pulpitis.[9]

Cross-Innervation

Cross-innervation from the contralateral inferior alveolar nerve has been implicated in failure to achieve anesthesia in anterior teeth after an IAN injection. Experimentally, cross-innervation occurs in incisors[367,458] but plays a very small role in failure of an IAN block.

Red Hair

In medicine, red-haired females have shown reduced subcutaneous efficacy of lidocaine and increased requirements for desflurane.[102] However, in dentistry, having red hair was unrelated to success rates of the inferior alveolar nerve block,[102] although it has been shown to be associated with higher levels of dental anxiety.[102]

A Theory on Why Failure Occurs with the Inferior Alveolar Nerve Block in Restorative Dentistry

The central core theory may be the best explanation of why failure occurs with the IAN block.[85,407] According to this theory, nerves on the outside of the nerve bundle supply molar teeth, and nerves on the inside of the nerve bundle supply anterior teeth (Fig. 4-10). Even if deposited at the correct site, the anesthetic solution may not diffuse into the nerve trunk and reach all nerves to produce an adequate block. Although this theory may explain the higher experimental failure rates with the IAN block in anterior teeth compared with posterior teeth,* it does not explain the increased failure rate observed in painful teeth.

*References 60, 112, 165, 179, 277, 322, 353, 388, 424, and 425.

ENHANCEMENT OF MANDIBULAR ANESTHESIA FOR RESTORATIVE DENTISTRY

Supplemental Articaine Infiltrations

An important clinical finding is that an articaine infiltration of the first molar, premolars, and anterior teeth after an IAN block should provide pulpal anesthesia for approximately 1 hour.[163,206,326] The second molar may require a supplemental intraosseous (IO) or intraligamentary (IL) injection to achieve success.

Supplemental Intraosseous Anesthesia

Supplemental IO injections of lidocaine and mepivacaine with vasoconstrictors allow quick onset and increase the success of the inferior alveolar nerve block for approximately 60 minutes (Fig. 4-11).[103,158] The addition of a supplemental IO injection reduced the incidence of slow onset of pulpal anesthesia to zero compared with the IAN block alone (18% incidence).[103] Using 3% mepivacaine plain for IO injection results in pulpal anesthesia for approximately 30 minutes (Fig. 4-12).[137]

Supplemental Intraligamentary Anesthesia

Supplemental IL injections of 2% lidocaine with 1:100,000 epinephrine increase the success of the inferior alveolar nerve block, but the duration is approximately 23 minutes.[61]

MAXILLARY ANESTHESIA FOR RESTORATIVE DENTISTRY

Descriptions of conventional techniques for maxillary anesthesia are available for review in numerous articles and textbooks.[195,262]

2% Lidocaine with 1:100,000 Epinephrine

As a frame of reference, the most commonly used injection for anesthetization of maxillary teeth is infiltration with a cartridge of 2% lidocaine with 1:100,000 epinephrine.

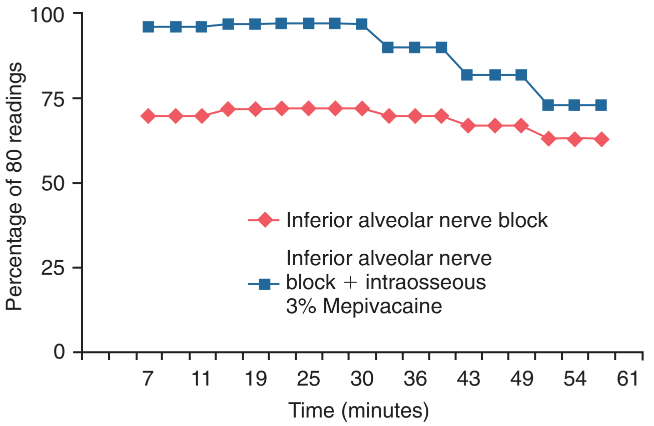

FIG. 4-12 Incidence of first mandibular molar anesthesia: comparison of the combination intraosseous injection with 3% mepivacaine plus the inferior alveolar nerve block to the inferior alveolar nerve block alone. Results were determined by lack of response to electrical pulp testing at the maximum setting (percentage of 80 readings) across time for 60 minutes. The combination technique proved significantly better for approximately 30 minutes.

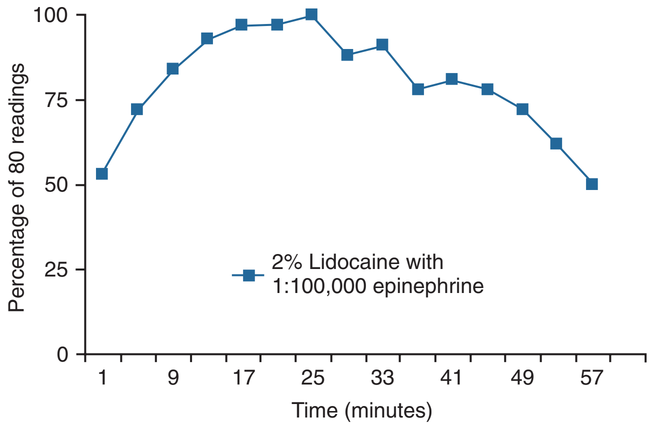

FIG. 4-13 Incidence of first maxillary molar anesthesia, as determined by lack of response to electrical pulp testing at the maximum setting (percentage of 80 readings) across time for 60 minutes.

Anesthetic Success

Infiltration results in a fairly high incidence of successful pulpal anesthesia (around 87% to 92%).[*] However, some patients may not be anesthetized because of individual variations in response to the drug administered, operator differences, and variations of anatomy and tooth position.

Onset of Pulpal Anesthesia

Pulpal anesthesia usually occurs in 3 to 5 minutes.[†]

Duration of Pulpal Anesthesia

The duration of pulpal anesthesia is a problem with maxillary infiltrations.[‡] Pulpal anesthesia of the anterior teeth declines after about 30 minutes, with most losing anesthesia by 60 minutes.[§] In premolars and first molars, pulpal anesthesia is good until about 40-45 minutes and then it starts to decline.[‖] Additional local anesthetic should be administered depending on the duration of the procedure and the tooth group affected.

Time Course of Pulpal Anesthesia for the Maxillary First Molar

Figure 4-13 shows the time course for complete pulpal anesthesia for an asymptomatic first molar, as defined by the percentage of patients who do not respond at all to an EPT stimulus over time. Some patients had a slow onset of anesthesia until around 11 minutes. The overall success rate (no response at the device's highest setting) is 95% to 100%, with peak effects observed at around 30 minutes after injection.

*References 48, 108, 156, 211, 246, 272, 287, 324, 334, 353, and 381.
†References 48, 108, 156, 211, 246, 272, 287, 324, 334, 353, and 381.
‡References 48, 108, 156, 211, 246, 272, 287, 324, 334, 353, and 381.
§References 48, 108, 156, 211, 246, 272, 287, 324, 334, 353, and 381.
‖References 48, 108, 156, 211, 246, 272, 287, 324, 334, 353, and 381.

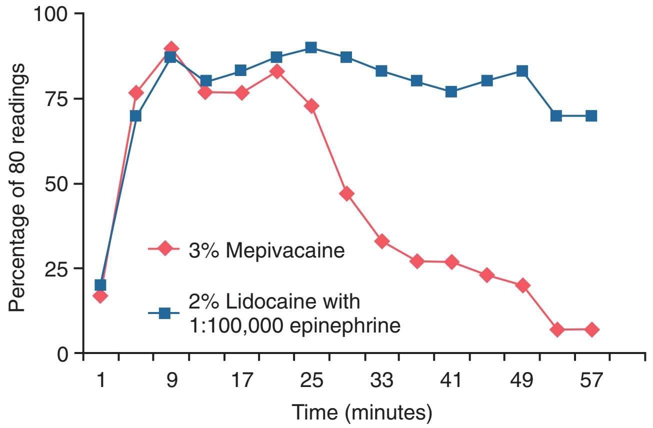

FIG. 4-14 Incidence of first maxillary molar anesthesia: comparison of 3% mepivacaine to 2% lidocaine with 1:100,000 epinephrine. Results were determined by lack of response to electrical pulp testing at the maximum setting (percentage of 80 readings) across time for 60 minutes. The 3% mepivacaine showed a shorter duration of anesthesia than the lidocaine solution.

Significance of Lip Numbness

Soft tissue anesthesia (lip or cheek numbness) is not necessarily related to the duration of pulpal anesthesia. Pulpal anesthesia does not last as long as soft tissue anesthesia.[156,272,287]

ALTERNATIVE ANESTHETIC SOLUTIONS FOR INFILTRATIONS

Plain Solutions: 3% Mepivacaine (Carbocaine, Polocaine, Scandonest) and 4% Prilocaine (Citanest Plain)

Anesthesia duration is shorter with these solutions.[211,272] Therefore, use these for procedures of short duration (10 to 15 minutes) (Fig. 4-14). These agents are generally not as safe as solutions with vasoconstrictors if *large* volumes are administered because they are rapidly absorbed systemically, resulting in excessive plasma concentrations and possible toxic reactions.[262]