Clinical Endodontics

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QUINTESSENCE PUBLISHING

Dedication

To John Dresser, whose continued commitment to excellence and the pursuit of knowledge sets the highest bar for what it means to provide exceptional patient-centered care.

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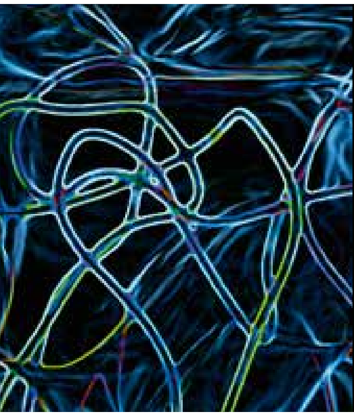

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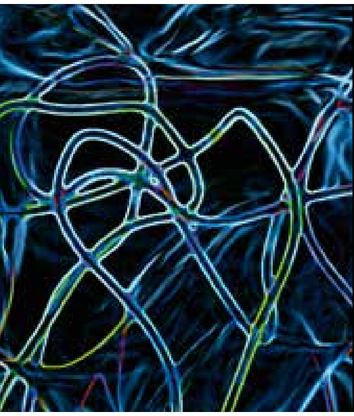

Preface

Endodontic care is integral to the practice of dentistry. Sadly, however, many practitioners are intimidated by endodontic diagnosis and treatment planning. This text aims to cover the full breadth of endodontic diagnosis and care to bring an evidence-based perspective to clinical practice. The vast swath of endodontic literature offers clinicians both classic wisdom and new information that can be applied directly to patient care, and readers will find literature references throughout the text to support evidence-based practice.

Though the origins of this book were in the development of predoctoral endodontics curricula, its comprehensive scope renders it useful for practitioners of all levels, including dental students, residents, general practitioners, and specialists alike. Even providers who do not perform the full scope of endodontic procedures should be knowledgeable about their existence and availability.

The main text is dedicated to the overall theory and biologic basis of diagnosis and treatment, including detailed procedure guides. The Quick Guide, found at the back of the book, is modeled on cookbooks and includes tray setups and step-by-step procedural instructions, making this guide useful for not only practitioners but also clinical staff tasked with operatory setup.

We hope you enjoy our illustrated and evidence-based guide to clinical endodontic practice and that it promotes both your learning and the delivery of excellent clinical care.

PART I

Establishing a Diagnosis

The practice of endodontics is grounded in the management of orofacial pain and infection. Pain and infection, however, are not exclusive to endodontic pathology. Furthermore, not all endodontic diagnoses warrant endodontic treatment. The establishment of an accurate and complete diagnosis is an essential prerequisite for any endodontic treatment. This section of the text discusses the materials and techniques for detecting and diagnosing endodontic pathology, as well as its differential diagnosis.

1

Examination Protocols

Diagnosis is the foundation of endodontics. The diagnosis of endodontic pathology and orofacial pain requires gathering a careful patient history and performing both clinical and radiographic examinations. These components are referred to as the subjective and objective exams. Taken together, the exam findings are used to establish the patient's diagnosis and direct the selection and provision of appropriate treatment modalities. This chapter reviews the components of the diagnostic exam.

Subjective Examination

As is true of all medical and dental encounters, a thoughtful and thorough patient interview, also known as the subjective examination, is both foundational to the development of a trusting patient-clinician relationship and provides necessary information to direct the objective examination that follows. This interview can take place either in person or, when in-person encounters are not possible, as a telehealth encounter via phone or video as permitted by local practice laws. The components of the subjective exam are *(1)* the chief complaint, *(2)* the history of the present illness (HPI), *(3)* the past dental history (PDH), and *(4)* the medical history (Fig 1-1).

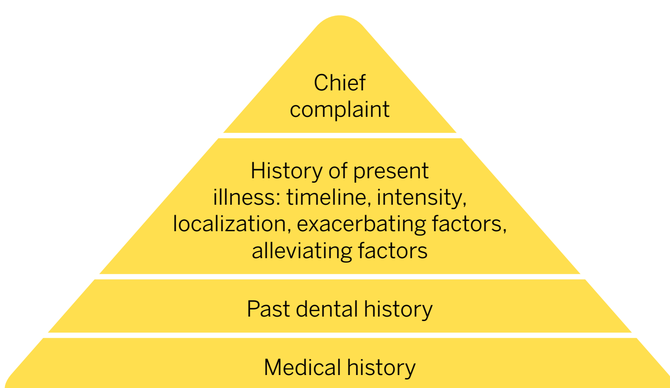

FIG 1-1 The components of the subjective examination.

The chief complaint is the reason the patient is seeking care. This should be recorded in the patient's own words, not only to demonstrate to the patient that their concerns are understood but also to ensure that treatment plans address the patient's explicit and individualized needs.

The HPI should further develop the clinician's understanding of the patient's chief complaint. If not immediately volunteered, the timeline of symptoms (ie, the onset and duration) and their trajectory over time (increased, decreased, or steady) should be established. Furthermore, clinicians must inquire about symptom intensity, localization, and exacerbating and alleviating factors. If analgesic use is reported, the timing of the last dosage should be established because medications may directly affect responses to clinical testing.

Because endodontic pathology develops as a result of pulpal irritation, the PDH provides clues to the etiology of the chief complaint, including but not limited to restorative care, endodontic treatment, fractures, and trauma. The setting, type, and timing of prior dental care should be ascertained. If trauma is included in the history, the specifics surrounding the traumatic injury must be understood. Deep restorative care may result in the development of endodontic pathology years after treatment.[1] Teeth with a history of deep restorations face a lifetime of elevated risk for requiring nonsurgical root canal therapy (NSRCT), with the risk being further increased for teeth serving as abutments for partial dentures than for those supporting single crowns.[2–6]

As with all dental examinations, a thorough medical history, including past and present illnesses, medications, and allergies, should be obtained. The medical history can alert clinicians to medications and conditions that may interfere with endodontic diagnosis. Ibuprofen taken to treat the chief complaint or another painful condition can directly mitigate responses to clinical testing, including responses to percussion, palpation, and cold testing.[7] Additionally, a history of head/neck radiation may lessen the expected responses to pulp sensitivity testing.[8]

The medical history may also alert clinicians to other medications or conditions that could impact the delivery of care. Blood thinners warrant consideration both because of their direct effects in increasing bleeding in cases of planned surgical care and because they contraindicate the use of nonsteroidal anti-inflammatory drug (NSAID) family pain relievers.[9,10] Antiresorptive medications, including bisphosphonate and RANKL inhibitors, or a history of head/neck radiation therapy affect treatment planning because they increase the risk of osteonecrosis following invasive dental procedures, including surgical endodontic care and extractions.[11–13] Patients with poorly controlled diabetes or other systemic or drug-related immune system compromise may have difficulty healing from infections, and consideration might be made for antibiotic coverage in consultation with their physicians.[14] Cardiac conditions warranting antibiotic premedication for endodontic procedures should be documented.[15,16]

Measurement of vital signs should also be included in the review of a patient's medical history. This should include measurement of the patient's blood pressure and body temperature. An oral or temporal temperature is important for detecting systemic effects of infection. A high-quality thermometer should be used and the measurement recorded in the patient's chart whenever infection is suspected.

The results of the subjective exam should be recorded in the patient's chart. From a medico-legal perspective, this ensures that patient needs and desires are being communicated and addressed. Most importantly, the patient interview should develop the clinician's differential diagnosis. The interview and differential diagnosis should then be utilized to guide the objective examination that follows.

Objective Examination

The objective examination includes both a clinical and radiographic examination. The clinical exam consists of a careful extraoral and intraoral inspection of the hard and soft tissues, as well as clinical testing. The radiographic examination should include both 2D and 3D radiographs, when relevant. The standard armamentarium for the objective endodontic exam is shown in Fig 1-2, and the clinical components are detailed in Fig 1-3.

FIG 1-2 The standard armamentarium for the clinical examination includes a clean mirror, an explorer, a periodontal probe, cotton-tipped applicators or pliers with a no. 2 or no. 4 cotton pellet, refrigerant spray, and bite testing implements including cotton rolls and/or commercially available bite testers, such as a Tooth Slooth (Professional Results) or Fracfinder (Denbur).

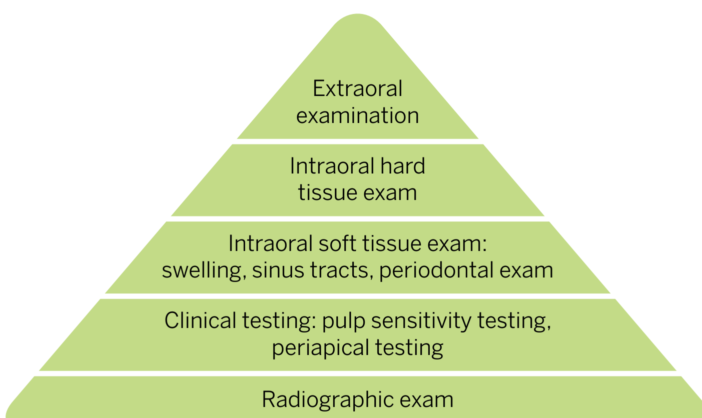

FIG 1-3 The components of the objective examination.

Extraoral examination

The extraoral examination of the head and neck should assess for swelling, asymmetries, and lymphadenopathy (Fig 1-4). The quality of any swelling should be assessed as fluctuant or firm. Palpation of submandibular and cervical lymph nodes can be used to detect lymphadenopathy resulting from infections of the head and neck region, though not necessarily specific to the dentition. Extraoral sinus tracts, though rare, should also be documented. These represent a means of drainage from an infected tooth. As with intraoral sinus tracts, they should be radiographically traced with gutta-percha to confirm the source.

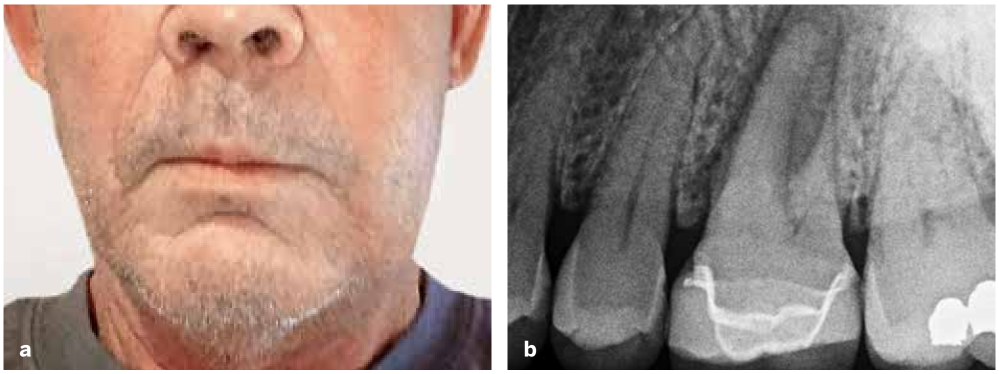

FIG 1-4 Extraoral swelling *(a)* may indicate an endodontically derived cellulitis, such as this case that occurred secondary to pulpal necrosis with acute apical abscess of the maxillary left first molar *(b)*.

The muscles of mastication and the temporomandibular joint should also be inspected during the extraoral examination (Fig 1-5). Palpation of the masseter and temporalis muscles, particularly in patients with a history of bruxism, is essential to evaluate whether a patient's chief complaint is the result of myofascial pain as opposed to endodontic pathology.

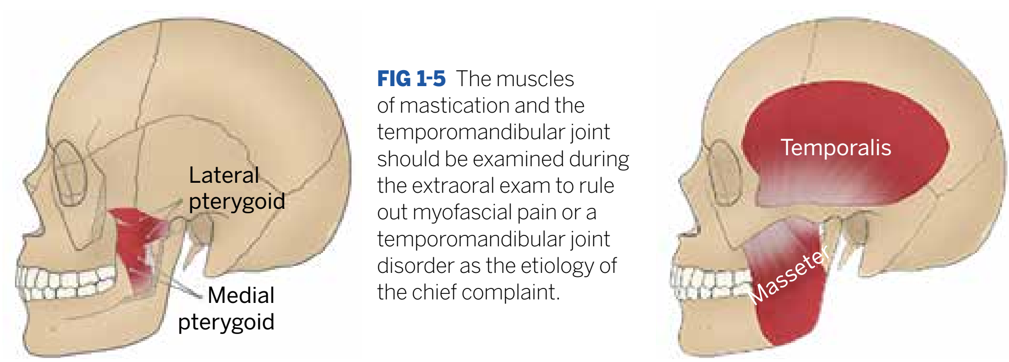

FIG 1-5 The muscles of mastication and the temporomandibular joint should be examined during the extraoral exam to rule out myofascial pain or a temporomandibular joint disorder as the etiology of the chief complaint.

Adjunctive trauma examination

When evaluating traumatic dental injuries, the objective examination should be expanded if the clinician is the first to examine the patient following the injury. A primary patient survey should be conducted following the mnemonic **ABCDE**. Clinicians must ensure a patent **airway** and stabilized cervical spine. They should also ensure that there is adequate **breathing** and ventilation and intact **circulation** without evidence of shock. Clinicians must assess for neurologic **disability**, and the patient should be fully undressed to achieve **exposure** of the full body for examination.[17] Additionally, because dental trauma carries the risk of concomitant head trauma, a neurologic screening tool, such as the Glasgow Coma Scale,[18,19] should be used to rule out neurologic compromise or decompensation, which would warrant immediate EMS referral (Table 1-1).

TABLE 1-1 The Glasgow Coma Scale

Behavior	Response	Score
Eye Opening Response	Spontaneously To speech To pain No response	4 3 2 1
Best Verbal Response	Oriented to time, place, and person Confused Inappropriate words Incomprehensible sounds No response	5 4 3 2 1
Best Motor Response	Obeys commands Moves to localized pain Flexion withdrawal from pain Abnormal flexion (decorticate) Abnormal extension (decerebrate) No response	6 5 4 3 2 1
Total Score	Best response Comatose client Totally unresponsive	15 8 or less 3

Intraoral examination

Hard tissue examination

A comprehensive examination of the dentition is crucial to establish both a potential etiology for endodontic pathology and to evaluate the restorability of the tooth or teeth in question. New or recurrent carious lesions should be identified. Assessment of the lesions with a dental explorer not only discloses caries depth but also reveals any associated sensitivity indicative of near or frank exposures of the adjacent pulp. The overall quality of existing restorations should be evaluated because poorly sealed restorations can permit coronal leakage even in the absence of frank caries.

Cracks or fractures should be visualized and explored for loss of tooth structure and separation or mobility between fractured segments. Cracks and fractures may be better visualized with the use of a fiber optic light to transilluminate the fracture line itself; the fracture will stop transmission of the light, delineating a clear break.[20,21] Certain dyes, including vegetable-based versions (eg, To Dye For, Roydent) and methylene blue, can also be used to more clearly delineate coronal fracture lines[21] (Fig 1-6). It can be difficult to assess the depth of unseparated fracture lines running mesiodistally in posterior teeth due to extensions into interproximal spaces. That said, this assessment is crucial to determine the prognosis for a tooth (see chapters 11 and 14 for more on fractured teeth).

FIG 1-6 Dyes such as methylene blue or vegetable-based dyes can be used to better visualize fracture lines.

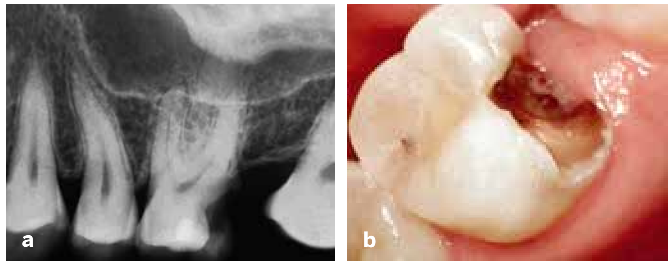

FIG 1-7 *(a and b)* The assessment of restorability should begin during the examination process because restorability dictates whether endodontic treatment can or should be provided in the presence of pulpal and periapical pathology. (Photo courtesy of Dr Alicia Willette.)

Whether caries or fractures are noted, clinicians must carefully evaluate restorability (Fig 1-7). Deep caries may violate biologic width, warranting consideration of adjunctive procedures, including crown-lengthening surgery or orthodontic extrusion. Cracks and fractures may similarly violate periodontal structures, warranting adjunctive procedures or extraction.

Just as caries and fractures must be assessed, so too must the color of the tooth or teeth in question. Discoloration of a tooth as compared to neighboring controls can indicate transient pulpal pathology or necrosis. Other discolorations may be present because of endodontic or restorative materials within the crown of the tooth, and although these may not create biologic issues, esthetic concerns may warrant management (Fig 1-8). The patient's level of concern about such discoloration will impact treatment planning, including the potential need for internal bleaching following endodontic treatment. Gray or brown discolorations suggest staining secondary to an infected pulp, whereas pink discolorations suggest resorptive etiologies.[22]

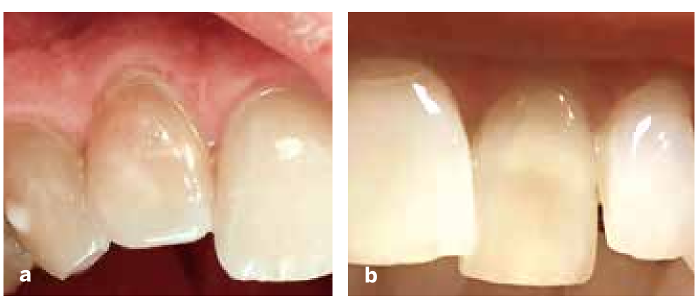

FIG 1-8 Discoloration of the dentition should be assessed as part of every endodontic evaluation. Pink discoloration *(a)* may indicate the development of a resorptive defect, whereas yellow, gray, or brown discoloration *(b)* points to pulpal necrosis or dental materials as the cause of discoloration.

A basic examination of occlusal patterns and contacts can be performed to check for alternative sources of pain as well as potential risk factors for fractures. Bruxism and parafunctional habits can both cause initial endodontic pathology when fractures develop and may cause posttreatment failures if not corrected. The presence of wear facets can similarly indicate parafunction and potential occlusal trauma.

It should be noted that there is a clear etiology for most cases of endodontic pathology. That said, spontaneous pulp necrosis may rarely occur due to adjacent nonodontogenic masses or tumors or surgical care leading to devitalization of roots. Case reports have additionally suggested that pulp necrosis might occur secondary to medical conditions including herpes zoster[23] and sickle cell anemia.[24]

Soft tissue examination

The intraoral soft tissues should be examined during every dental examination. The endodontic exam specifically aims to visualize any signs of intraoral swelling, sinus tracts, or periodontal defects.

- **Swelling:** Acute endodontic infections are associated with the development of swelling (Fig 1-9). Many intraoral swellings are visible, and manual palpation can also help to detect subtle swellings, especially when making comparisons to contralateral tissues. The location of the swelling must be carefully documented. Swelling associated with endodontic pathology is often detectable buccal or facial to the tooth, but palatal or lingual swellings may also develop. Endodontically derived swelling is most often located adjacent to the root apex of the affected tooth. Swelling located closer to the gingival margin raises suspicion of periodontal pathology, fractures, or resorptive defects but may also result from periodontal-endodontic infections.[25] As with extraoral swellings, the quality of the swelling as fluctuant or firm should be noted, as well as its dimensions and extension.

FIG 1-9 Localized swelling associated with endodontic pathology typically occurs adjacent to the apices of the teeth involved. This patient presented with an acute apical abscess associated with the maxillary left first molar. The fluctuant swelling was noted apical to the tooth. (Case courtesy of Dr Coco Lin.)

- **Sinus tracts:** Chronic endodontic infections are associated with sinus tracts. These sinus tracts present as an opening through the alveolar mucosa and may develop on the buccal or lingual/palatal aspects of teeth (Fig 1-10). Like swellings, sinus tracts of endodontic origin are typically located adjacent to the root apex of the affected tooth.[26] Coronally positioned sinus tracts raise suspicion of vertical root fractures or periodontal-endodontic infections. Because sinus tracts may not always present directly adjacent to their source, radiographic tracing with gutta-percha is essential. CBCT imaging represents an alternative radiographic means of assessing sinus tracts; the pathway of bone loss can be followed from the radiographic lesion to the sinus tract opening as visualized clinically.

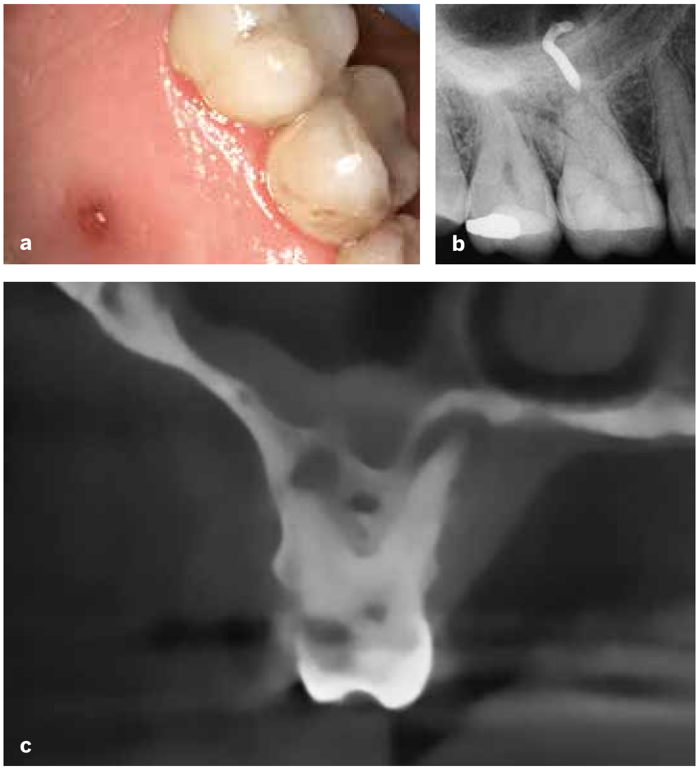

FIG 1-10 Sinus tracts indicate a draining infection, and radiographs must be used to confirm their source. Both periapical imaging utilizing a gutta-percha cone for tracing or CBCT imaging to accurately show the pathology and its tract through bone to soft tissue are acceptable options. In the case shown, a palatal sinus tract *(a)* was traced to the maxillary right first molar first with gutta-percha and periapical imaging *(b)* and then via CBCT imaging without tracing *(c)*.

- **Periodontal exam:** The soft tissue exam should include a limited periodontal exam, incorporating measurement of circumferential probing depths, detection of associated bleeding or purulence, assessment of mobility, and checking for recession (Fig 1-11). Localized narrow and deep probing measurements are associated with both periodontal-endodontic infections and vertical root fractures.[26] Wider defects or generalized probing depths, on the other hand, are more frequently associated with periodontal disease. Bleeding or purulence on probing can indicate inflammation or infection, respectively. Mobility of a single tooth may indicate severe periodontal disease or a larger endodontic infection with loss of bone support. Mobility of several teeth together suggests alveolar fracture.

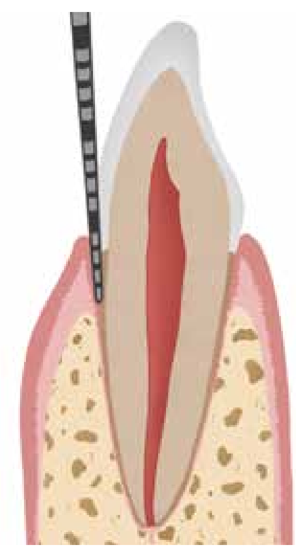

FIG 1-11 A limited periodontal exam, including an assessment of probing depths and mobility, should be performed on all teeth undergoing endodontic evaluation.

Clinical testing

The diagnosis of endodontic pathology requires an accurate replication of the patient's chief complaint. This is accomplished through clinical tests referred to as pulp sensitivity and periapical tests. These tests act as conduits to determine the health of the dental pulp and to detect signs of inflammation of the adjacent periodontal ligament (PDL).[27] The results should be considered as a whole. It is rare that the results of a single test can be used to confer the absolute diagnosis for a tooth. The results of two or more of these tests will confirm the presence or absence of endodontic disease.

As with all types of diagnostic tests, control testing is essential. These results must also be recorded in the patient's chart. Referred pain from endodontic pathology is common, and confirming the source of pain via clinical and radiographic exam findings is essential. Referral patterns include pain originating in neighboring teeth or even teeth in the opposing arch.[28] When the pain is difficult to localize, testing should be completed on all teeth in the suspected arch as well as the opposing arch. Contralateral teeth may be used as controls when neighboring controls are unavailable or perhaps have been previously endodontically treated. Consideration should be given to the type of restoration on control teeth because teeth with indirect restorations or metallic restorations may globally exhibit stronger responses to thermal testing than those with full-coverage restorations, particularly ceramic restorations. Clinicians must never ignore the possibility that more than one tooth may be the source of symptoms. Figure 1-12 provides an example of control selection.

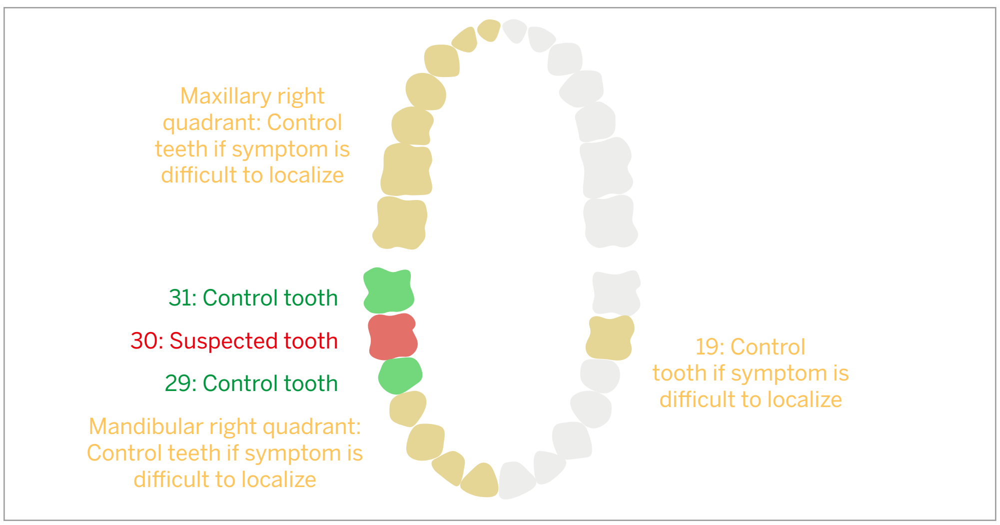

FIG 1-12 An example of control teeth used when testing for suspected pathology in the mandibular right first molar. At the very least, the adjacent second molar and second premolar should be tested as control teeth. In patients with poorly localized pain, the area of testing should be expanded to include the remaining teeth in the quadrant (teeth 25 to 28), as well as teeth in the opposing arch (teeth 2 to 8) to rule out referred pain. The mandibular left first molar can also be used as a control tooth; pulp sensitivity tests and PDL tests should provoke similar responses in the contralateral tooth.

PULP SENSITIVITY TESTS

Testing modalities that can be used to ascertain the health or disease of the pulp tissue include cold testing, heat testing, and electric pulp testing. Pulp sensitivity testing measures a response to conduit measures of nerve sensibility. Presently, no assessment methods for the true measures of pulp vitality are available for use in routine clinical

FIG 1-13 The armamentarium for pulp sensitivity testing should include a refrigerant spray (eg, EdgeIce, EdgeEndo) and either a cotton-tipped applicator or cotton pellet.

practice, but modalities are under investigation in laboratory settings. For now, the term "pulp sensitivity testing" is more accurate than "pulp vitality testing."

As a result of testing limitations and the fact that the presence of vital tissues does not always correspond to a response to tests, false positive and false negative results are possible. Limitations in accuracy must be considered whenever inconsistent test results arise, and a diagnosis should never be made based solely on the results of sensitivity testing. Pulp sensitivity tests are notoriously inaccurate in immature teeth[29] and immediately following traumatic dental injuries.[30] Consequently, extra care must be taken when making a diagnosis with these comorbidities.

Cold testing is the most accurate pulp sensitivity test currently available.[31] Refrigerant sprays are considered the safest and most convenient and effective means of cold testing.[31,32] These can be delivered to the surface of the tooth using either cotton-tipped applicators or a cotton pellet held with cotton pliers (Fig 1-13). Because the buccal or facial surface balances the needs for accessibility and proximity to the pulp chamber, it is the surface of choice for cold testing. That said, the occlusal and lingual or palatal surfaces can be tested when an initial response is not detected. A common issue with cold testing is insufficient application of the refrigerant spray to the cotton, which may not elicit a response. Thus, it is important to ensure that the delivery device is sufficiently soaked in cold spray, which may require several seconds of spraying to enhance test accuracy.

Patients should be instructed to raise their hand to communicate the sensation of cold or pain resulting from the test and to keep their hand raised until the sensation diminishes to allow for detection of both the presence and duration of the response. Additionally, patients should be asked to compare the intensity of the sensation felt after each tooth is tested in order to determine if a tooth exhibits a heightened or reduced response compared to controls. Although cold testing may be less accurate on teeth restored with full-coverage restorations,[33] testing should still be completed because many heavily restored teeth will continue to exhibit a response.[34] Ultimately, comparison with similarly restored controls allows for the best assessment of what is normal for the individual patient.

Although heat testing is not as accurate as cold testing,[31] it is useful when heat sensitivity is part of the patient's chief complaint. Heat sensitivity is most commonly reported in teeth with symptomatic irreversible pulpitis or necrosis and has also been reported in previously treated teeth due to the presence of untreated anatomy.[35] Heated gutta-percha is the safest and most effective means for heat testing.[36] This can be done by heating gutta-percha over a flame on a plastic instrument or by using a commercially available heat testing tip with an obturation downpack device. The commercially available tips are considered the safest means for heat testing at this time (Fig 1-14).

FIG 1-14 Heat testing may be safely and conveniently performed with a commercially available welled tip attached to an obturation downpack device. (Photo courtesy of B&L Biotech.)

Electric pulp testing (EPT) is an adjunctive pulp sensitivity test that is best used to confirm the presence or absence of sensitive, and presumably vital, tissue in a tooth (Fig 1-15). EPT should not be used in teeth without exposed enamel or cementum because the electrical impulse will be impeded by any foreign material barriers, including restorative materials.[31] Historically, it was advised not to use EPT in patients with pacemakers, but there is no published evidence that EPT units interfere with pacemaker devices.[37] That said, as with all medical devices, confirmation of safety with the pacemaker manufacturer is advised.

EPT units display a readout corresponding to the electric current, ranging from 0 to 80. If a response is felt in that range, especially if it is similar to that of a control tooth, the presence of vital tissue is inferred. If no response is detected during the full duration of the test up to a readout of 80, the absence of vital pulp tissue is inferred. Specific numbers for readouts are not indicative of normal or inflamed tissue, underscoring the need for careful comparison with control teeth.

FIG 1-15 Kerr Endodontic Vitality Scanner 2006. Electric pulp testing is a useful and safe pulp sensitivity test to confirm the presence or absence of sensitive tissue within a tooth.

In applying EPT, an electric circuit is created by use of a ground and an electrode. The electrode end of the unit, coated in toothpaste to maximize conduction, should be applied to the cusp tip or incisal edge of the exposed enamel, while the opposing ground component should be rested on the contralateral commissure of the lip to complete the circuit. The electrode applies electric current, increasing on a logarithmic scale, to the exposed tooth structure; it should be removed once the patient reports a response. Patients should be advised to raise their hand to indicate the sensation as soon as it is felt so that the electrode can be removed.

False positives and negatives are common with EPT.[31] The test may be wholly unreliable in that no tooth is responsive in an individual patient. Other patients may report a late sensation of "vibration" in a nonvital tooth, which differs from the responses in presumed

FIG 1-16 Percussion tests can be performed with a mirror handle as depicted. In symptomatic teeth, digital pressure can be used to assess percussion response. (Image courtesy of My Dental Key.)

FIG 1-17 Palpation testing can be used not only to assess symptoms resulting from apical inflammation but also to detect swelling and other anatomical abnormalities. (Image courtesy of My Dental Key.)

normal controls. EPT is generally not a reliable test in immature teeth because the nerves responsive to the test develop around the time of root maturation.[29] EPT may, however, be more reliable than thermal tests in teeth exhibiting pulpal canal obliteration or calcification because it relies on ionic changes in nerves rather than dentinal tubular fluid movement, which is the basis for thermal responses.[38]

PERIAPICAL TESTS

Periapical tests represent the gold standard for assessing inflammation within the periodontium. Typical testing modalities include percussion testing, palpation testing, and bite testing. Positive findings for periapical testing must be considered alongside pulp sensitivity tests. Although abnormalities are common with endodontic disease extending into the periapex, abnormal periapical test results may derive from nonendodontic pathology, including periodontal disease, acute traumatic injuries, and occlusal trauma.[39]

Percussion testing is classically performed with a metal mirror handle struck firmly on the surface of the tooth. For extremely sensitive teeth, testing should begin with light manual pressure with the clinician's finger before moving to the more noxious metal instrument (Fig 1-16). Because percussion sensitivity can differ depending on the surface tapped, a suspected tooth can be percussed on the occlusal, facial/buccal, and palatal/lingual surfaces. Teeth without inflammation of the periapical tissues should not exhibit pain on percussion. Teeth with positive percussion tests are said to have mechanical allodynia, or a painful response to a normally non-painful stimulus.[40] This test allows for localization of periapical inflammation because, unlike bite testing, it allows for testing one arch at a time. That said, the teeth adjacent to a very percussion-tender tooth may also exhibit mild sensitivity if inflammation has spread to adjacent structures.

Manual palpation of the soft tissues overlying root structure can not only reveal sensitivity of the periapical structures caused by inflammation but can also facilitate the detection of swelling, bony expansion, or other asymmetries (Fig 1-17). Because the root apices most often sit proximally to the buccal or facial cortical plates, palpation tenderness is most often noted in these areas. That said, examination of the lingual or palatal mucosa is also advisable to rule out pathology in these areas.

Bite sensitivity can be associated with periapical inflammation or cracked or fractured teeth.[39] Testing is performed using either a cotton roll, a cotton-tipped applicator, or a commercially available plastic tester such as the Tooth Slooth (Professional Results) or Fracfinder (Denbur), which allows for testing of individual cusps (Fig 1-18). Unlike percussion testing, bite testing cannot reliably localize symptoms to the maxilla or mandible.

Documentation of clinical findings is a crucial part of clinical practice both for medicolegal reasons and to consolidate information for diagnosis and follow-up. Creating a system for documentation that organizes numerous data points is essential. Depending on the established protocols in a practice setting, recordkeeping may take the form of a narrative, a table (Table 1-2), or a hybrid of both. Regardless of the means utilized, shorthand characters like "+" and "-" are often used to record clinical findings.

FIG 1-18 Biting tests should replicate a patient's biting sensitivity complaints. Commercially available bite sticks can be used for this test, but cotton rolls and cotton-tipped applicators may also be used. (Image courtesy of My Dental Key.)

TABLE 1-2 Example compilation of diagnostic testing results for the mandibular right quadrant

Tooth	29	30	31
Cold	+	–	+
Percussion	–	+	–
Palpation	–	+	–
Biting	–	+	–

"+" signs indicate positive test results, whereas "–" signs indicate negative responses to tests. An alternative shorthand narrative for the same results would state: 30 exam: Perc +, Palp +, Biting +, Cold –; results for 29 and 30 WNL.

Radiographic examination

The final portion of the objective examination is the radiographic exam. Radiographs should adequately visualize both crown and root structures. Radiographic findings should provide further clues as to the etiology of endodontic disease. Standard imaging in endodontics includes bitewing and periapical radiographs, though CBCT is becoming increasingly relevant in endodontic diagnosis.[41,42]

2D imaging

2D radiography, including periapical, bitewing, and panoramic radiographs (Fig 1-19), remains the standard in dentistry and in endodontic diagnosis. Images must be of sufficient quality to provide accurate diagnostic information.

- **Periapical radiographs:** These images represent the gold standard radiograph for endodontic diagnosis. High-quality images should depict the full crown and root of the tooth in question. If apical periodontitis is present, the entirety of the radiolucency must be visible within the image. When relying on periapical imaging alone for endodontic diagnosis, multiple images taken from varying horizontal and vertical angulations are recommended for improved diagnostics, visualization, and localization.[43]

FIG 1-19 2D radiographs include *(a)* pericapical, *(b)* bitewing, and *(c)* panoramic radiographs. Periapical images remain the standard of care in endodontic diagnosis.

- **Bitewing radiographs:** These images are a useful adjunct to periapical images in endodontic diagnosis. They more accurately depict the proximity of caries, restorative margins, and coronal fractures to the pulp. This assessment is critical both to predict carious exposures and to assess the restorability of the tooth in question. Bitewings also provide a more accurate representation of periodontal bone heights. Furthermore, they may uniquely show external cervical resorption when it presents on the mesial or distal aspects of a tooth. Bitewings are especially useful in endodontic assessment because they present the accurate size, shape, and localization of the pulp chamber.[44]
- **Panoramic radiographs:** Panoramic radiographs have limited utility in endodontic diagnosis given issues with poor resolution and anatomical noise. Their utility lies in the work-up of traumatic dental injuries, particularly in evaluating for alveolar, mandibular, and condylar fractures.[45] That said, clinicians who routinely take panoramic radiographs for their patients should examine them for evidence of endodontic pathology.

2D images are limited by structural overlap, particularly of adjacent anatomy,[46] geometric distortion,[47] and challenges in localization of findings. Lesions must either be large[48] or extend through cortical bone in order to be visualized.[46] Localizing findings can be challenging with 2D radiographs and requires use of the Buccal Object Rule (also known as Clark's Rule or the Same Lingual Opposite Buccal [SLOB] Rule), which employs multiple angled radiographs.[49] With this technique, pathology on the lingual or palatal aspects of the tooth will move in the same direction as the x-ray tube head, whereas pathology on the buccal aspect will move in the opposite direction (Fig 1-20).

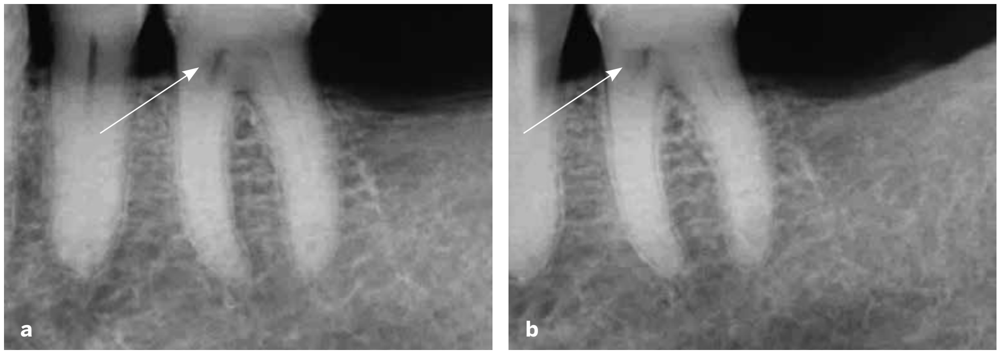

FIG 1-20 The use of multiple angled radiographs can help localize findings to the buccal or lingual aspect of a tooth. This is referred to as Clark's Rule or the SLOB Rule. Pathology on the lingual aspect of the tooth will move in the same direction as the x-ray tube, whereas pathology on the buccal aspect will move in the opposite direction. In this instance, the coronal radiolucency noted in *a* shifted mesially in image *b* when the x-ray tube was moved distally, indicating that the pathology is located on the buccal aspect because it moved in the opposite direction of the tube.

3D imaging

CBCT imaging is not yet the standard of care in endodontic diagnosis, but its utility has become more apparent with broader usage. Ultimately, 3D imaging overcomes the myriad limitations of 2D radiography, including structural overlap, geometric distortion, and the limited ability to localize pathology in space (Fig 1-21). CBCT imaging possesses greater sensitivity than periapical films and can be used to detect pathology in earlier stages of development.[50–52] CBCT images are also dimensionally accurate,[52] eliminating the geometric and spatial distortion associated with 2D images and allowing for accurate visualization of anatomical relationships. CBCT imaging does, however, have limitations. The increased cost and reduced availability of the technology can limit its use. Furthermore, capturing images takes between 20 and 40 seconds, and patients with special needs, pediatric patients, and those with tremors may have difficulty keeping still long enough for image capture.

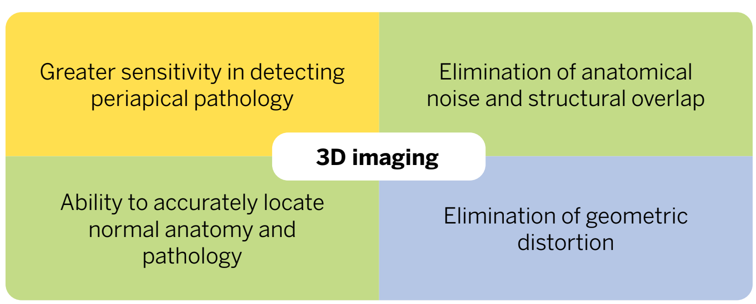

FIG 1-21 Advantages of 3D imaging over 2D imaging.

Many patients have concerns regarding radiation dosage with CBCT imaging because they are aware of the high radiation doses associated with medical CTs. Generally speaking, although doses may vary among models, the limited field of view CBCT machines used routinely in endodontics impart radiation dosages that are only nominally more than the dosages from multiple 2D images often used for endodontic diagnosis.[53–55] That said, not every case requires multiple periapical images, and following the principles of ALARA (as low as reasonably achievable), the lowest radiation dosage appropriate for diagnosis and treatment should be utilized.[56]

CBCT images provide radiographic data in three orthogonal planes: the axial, the coronal, and the sagittal. The axial plane is viewed from the patient's toes to their head, the coronal from anterior to posterior, and the sagittal from the patient's lateral side (Fig 1-22). Images must be interpreted in their entirety, including all soft and hard tissues depicted. Consequently, clinicians must be familiar with normal soft and hard tissue anatomy as visualized in three dimensions, including extragnathic structures. Depending on the area of exposure, CBCT imaging has the potential to showcase both normal anatomical structures and potential pathology that may be outside the routine scope of dental practice. Inexperienced clinicians should consider additional training and, in certain cases, consult with an oral and maxillofacial radiologist for an image overread, particularly when aberrant findings are found.

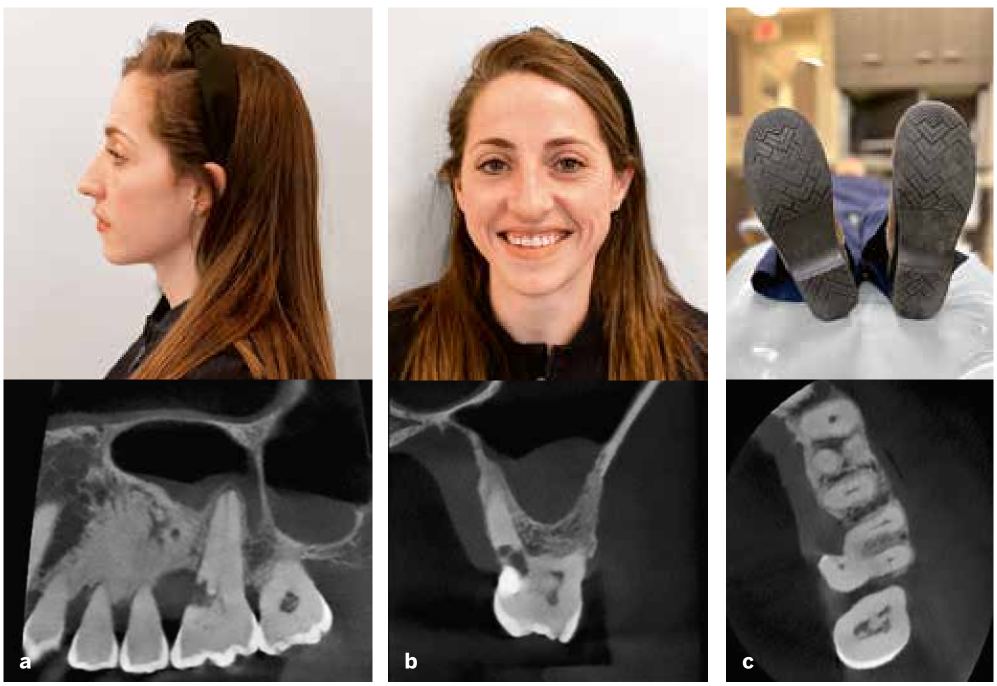

FIG 1-22 CBCT images are evaluated in three planes: the sagittal, the coronal, and the axial. *(a)* The sagittal plane is a lateral view of the patient, *(b)* the coronal plane is an anteroposterior view of the patient, and *(c)* the axial view is from the patient's feet.

The indications for CBCT imaging are wide ranging (Box 1-1). When available, CBCT imaging can be considered routine in the diagnosis of traumatic dental injuries, suspected resorption, root fractures, and in previously endodontically treated teeth, particularly when retreatment or apical microsurgery is being considered.[41,42,57] CBCT imaging is also recommended when existing clinical and radiographic means are insufficient to make a definitive diagnosis.[41,42] Furthermore, images are useful intraoperatively to address challenging anatomical configurations or suspected complications like perforations or instrument separation.[41,42,57,58] Lastly, CBCT can be considered for follow-up imaging, particularly when it was utilized during the diagnostic workup[41,42] (Fig 1-23).

BOX 1-1 Indications for CBCT imaging in endodontics[41,42]

- When existing clinical and radiographic means are insufficient to make a definitive diagnosis
- Assessment of previously endodontically treated teeth, particularly when considering retreatment or apical microsurgery
- Assessment of traumatic dental injuries
- Evaluation of root resorption
- Evaluation for fracture pathology
- Intraoperative location of calcified canals or complication assessment (eg, perforations, separated instruments)
- Follow-up, particularly when CBCT imaging was utilized during the diagnostic work-up

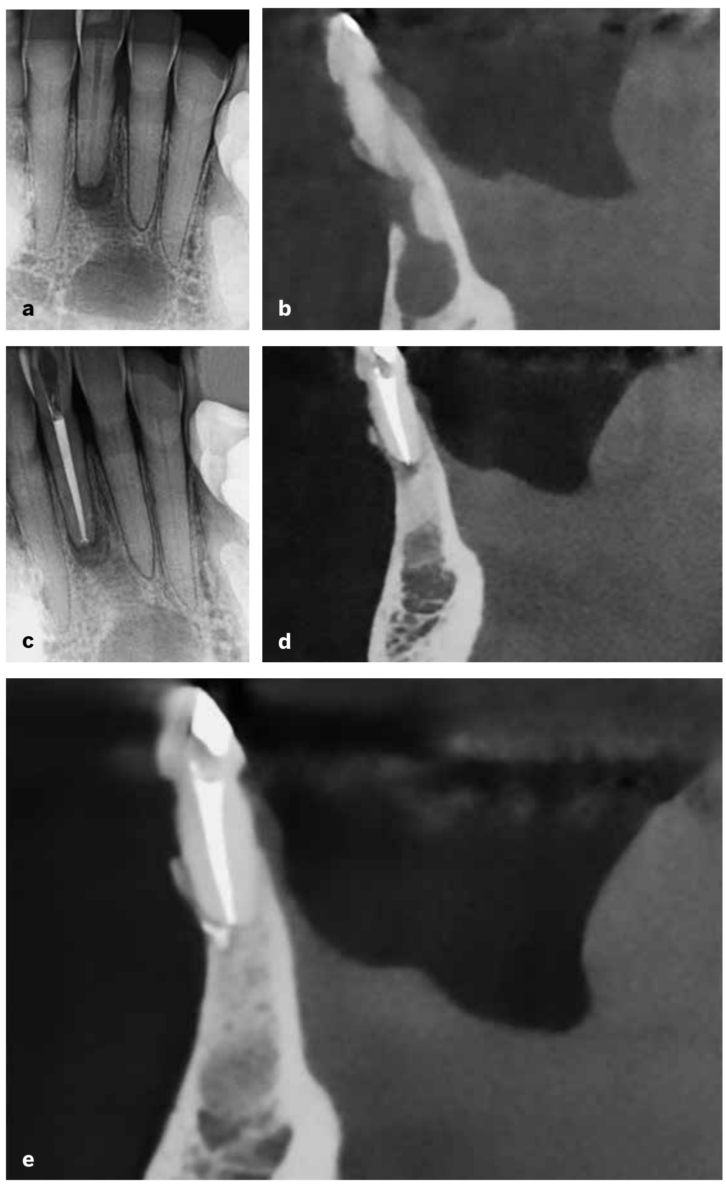

FIG 1-23 CBCT imaging can prove useful in radiographic follow-up after endodontic treatment, particularly when it was employed during diagnosis. *(a and b)* This patient presented with a large and unusually shaped periapical radiolucency associated with a necrotic tooth, as seen on the periapical radiograph and the sagittal section of CBCT imaging. *(c)* NSRCT was completed, and close follow-up was warranted to determine if surgical intervention would be needed. *(d)* The early CBCT follow-up at 3 months demonstrated signs of bone fill that would not likely have been apparent with 2D periapical imaging. *(e)* Complete apical healing was noted at the 1-year follow-up.

Although useful, CBCT images have several limitations. They are subject to artifacts creating scatter and distortion, particularly around dense, and especially metallic, restorative materials. As a result, their utility is limited in the detection of recurrent caries and especially the detection of lateral root pathology or suspected root fractures when metal posts are present.[59,60] The application of filters and artificial intelligence are active areas of research to improve upon these limitations.[61]

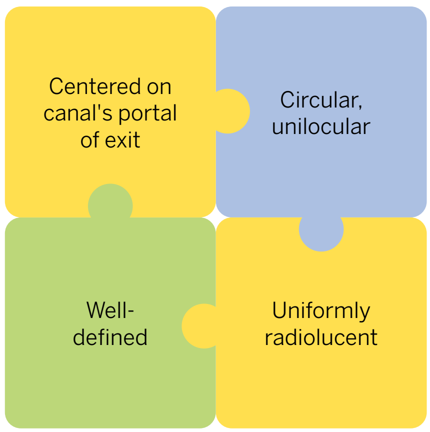

FIG 1-24 Radiographic characteristics of endodontic pathology.

Radiographic interpretation

In describing any radiographic lesion, attention should be paid to the lesion's localization, periphery and shape, internal structure, and effects on surrounding structures.[62] Lesions of endodontic origin (LEOs) have a characteristic appearance in both 2D and 3D imaging (Figs 1-24 and 1-25). Most LEOs are radiolucent. LEOs will be centered on the canal's portal of exit, which may coincide with the radiographic apex or be off center, depending on canal anatomy. LEOs are well-defined, unilocular, and uniformly radiolucent. Early LEOs present as PDL widening localized to the apical portion of the PDL. Less commonly, LEOs may present as radiopacities. This is referred to as condensing osteitis, wherein a localized sclerotic reaction develops in response to chronic pulpal inflammation or infection (Fig 1-26), and is distinct from other periradicular radiopacities not associated with endodontic disease, including cemento-osseous dysplasia, dense bone islands, hypercementosis, and cementoblastomas.

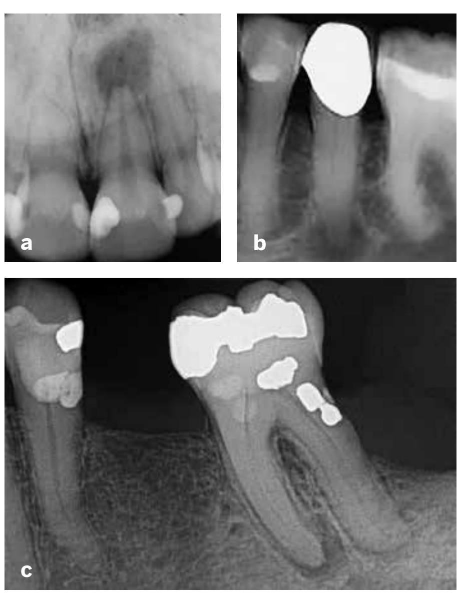

FIG 1-25 *(a to c)* Examples of radiolucent lesions of endodontic origin. They present as well-defined, unilocular, and uniform radiolucencies centered around the canal's portal of exit.

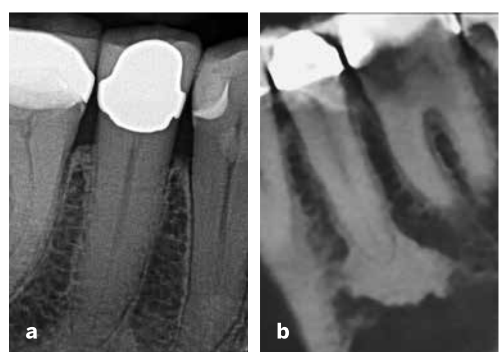

FIG 1-26 While most lesions of endodontic origin are radiolucent, condensing osteitis represents a radiopacity of endodontic origin and can be seen in periapical *(a)* and CBCT *(b)* images. In these cases, a localized sclerotic reaction develops in response to chronic pulpal inflammation or infection.