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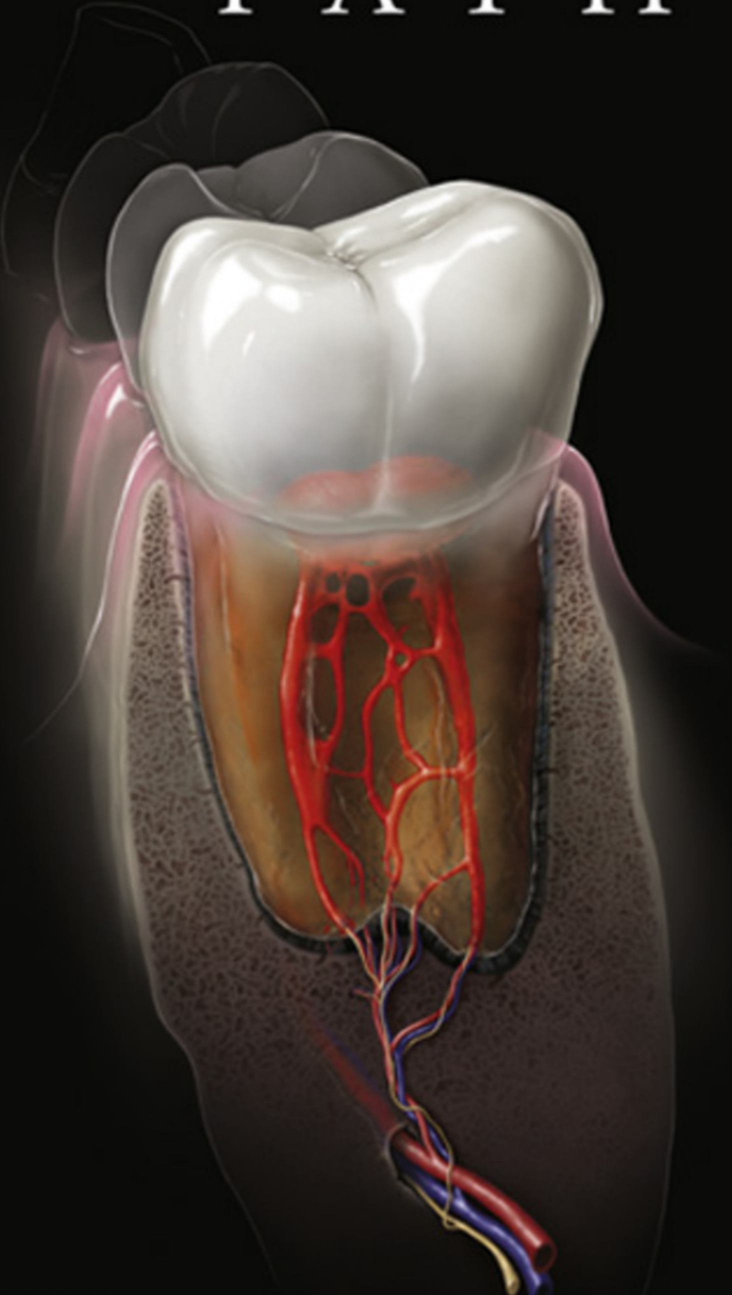
KENNETH M. HARGREAVES | LOUIS H. BERMAN

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
Louis H. Berman

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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.

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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.)

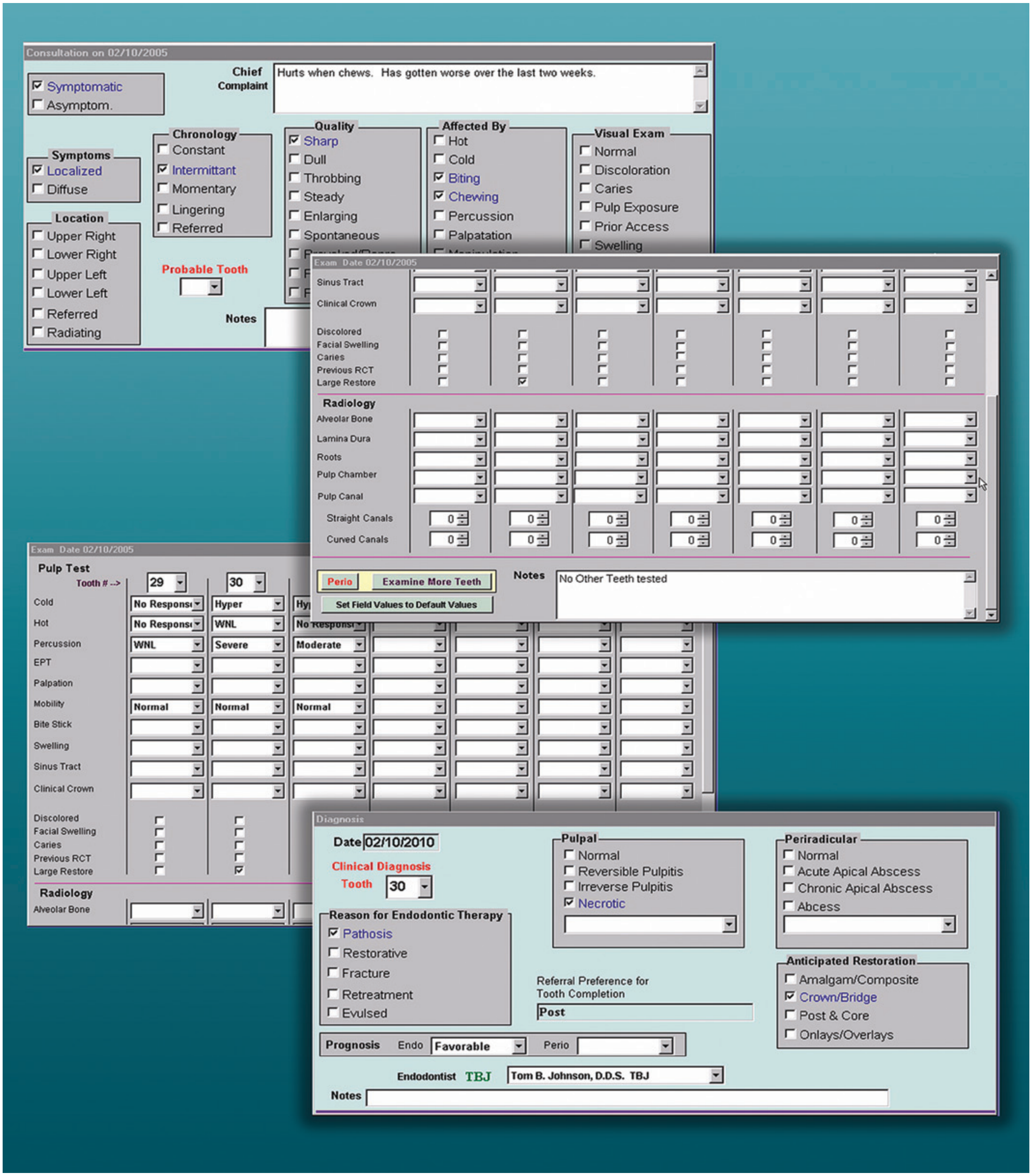

FIG. 1-4 Several practice management software packages have features for charting endodontic diagnoses using user-defined drop-down menus and areas for specific notations. Note that for legal purposes, it is desirable that all recorded documentation have the ability to be locked, or if any modifications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

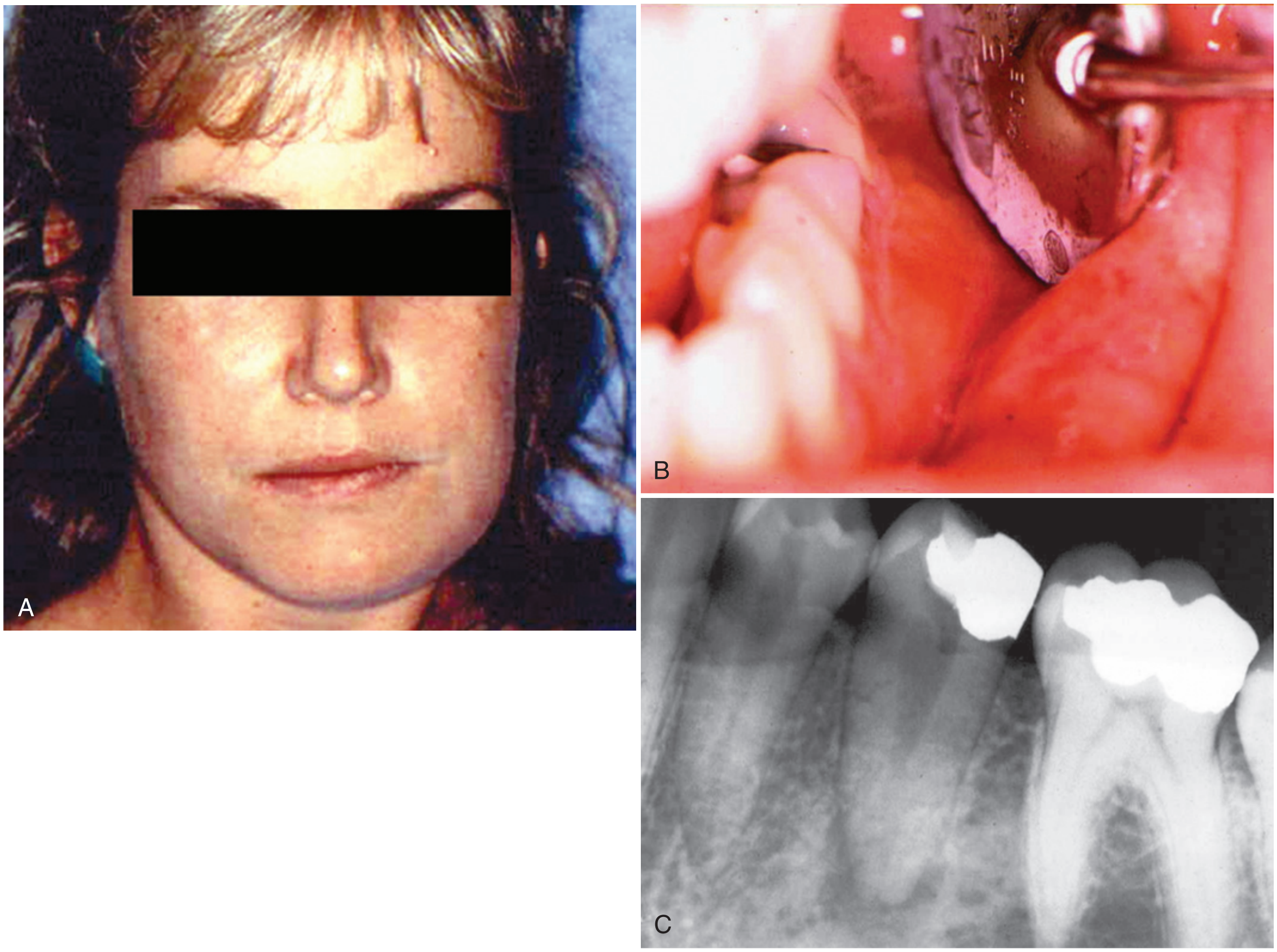

FIG. 1-7 **A,** Buccal space swelling of the left side of the patient's face. Note the asymmetry of the left side of the face. **B,** Intraoral view shows swelling present in the left posterior mucobuccal fold. **C,** This buccal space infection was associated with periradicular disease from the mandibular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

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.

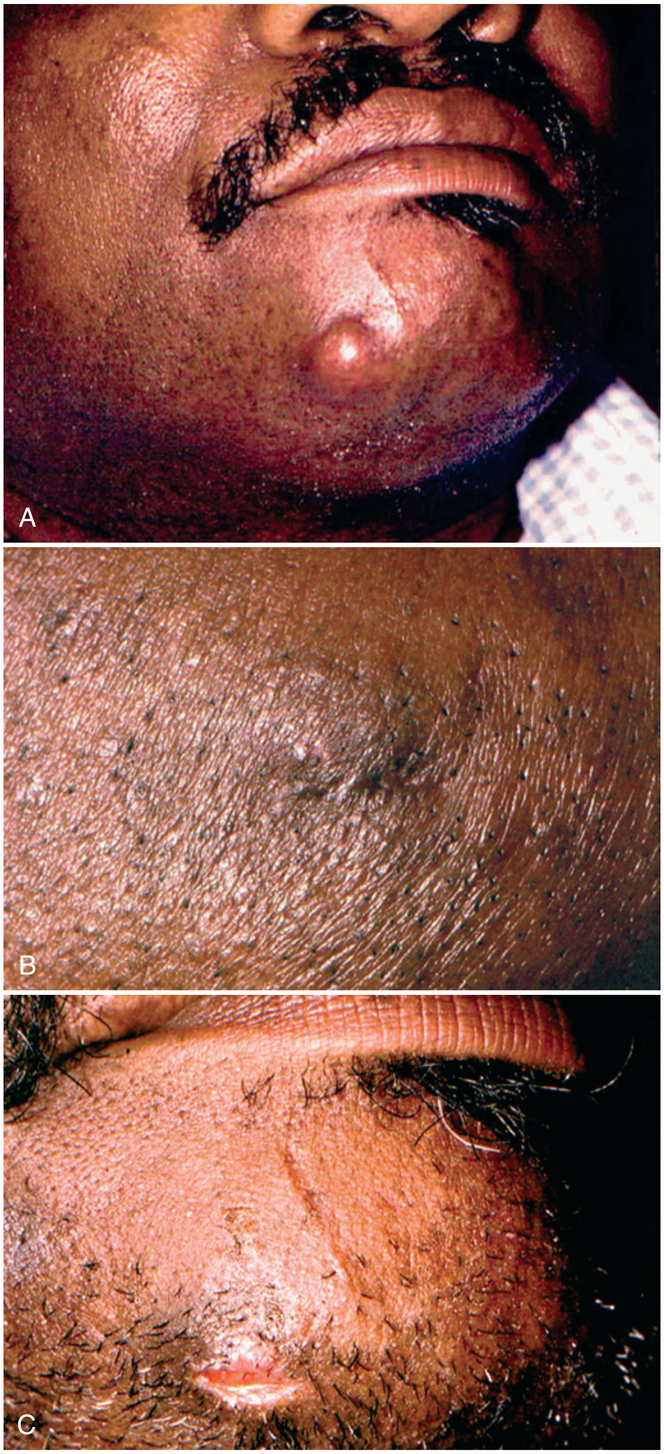

FIG. 1-9 A, Extraoral drainage associated with periradicular disease from the mandibular right canine. Note the parulis on the right anterior side of the face. B, Initial scar associated with the extraoral drainage incision after the parulis was drained and root canal therapy performed on the canine.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

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]

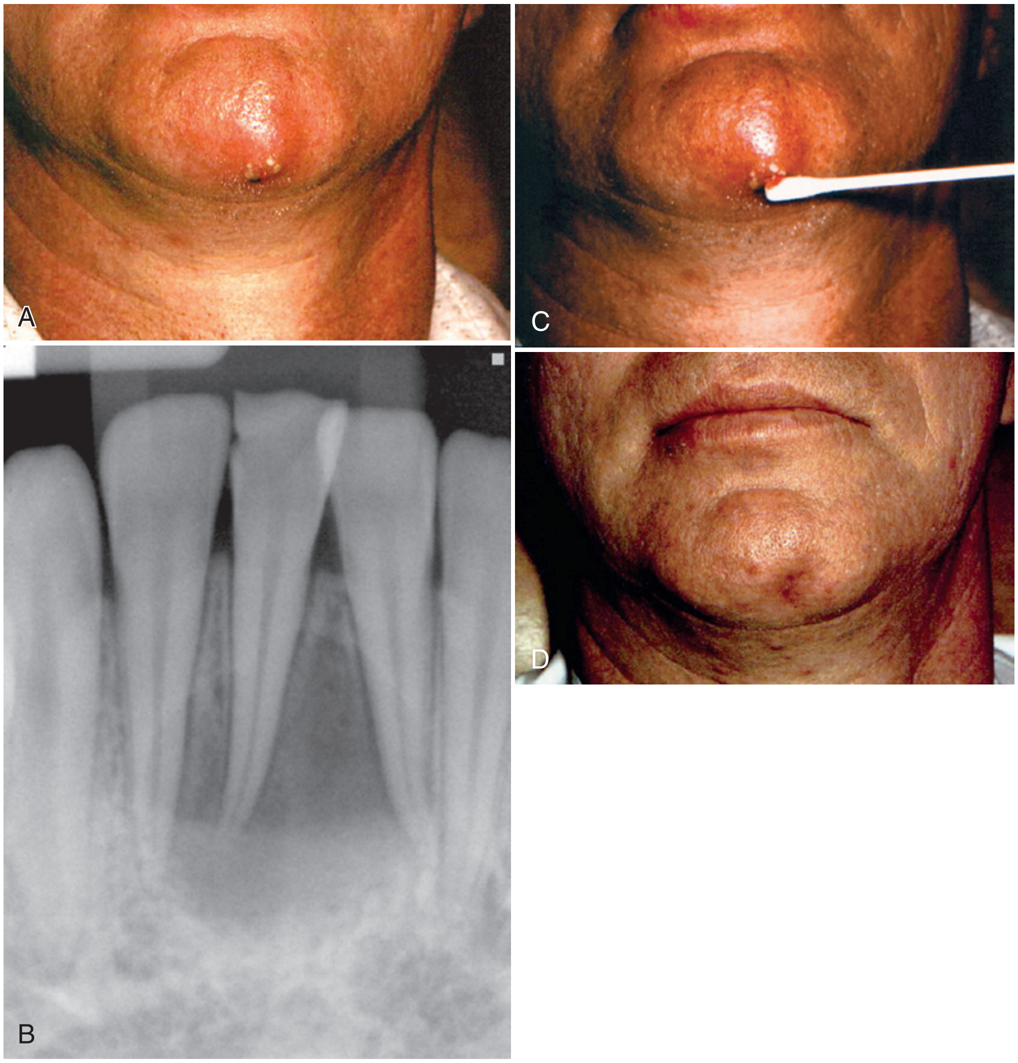

FIG. 1-10 A, Extraoral sinus tract opening onto the skin in the central chin area. B, Radiograph showing large radiolucency associated with the mandibular incisors. C, A culture is obtained from the drainage of the extraoral sinus tract. D, The healed opening of the extraoral sinus tract 1 month after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

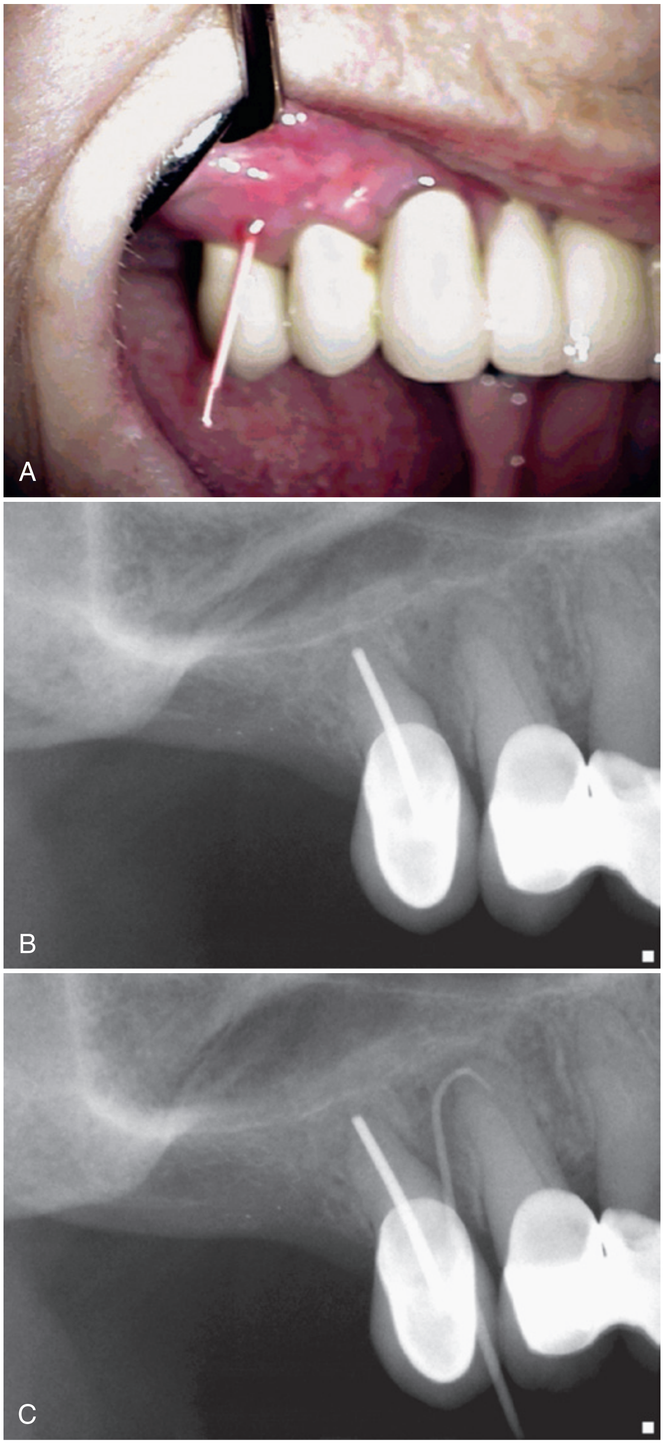

FIG. 1-14 **A,** To locate the source of an infection, the sinus tract can be traced by threading the stoma with a gutta-percha point. **B,** Radiograph of the area shows an old root canal in a maxillary second premolar and a questionable radiolucent area associated with the first premolar, with no clear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

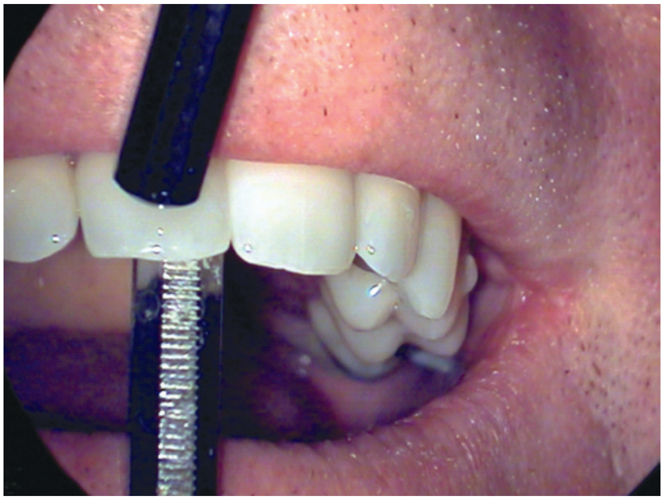

FIG. 1-16 Mobility testing of a tooth, using the back ends of two mirror handles.

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

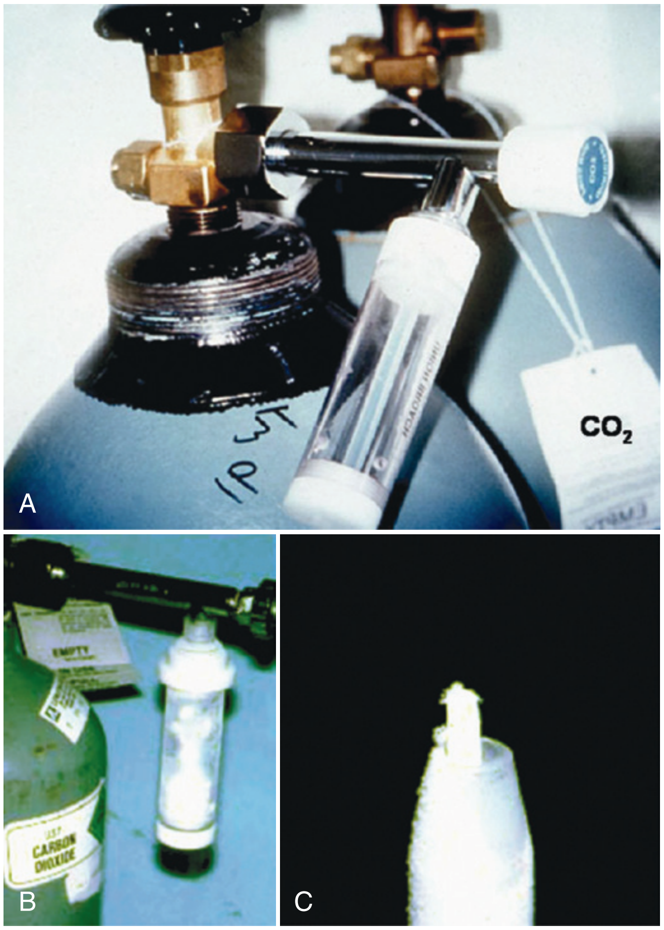

FIG. 1-17 **A**, Carbon dioxide tank with apparatus attached to form solid CO_2 stick/pencil. **B**, CO_2 gas being transformed into a solid stick/pencil. **C**, CO_2 stick/pencil extruded from end of a plastic carrier and ready for use.

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]

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 midfacial 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.

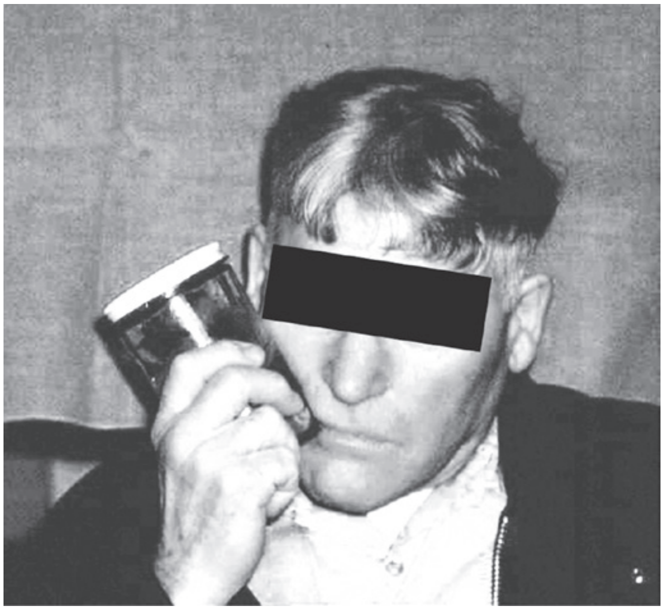

FIG. 1-19 Irreversible pulpitis associated with the mandibular right second molar. Patient has found that the only way to alleviate the pain is to place a jar filled with ice water against the right side of his face.

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

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

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.)

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. 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

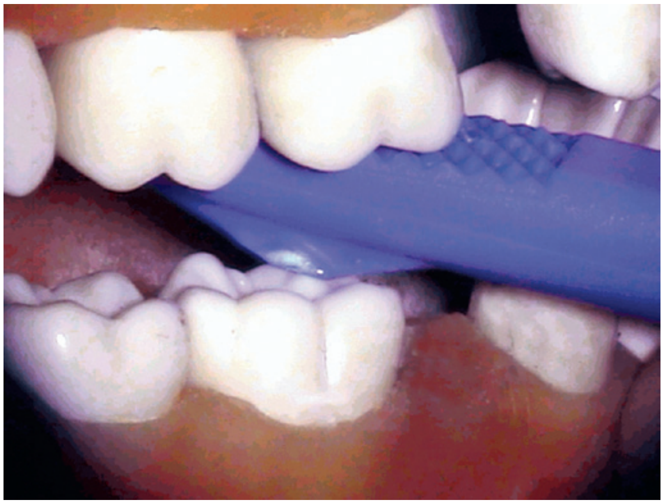

FIG. 1-22 To determine which tooth, or tooth part, is sensitive to mastication, having the patient bite on a specially designed bite stick is often helpful.

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,

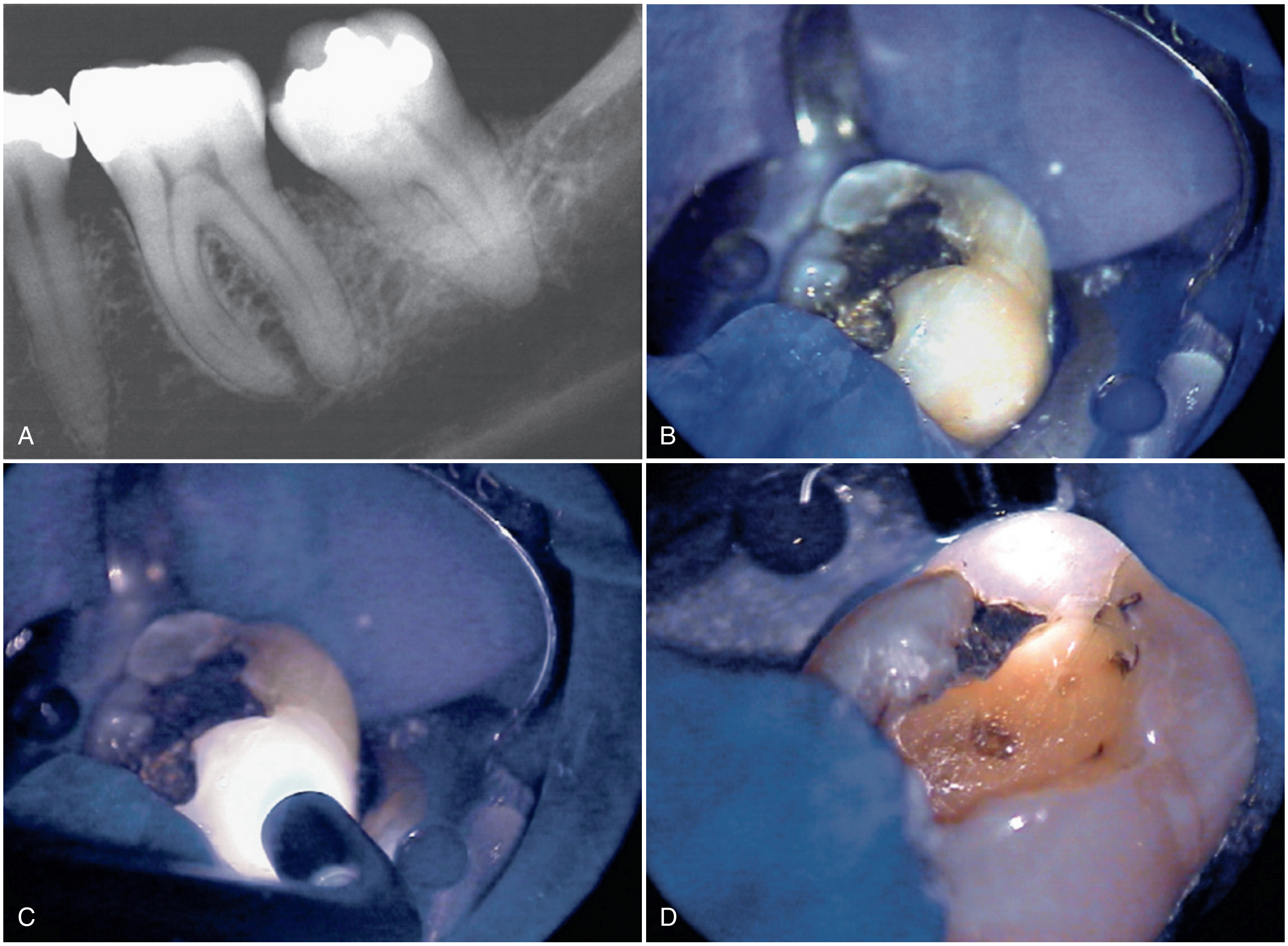

FIG. 1-23 Sometimes there is no clear indication of why a tooth is symptomatic. This radiograph shows a mandibular second molar with a moderately deep restoration (**A**); the pulp tests nonvital. Without any transillumination, a fracture cannot be detected (**B**). However, by placing a high-intensity 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.

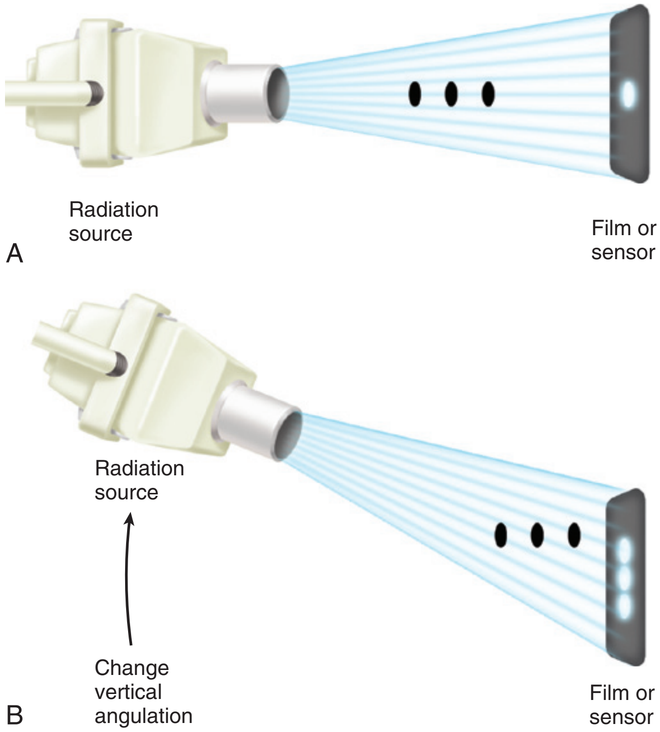

FIG. 1-25 Radiographic images are only two-dimensional, and often it is difficult to discriminate the relative location of overlapping objects. **A,** When the source of radiation is directly perpendicular to overlapping objects, the image is captured without much separation of the objects. However,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