Identify and Determine the Metrics, Hierarchy, and Predictive Value of All the Parameters and/or Methods Used During Endodontic Diagnosis

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Abstract

A Consensus Conference on Terminology was convened by the American Association of Endodontists in Chicago on Oct 3, 2008 to review solicited papers on focused questions. This paper addressed the question: Identify and determine the metrics, hierarchy, and predictive value of all the parameters and/or methods used during endodontic diagnosis. The best available clinical evidence was used to determine the sensitivity, specificity, and predictive value of pulpal and periapical testing methods and imaging technologies. Diagnosis of dental pulp diseases suffers from operator's inability to test/image that tissue directly due to its location within dentin. In general, current pulp tests are more valid in determining teeth that are free of disease, but less effective in identifying teeth with pulp disease. Radiographic imaging is probably the most commonly used diagnostic tool to determine the status of root-supporting tissue, although interpretation of structural changes in the periradicular tissues is still considered unreliable. *(J Endod 2009;35:1635–1644)*

Key Words

Cone beam computed radiography (CBCT), diagnostic imaging, digital radiography, endodontic diagnosis, periapical radiography, pulp testing

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Each subcommittee member was assigned a subquestion to Question #1 and asked to use the best available evidence to provide the necessary background information in these areas to the participants of the AAE Consensus Conference on Diagnostic Terminology scheduled for October 3, 2008, in Chicago, IL. It is intended to assist them in critiquing the value of the information, identifying gaps in the knowledge base, and establishing a consensus relative to diagnostic terminology and codification.

Each member was also asked to consider an individual response to Subquestion #3 for his area. Therefore, Subquestion #3 is now included in the other questions. The committee was convened by conference call, and a deadline of March 30, 2008, for preliminary drafts was established. All final drafts were submitted by May 30, 2008.

Each member was invited to use whatever scientific and clinical support he/she needed for his/her section and report accordingly in a bibliography. Additionally and separately, a search strategy was developed to identify clinical evidence and assign a level of evidence; overlap was expected.

There was no attempt to standardize the responses with any other subcommittees with the hope that different approaches may broaden the search for answers and still leave the opportunity to edit as appropriate after external review and comment.

A special emphasis was placed on the evidence-based approach. This relies heavily on the importance given to randomized, controlled clinical trials, and there are relatively few in this topic area. Consequently, each member interpreted the information his/her own clinical experiences and the available evidence; some bias is unavoidable. There is a long enough history of clinical experience with diagnostic methods and interpretation to provide the necessary judgment that complements the evidence-based approach in the absences of rigorous trials. It is this logical approach that will most likely be used to both support and challenge prevailing opinions at the Consensus Conference.

The diagnosis of dental pulp diseases suffers from the operator's inability to test/or image that tissue directly because of its location within a relatively hard tissue, dentin. It appears to be impossible to directly test dental pulp; therefore, all information elicited must be interpreted indirectly from the patient response to a stimulus placed externally to the tissue. In general, pulp tests used are more valid in determining teeth that are free of disease but less effective in identifying teeth with pulp disease. Tests can be considered relatively noninvasive, easy to use, and cost-effective.

Radiographic imaging is probably the most commonly used diagnostic tool to determine the status of root-supporting tissue, although interpretation of structural changes in the periradicular tissues is known to be unreliable. Radiographic improvements that have reduced radiation exposure and improved convenience are not generally accepted as cost-effectively facilitating visualization of changes in a measurable way.

Subquestion #1: What Are the Methods and Diagnostic Approaches Available to Gather Necessary Information about the Status of the Pulp?

The use of three terms not included in the AAE *Glossary of Endodontic Terms* (1) may lead to more definitive, possibly quantifiable, endodontic diagnoses. They are (1) sensitivity; the ability of a test to identify teeth that are diseased; (2) specificity, the ability of a test to identify teeth without disease; and (3) predictive value, the ability of a test to foretell what the diagnosis actually is. We can use the terms "positive predictive value" and "negative predictive value" as a relationship of the proportion of teeth with positive or negative test results that are correctly diagnosed.

- Methods
  - Pulp testing
    - Thermal (heat/cold)
    - Electric
    - Laser Doppler flowmetry (LDF)
    - Pulse oximetry
  - Palpation
  - Percussion
- Diagnostic approaches
  - Bite test
  - Test cavity
  - Staining/transillumination
  - Selective anesthesia
  - Radiographic examination/interpretation
    - Intraoral–periapical/bitewing
    - Extraoral–occlusal, APs
    - Digital
    - MicroCT, cone beam computed tomography (CBCT), other scans
- Dental history/medical history
- Evaluation of pain signs/symptoms

The definition of diagnosis is "the art and science of detecting deviations from health and the cause and nature thereof" (1). It may be more definitive to use the term "differential diagnosis" as more realistic in its application and usage in endodontics. It is defined as "the process of identifying a condition by comparing the symptoms of all (or other) pathologic processes that may produce signs and symptoms" (1).

The diagnosis of dental pulp diseases suffers from the operator's inability to test/image that tissue directly because of its location within the dentin. This tissue is a structure that is primarily tubular in formation that changes throughout life because both it and enamel are challenged by external, adverse stimuli. The tubular structure of dentin and the fluid contained within serves in some instances as a way of judging the condition of the dental pulp; those judgments also suffer from the inability of applying a stimulus directly on the pulp tissue itself.

To understand diagnostic results, the operator must understand the biology of the dental pulp. Therefore, consideration of patient response to different testing modalities is fundamental to the understanding of diagnostic methods.

Historically, pulp testing has not changed dramatically over a great number of years. Theory and application appear to have improved through the development of testing devices that purport to give endodontists a better picture as to what the dental pulp might appear as histologically. The principle that test results do not coincide with the tissue appearance certainly seems to be still true (one cannot equate clinical symptoms with pulpal histology) (2, 3). To that end, this article will briefly discuss each of the tests used (in contemporary endodontics) as a means of arriving at a credible diagnosis. A brief review of pertinent literature and how each test is used will be included.

Differences in the how and why of applying various stimuli vary between (1) the length of time of application of stimulus, (2) the area of placement of stimulus probe, (3) the temperature of the probe (heat, cold, and EPT), (4) the aspect of "pre" pain response versus pain response (odontogenic vs nonodontogenic response), (5) pressure application (percussion, palpation, and tooth slooth), (6) the direction of application of pressure, (7) the age of patient (child, adolescent, adult, aging individual, plus 65, elderly–over 75/80), (8) predicative values (can response be trusted), (9) the trust in patient response, (10) the presence of systemic diseases, and (11) the supporting literature.

The quantification of a patient's response is interesting from the standpoint of the numbers possibly being of greater value than descriptive words or phrases. The ability of the visual analog scale to quantify a stimulus causing a certain response combines use of words (mild, moderate, and severe) with numbers (1–10), with 1 being no pain or the least severe and 10 being the most severe/painful. Everything in between is considered less severe/painful extending to most severe/painful.

An illustration may serve to show how difficult it is to quantify response to a stimulus applied to a tooth to make a diagnosis. Electrical pulp testers in the mid-20th century used a 0 to 10 scale with increasing amounts of voltage, which increased sensitivity when the electrical stimulus was applied to the test tooth until the patient showed a response, usually by violently jerking their head away from the pulp tester. Two aspects of this type of testing are subject to interpretation. The first concerns the use of the number at which the patient responded and what it might mean in arriving at a diagnosis of anything from a normal pulp to an irreversibly inflamed pulp requiring treatment. The higher the number and more violent the response indicated a diseased pulp, giving no credence to the response alone, that, in fact could well have indicated normal tissue present in the test tooth but a greater amount of current that really caused the response.

To solve this dilemma, a new electric pulp tester was developed that ramped response upward from 0 to 80, with each increase in number indicating an increase in voltage. The following scale of "normal" responses was included: 10 to 40, incisors; 20 to 50, bicuspids; and 30 to 70. It took endodontists no time at all to understand that the number of tooth response was meaningless for several reasons that we have no space to include here other than to state that the numbers overlapped, dictating an impossible diagnostic situation. However, the device has an advantage that older devices did not have. It was possible to identify "prepain" versus "pain" by setting the rate increase of impulses at a slower level, allowing a response to a change of "environment" in the tooth (a tickle or other feeling not normally there) rather than actual pain. This was interpreted as "prepain," which would have become pain as the number of impulses increased. Older endodontists proved this by continuing to test (use of lip clip), much to the discomfort of the patient. When the lip clip was instead held by the patient and dropped when the sensitivity began to change, pain was not reported, only a change in "feeling" of the test tooth.

This is true when temperature change is used in endodontic diagnosis. Cold tests originally used ice chips or frozen ice sticks at 0°C held against the tooth until a response was noted. In anterior incisors, with thinner amounts of dentin facially, a rapid, sometimes painful response was considered diagnostic of disease. A molar tested in the same manner would not respond, which could indicate disease. The answer was to use cold stimuli at −20° and −40°C, which caused molars to respond, but really could not be used for incisors. Again, no consideration was given to the anterior response at 0°C and the molar response at −20°C, which both have been normal, because a "no" response could also be considered to be normal. When faced with the predictive value of diagnostic tests, an early study examined histologic preparations in relation to patient response to those tests (4). In general, tests used identified patients who were free of disease but were less effective in identifying patients who had pulp disease. Patients who tested positive for irreversible pulpitis were disease negative when the pulp was examined histologically. The inability to equate pulp disease was shown earlier by others (2, 3).

This is essentially true when the literature is examined. Various strategies have been used in order to determine if there is existing evidence available to support the hypothesis that endodontic diagnostic testing is valid and reliable. As noted by literature searches, there are not a great number of articles available that allow the reader to base his/her testing results on evidence-developed data. The predictive value of endodontic diagnostic tests lessens when one realizes that all tests are performed with either restorations or two relatively hard dental tissues (enamel and dentin) intervening between the stimulus and the dental pulp tissue. Despite this problem, some tests can be predictive if the subject's symptoms can be duplicated by the use of external stimuli. The normally used everyday tests and the newer tests such as Laser Doppler Flowmetry (LDF), O_2 saturation, and the latest imaging devices, including computed tomography scans, appear to be too expensive for use in endodontic diagnosis. Digital radiography and the various computed tomography devices and their use in diagnosis are discussed in a later subquestion.

A discussion of tests used in the determination of vitality and disease necessitates a description of the stimulus, where the stimulus is placed, the condition of the crown of the tooth (presence of caries, restorations, fractures), and the location of the pulp tissue in relationship to the crown and root of the tooth. Obviously, it appears to be impossible to directly test dental pulp; therefore, all information elicited must be interpreted indirectly from the patient response to a stimulus placed externally to the tissue.

The following are descriptions of various tests used to determine vitality (healthy, diseased) or nonvitality (necrosis and periradicular pathoses). The following are rules to be followed that, hopefully, aid in the diagnosis: (1) test teeth that are not suspected to be pulpally involved are tested before testing the suspected tooth (baseline patient response), (2) duplicate the symptoms, (3) correlate finding (signs and symptoms), and (4) place stimulus on the middle third of the facial surface of the tooth to be tested.

Thermal Testing

Thermal testing with heat delivers a stimulus with warmed gutta-percha or warmed water. Thermal testing with cold delivers a stimulus with a spray refrigerant applied to a cotton swab or large, loose cotton pellet. Understanding that the various responses of pulpal afferents to thermal tests can, and in many instances does, determine health versus disease caused by a particular primary afferent nerve response and, by necessity, the patient's symptoms (5–9).

Electric

The application of an electrical current is most useful in determining vitality versus nonvitality but not health or disease (5, 6).

Laser Doppler Flowmetry

LDF assesses pulp blood flow by passing light through an intact tooth and measuring the return of light reflected off of circulating red blood cells. There are too many shortcomings to LDF use for it to be considered as reliable (10–16). Many studies were concerned with vitality determinations in luxated, avulsed, or root-fractured teeth.

Pulse Oximetry

Pulse oximetry measures oxygen concentration of blood flowing past a detector/probe placed on the tooth (same shortcomings as in LDF) (6).

Palpation/Percussion

Palpation/percussion can isolate an involved tooth but, dependent on how results are interpreted, may not differentiate between pulpal/periodontal diseases.

Thermal Testing

Hot and cold stimuli have been thought to cause movement of dentinal fluid within tubules, either through contraction (cold) or expansion (heat) of the fluid causing movement within the tubule. Because A-delta nerve fibers are thought to be located around the odontoblastic cell layer and extend into tubules, movement of dental fluid would affect these fibers, causing a response. However, continuing debate appears to indicate that because quantitative data presently are not available, the use of hot/cold stimuli response remains qualitative and, therefore, not necessarily indicative of pulpal disease.

The same may be said of electrical stimulation (as previously discussed). In the final analysis, the tests used in endodontic methods are based on qualitative response. We do not know at what temperature (hot/cold) a patient responds and if the temperature of response is quantifiable, reproducible, and near the same values from patient to patient. The response to electrical stimulation is one of yes or no; it was felt or it was not. The other tests used in diagnosis (palpation, percussion, bite, cavity, and so on) appear to be the same.

Tests used to determine health versus disease of the dental pulp tissue do not show sensitivity and specificity. We remain committed to these tests presently as one part of the diagnostic method but also take into consideration the symptoms the patient presents with (and duplication of these symptoms), the signs noted in a thorough clinical examination, past dental history, radiographic examination, and medical history, if applicable.

Laser Doppler Flowmetry

LDF passes a laser light through tooth structure, light bounces off erythrocytes (red blood cells), is returned to a receiver channel in laser probe, and is recorded as pulpal blood flow. It requires natural tooth structure and can't be used through restorations. Test teeth must be isolated in a manner that precludes laser light interacting with gingival RBCs and being recorded together with those from pulpal blood cells. The device is also prone to pick up sound, like air currents (environmental issues), therefore the results are questionable due to lack of reproducibility, sensitivity to environment and its sizeable costs.

Pulse Oximetry

The process measures oxygen saturation in external soft tissue. It has been suggested that it is capable of passing its signal through enamel and dentin. It must also be used on natural tooth structure. The device, as with LDF, uses a probe that transmits red (640 mm) and infrared light through the tissue (received by a photodetector). Because oxygenated and deoxygenated hemoglobin absorb different amounts of each light, pulsating changes in blood volume cause periodic changes in the amount of light absorbed by the vascular bed before reaching the photodetector. To date, it has not been considered to be capable of judging pulp vitality in a manner that would allow a proper degree of sensitivity and specificity. It must again be stressed that LDF and pulse oximetry can only be used on natural tooth structure and never on restorations. When used clinically and having a possible response, a rubber dam should isolate the test teeth and the gingival tissue below the dam blocked with an opaque substance (tin foil).

Other Diagnostic Approaches

Selective anesthesia. It is useful in differentiating between a mandibular/maxillary origin and in possibly differentiating between maxillary teeth.

Cavity test. The cavity test can differentiate between adjacent teeth if one is believed to be pulpally involved. It is most useful in necrotic teeth in the absence of periradicular lesions and reproducible responses to other pulp tests.

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Subquestion #2: What Are the Methods and Diagnostic Approaches Available to Gather the Necessary Information about the Status of the Root-supporting Tissues?

With the exception of surgical exploration and histological examination (biopsy), all methods to determine the status of the root-supporting structures rely on indirect diagnostic evidence. Radiographic imaging is probably the most commonly used diagnostic tool, although interpretation of structural changes in the periradicular tissues is known to be unreliable (1–8). Intraexaminer and interexaminer agreement on assessment of periapical structures is problematic. In addition, current two-dimensional imaging techniques have a limited ability to detect early changes in the root-supporting structures. Although an often-cited classic study found that artificially created lesions confined to the cancellous bone could not be detected with standard periapical radiographic imaging until the cortical plate was partially eroded (1, 2), more recent studies have shown that early changes in cancellous bone can be detected before erosion of the cortical plate, although this is highly dependent on location in the mouth and bone density (9, 10).

The ability to detect early and subtle periradicular changes in bone density is a critical component of endodontic diagnosis and outcomes assessment. Image enhancement capabilities of digital radiography systems may improve diagnostic accuracy (11). Digital radiography appears to be at least equal to D-speed film in the detection of periapical bone defects (12). Contrast enhancement of digital images may improve the ability to detect and measure the size of periradicular lesions when compared with Kodak Ektaspeed Plus (Eastman Kodak, Rochester, NY) film (13). Digital subtraction radiography may also emerge as a useful enhancement to standard digital radiography, particularly in the evaluation of healing (14, 15).

Cone beam computed tomography (CBCT), ultrasound, and other emerging technologies seem to be very promising tools for more accurate diagnosis of changes in the root-supporting structures (16–21). When CBCT was used as the reference standard for identifying apical periodontitis, Estrela et al (22) found that the overall sensitivity for periapical and panoramic radiographs was 0.55 and 0.28, respectively. Sensitivity varied slightly based on tooth type (location), but specificity was very high for both imaging techniques and all tooth types (0.96-1.00). This study shows the relatively high probability of a false-negative result with both periapical and panoramic imaging techniques. In a sample of 50 patients referred for surgical treatment because of persistent apical periodontitis, Velvart et al (21) found that high-resolution computed tomography scans were able to accurately identify 100% (78/78) of the periapical lesions diagnosed surgically. In this same study, only 78% (61/78) of the periapical lesions were detected by conventional radiographic imaging. Although periapical cysts and granulomas cannot be reliably differentiated with conventional periapical radiographs (23–25), computed tomography scans have the potential for improved diagnostic accuracy (24). Histologic evaluation of a surgical specimen remains the generally accepted gold standard for definitive diagnosis of periradicular pathosis.

Percussion testing is generally considered to be a reasonably reliable technique for identifying inflammation in the periodontal ligament space (26); however, standardization is lacking and positive findings are not specific for endodontic pathosis. Klausen et al (27) reported sensitivity of .70 and specificity of .51 for the clinical sign, "tenderness to percussion," as a diagnostic test for apical periodontitis. Recent attempts to standardize the measurement of mechanical allodynia may lead to the future development of clinically useful diagnostic tools (28–30). A positive response to the biting stress test is highly suggestive of periodontal inflammation or incomplete crown/root fracture;

however, these entities represent two distinct clinical problems with different treatment options and objectives. Incomplete crown/root fractures present a unique treatment planning dilemma because it is often not possible to determine the extent of the fracture, and, therefore, the prognosis for conservative treatment is often uncertain (31–33). Biting stress sensitivity, pain on percussion, isolated deep periodontal probing, pulp vitality status, conventional and digital radiography (34), computed tomography scans (20), and direct transillumination are all useful tests; even so, surgical exploration is often necessary to confirm the presence and evaluate the extent of a root fracture.

Isolated tenderness to palpation in the root apex area of a tooth is suggestive of relatively advanced periapical inflammation and/or infection. Two other diagnostic methods, mobility and periodontal pocket depth, are somewhat more standardized than percussion, palpation, and biting stress tests. However, from the perspective of endodontic diagnosis, these tests provide only limited information regarding changes in the root-supporting structures.

In the early 1970s, electrophoresis of periapical fluid obtained through a standard orthograde root canal access was proposed as a technique for the differentiation of periapical cysts and granulomas (35, 36). Although this approach yielded equivocal results (37) and thus never gained widespread acceptance, there is an emerging interest in the use of gingival crevicular fluid as a diagnostic tool for periradicular inflammation (38, 39). The identification and characterization of specific biochemical markers in the gingival crevicular fluid of teeth with active periapical disease may lead to the development of useful diagnostic tools, although this is still speculative.

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Subquestion #3: What Is the Hierarchy of Parameters (Clinical and Radiographic Presentations, Clinical Tests, Histopathological Features, Molecular Findings, Treatment Plan, Treatment Outcome, and So On) that Should Be Used in Designating Diagnostic Terms in Endodontics?

Each committee member was asked to make recommendations in the body of the other subquestions.

Subquestion #4: What Are the Levels of Evidence Supporting the Sensitivity, Specificity, and Predictive Values of Contemporary Pulpal and Periapical Testing Tools, and to What Extent Should They Be Definitive in Rendering Diagnosis in Different Conditions?

Search Methods for Identification of Literature

In order to initially identify the parameters and/or methods used during endodontic diagnosis, a review of available literature was undertaken. This review process is not to be misconstrued as a systematic review of all available dental literature.

An attempt was made to locate any existing systematic reviews of the assigned topical question. The American Dental Association and the *Journal of Evidence-Based Dental Practice*'s Champion Toolkit available at *www.ada.org/prof/resources/ebd/conferences_evidence.pdf* was used to help identify a potential summary of systematic reviews Web sites. There were no systematic reviews located concerning endodontic diagnosis or dental pulp tests.

The Web sites explored included the following:

- EBD at ADA.org—*www.ada.org/goto/ebd*
- *Journal of Evidence-Based Dental Practice*—*http://journals.elsevierhealth.com/periodicals/ymed*
- Database of Abstracts of Reviews of Effectiveness (DARE)—*www.crd.york.ac.uk/CRDWeb/*
- National Library for Health—Oral Health Specialist Library—*www.library.nhs.uk/oralhealth/*
- *Evidence-Based Dentistry* (UK) —*www.nature.com/ebd/archive/index.html*
- Evidentista (Pan-American Centers for Evidence-Based Dentistry)—*http://us.evidentista.org/?o=1026*
- Centre for Evidence-Based Dentistry—*www.cebd.org/?o=1069*

Next, using the PubMed search engine (*www.ncbi.nlm.nih.gov/sites/entrez?db=pubmed*), the MEDLINE database was searched utilizing the MeSH vocabulary term “Dental Pulp Test” from the MeSH tree structure; this search identified 777 citations. Next, the search limits of “Humans” and “Dental Journals” were applied, which reduced the citation list to 630 articles. The citations were then reviewed for relevance to the assigned task of “Identify and determine the metrics, hierarchy and predictive values of all parameters and/or methods used during endodontic diagnosis.” This review process subjectively produced a collection of 120 articles. Subsequently, the related articles and links associated with each citation were explored and expanded the citation collection to 175 articles. An abstract of each citation was then read to determine the articles most appropriate to the committee assignment. Each article was reviewed and the type/level of evidence determined. The 39 articles that seemed most appropriate to the assigned task question are chronologically listed below.

1. Lin J, Chandler NP. Electric pulp testing: a review. Int Endod J 2008;41:365–74. Epub 2008 Feb 20. Review. PMID: 18298572 [PubMed–indexed for MEDLINE] Type/Level of Evidence–Review, Expert Opinion/Level 5
2. Lin J, Chandler N, Purton D, et al. Appropriate electrode placement site for electric pulp testing first molar teeth. J Endod 2007;33:1296–8. Epub 2007 Sep 29. PMID: 17963950 [PubMed–indexed for MEDLINE] Type/Level of Evidence–Case Series/Level 4
3. Gopikrishna V, Tinagupta K, Kandaswamy D. Comparison of electrical, thermal, and pulse oximetry methods for assessing pulp vitality in recently traumatized teeth. J Endod 2007;33:531–5. Epub 2007 Mar 12. PMID: 17437866 [PubMed–indexed for MEDLINE] Type/Level of Evidence–Case Series/Level 4
4. Gopikrishna V, Tinagupta K, Kandaswamy D. Evaluation of efficacy of a new custom-made pulse oximeter dental probe in comparison with the electrical and thermal tests for assessing pulp vitality. J Endod 2007;33:411–4. Epub 2007 Feb 23. PMID: 17368329 [PubMed–indexed for MEDLINE] Type/Level of Evidence–Cohort Study/Level 2
5. Sasano T, Onodera D, Hashimoto K, et al. Possible application of transmitted laser light for the assessment of human pulp vitality. Part 2. Increased laser power for enhanced detection of pulpal blood flow. Dent Traumatol 2005;21:37–41. PMID: 15660755 [PubMed–indexed for MEDLINE] Type/Level of Evidence–Case Series/Level 4
6. Miller SO, Johnson JD, Allemang JD, et al. Cold testing through full-coverage restorations. J Endod 2004;30:695–700. PMID: 15448461 [PubMed–indexed for MEDLINE] Type/Level of Evidence–Expert Opinion, Benchtop/Level 5
7. Kress B, Buhl Y, Anders L, et al. Quantitative analysis of MRI signal intensity as a tool for evaluating tooth pulp vitality. Dentomaxillofac Radiol 2004;33:241–4. PMID: 15533978 [PubMed–indexed for MEDLINE] Type/Level of Evidence–Case Series/Level 4
8. Rivera EM, Williamson A. Diagnosis and treatment planning: cracked tooth. Tex Dent J 2003;120:278–83. Review. PMID: 12723111 [PubMed–indexed for MEDLINE] Type/Level of Evidence–Expert Opinion/Level 5
9. Miwa Z, Ikawa M, Iijima H, et al. Pulpal blood flow in vital and nonvital young permanent teeth measured by transmitted-light photoplethysmography: a pilot study. Pediatr Dent 2002;24:594–8. PMID: 12528955 [PubMed–indexed for MEDLINE] Type/Level of Evidence–Case Series/Level 4

10. Jones VR, Rivera EM, Walton RE. Comparison of carbon dioxide versus refrigerant spray to determine pulpal responsiveness. J Endod 2002;28:531–3. PMID: 12126383 [PubMed–indexed for MEDLINE] Type/Level of Evidence–Cohort Study/Level 2
11. Cave SG, Freer TJ, Podlich HM. Pulp-test responses in orthodontic patients. Aust Orthod J 2002;18:27–34. PMID: 12502126 [PubMed–indexed for MEDLINE] Type/Level of Evidence–Cohort Study/Level 2
12. Radhakrishnan S, Munshi AK, Hegde AM. Pulse oximetry: a diagnostic instrument in pulpal vitality testing. J Clin Pediatr Dent 2002;26:141–5. PMID: 11874005 [PubMed–indexed for MEDLINE] Type/Level of Evidence–Case Series/Level 4
13. Amir FA, Gutmann JL, Witherspoon DE. Calcific metamorphosis: a challenge in endodontic diagnosis and treatment. Quintessence Int 2001;32:447–55. Review. PMID: 11491624 [PubMed–indexed for MEDLINE] Type/Level of Evidence–Review, Expert Opinion/Level 5
14. Selden HS. Diagnostic thermal pulp testing: a technique. J Endod 2000;26:623–4. PMID: 11199808 [PubMed–indexed for MEDLINE] Type/Level of Evidence–Expert Opinion/Level 5
15. Bender IB. Pulpal pain diagnosis—a review. J Endod 2000;26:175–9. Review. PMID: 11199715 [PubMed–indexed for MEDLINE] Type/Level of Evidence–Review, Expert Opinion/ Level 5
16. Bender IB. Reversible and irreversible painful pulpitides: diagnosis and treatment. Aust Endod J 2000;26:10–4. PMID: 11359291 [PubMed–indexed for MEDLINE] Type/Level of Evidence–Full Text not Evaluated, Expert Opinion/Level 5
17. Petersson K, Söderström C, Kiani-Anaraki M, et al. Evaluation of the ability of thermal and electrical tests to register pulp vitality. Endod Dent Traumatol 1999;15:127–31. PMID: 10530156 [PubMed–indexed for MEDLINE] Type/Level of Evidence–Case Series/Level 4
18. Brisset T. Photoplethysmography: a diagnostic aid in conservative dentistry-endodontics. Odontostomatol Trop 1999;22:5–8. French. PMID: 11372095 [PubMed–indexed for MEDLINE] Type/Level of Evidence–No English Full Text, Expert Opinion/Level 5
19. Jin G, Gu Z. A study of the diagnostic location of pulpitis. Chin J Dent Res 1999;2:63–6. PMID: 10863410 [PubMed–indexed for MEDLINE] Type/Level of Evidence–No English Full Text, Case Series/ Level 4
20. Goho C. Pulse oximetry evaluation of vitality in primary and immature permanent teeth. Pediatr Dent 1999;21:125–7. PMID: 10197340 [PubMed–indexed for MEDLINE] Type/Level of Evidence–Case Series/Level 4
21. Pierce A. Pulpal injury: pathology, diagnosis and periodontal reactions. Aust Endod J 1998;24:60–5. PMID: 11431815 [PubMed–indexed for MEDLINE] Type/Level of Evidence–Full Text not Evaluated, Expert Opinion/Level 5
22. Robertson A, Andreasen FM, Bergenholtz G, et al. Incidence of pulp necrosis subsequent to pulp canal obliteration from trauma of permanent incisors. J Endod 1996;22:557–60. PMID: 9198446 [PubMed–indexed for MEDLINE] Type/Level of Evidence–Case Series/Level 4
23. Asfour MA, Millar BJ, Smith PB. An assessment of the reliability of pulp testing deciduous teeth. Int J Paediatr Dent 1996;6:163–6. PMID: 9115971 [PubMed–indexed for MEDLINE] Type/Level of Evidence–Case Series/Level 4
24. Pileggi R, Dumsha TC, Myslinksi NR. The reliability of electric pulp test after concussion injury. Endod Dent Traumatol 1996;12:16–9. PMID: 8631284 [PubMed–indexed for MEDLINE] Type/Level of Evidence–Expert Opinion (Animal)/Level 5
25. Peters DD, Baumgartner JC, Lorton L. Adult pulpal diagnosis. I. Evaluation of the positive and negative responses to cold and electrical pulp tests. J Endod 1994;20:506–11. PMID: 7714424 [PubMed–indexed for MEDLINE] Type/Level of Evidence–Case Series/Level 4
26. Pantera EA Jr, Anderson RW, Pantera CT. Reliability of electric pulp testing after pulpal testing with dichlorodifluoromethane. J Endod 1993;19:312–4. PMID: 8228753 [PubMed–indexed for MEDLINE] Type/Level of Evidence–Cohort Study/Level 2
27. Mandel E, Machtou P, Torabinejad M. Clinical diagnosis and treatment of endodontic and periodontal lesions. Quintessence Int 1993;24:135–9. PMID: 8511265 [PubMed–indexed for MEDLINE] Type/Level of Evidence–Expert Opinion/Level 5
28. Garcés Ortiz M, Leyva Huerta ER. Correlation of clinico-radiographic findings with histopathology in teeth diagnosed as necrotic. Pract Odontol 1990;11:49–53. Spanish. PMID: 2132281 [PubMed–indexed for MEDLINE] Type/Level of Evidence–No English Full Text, Case Series/Level 4
29. Rowe AH, Pitt Ford TR. The assessment of pulpal vitality. Int Endod J 1990;23(2):77-83. PMID: 2202687 [PubMed - indexed for MEDLINE] Type/Level of Evidence–Review, Expert Opinion/Level 5
30. Georgopoulou M, Kerani M. The reliability of electrical and thermal pulp tests. A clinical study. Stomatologia (Athenai) 1989;46:317–26. Greek, Modern. PMID: 2640533 [PubMed–indexed for MEDLINE] Type/Level of Evidence–No English Full Text, Case Series/ Level 4
31. Bender IB, Landau MA, Fonsecca S, et al. The optimum placement-site of the electrode in electric pulp testing of the 12 anterior teeth. J Am Dent Assoc 1989;118:305–10. PMID: 2921428 [PubMed–indexed for MEDLINE] Type/Level of Evidence–Case Series/Level 4
32. Daley J, Boyd E, Cooper J, O'Driscoll P. Optical assessment of dental pulp vitality. J Biomed Eng 1988;10:146–8. PMID: 3361869 [PubMed–indexed for MEDLINE] Type/Level of Evidence–Case Series/Level 4
33. Hyman JJ, Cohen ME. The predictive value of endodontic diagnostic tests. Oral Surg Oral Med Oral Pathol 1984;58:343–6. PMID: 6592532 [PubMed–indexed for MEDLINE] Type/Level of Evidence–Review of 5 previous case series reports and an attempt to meta-analyze, Expert Opinion/Level 5
34. Abou-Rass M. The stressed pulp condition: an endodontic-restorative diagnostic concept. J Prosthet Dent 1982;48:264–7. Review. PMID: 6750089 [PubMed–indexed for MEDLINE] Type/Level of Evidence–Review Expert Opinion/Level 5
35. Cooley RL, Robison SF. Variables associated with electric pulp testing. Oral Surg Oral Med Oral Pathol 1980;50:66–73. PMID: 6930604 [PubMed–indexed for MEDLINE] Type/Level of Evidence–Case Series/Level 4
36. Klein H. Pulp responses to an electric pulp stimulator in developing permanent anterior dentition. ASDC J Dent Child 1978;45:199–202. PMID: 277443 [PubMed–indexed for MEDLINE Type/Level of Evidence–Case Series/Level 4
37. Ehrmann EH. Pulp testers and pulp testing with particular reference to the use of dry ice. Aust Dent J 1977;22:272–9. PMID: 277144 [PubMed–indexed for MEDLINE] Type/Level of Evidence–Expert Opinion/Level 5
38. Fulling HJ, Andreasen JO. Influence of splints and temporary crowns upon electric and thermal pulp-testing procedures. Scand J Dent Res 1976;84:291–6. PMID: 1068506 [PubMed–indexed for MEDLINE] Type/Level of Evidence–Case Series/Level 4
39. Fulling HJ, Andreasen JO. Influence of maturation status and tooth type of permanent teeth upon electrometric and thermal pulp testing. Scand J Dent Res 1976;84:286–90. PMID: 1068505

[PubMed–indexed for MEDLINE] Type/Level of Evidence–Case Series/Level 4

The Editorial Board of the *Journal of Endodontics* has recently completed a focused review of the "essential endodontic literature." The section of this literature-based online study guide entitled "Pulpal and Periradicular Diagnosis" was also used to ensure inclusion of the most appropriate evidence (*http://download.journals.elsevierhealth.com/pdfs/journals/0099-2399/PIIS0099239907005626.pdf*). Six additional citations from the "Pulpal Diagnostic Tests" section were subsequently included bringing the reference total to 45 citations. These additional citations included:

40. Trowbridge HO, Franks M, Korostoff E, et al. Sensory response to thermal stimulation in human teeth. J Endod 1980;6:405–12. PMID: 6935330 [PubMed - indexed for MEDLINE] Type/Level of Evidence–Case Series/Level 4
41. Chambers IG. The role and methods of pulp testing in oral diagnosis: A review. Int Endod J 1982;15:1–15. PMID: 7047409 [PubMed - indexed for MEDLINE] Type/Level of Evidence–Review/Level 5
42. Keir DM, Walker WA III, Schindler WG, Dazey SE. Thermally induced pulpalgia in endodontically treated teeth. J Endod 1991;17:38–40. PMID: 1895039 [PubMed - indexed for MEDLINE] Type/Level of Evidence–Case Series/Level 4
43. Tidwell E, Witherspoon DE, Gutmann JL, et al. Thermal sensitivity of endodontically treated teeth. Int Endod J 1999;32:138–45. PMID: 10371910 [PubMed - indexed for MEDLINE] Type/Level of Evidence–Case Series/Level 4
44. Jones DM. Effect of the type carrier used on the results of dichlorodifluoromethane application to teeth. J Endod 1999;25:692–4. PMID: 10687531 [PubMed - indexed for MEDLINE] Type/Level of Evidence–Expert Opinion, Benchtop/Level 5
45. Kardelis A, Mainberg T, Sulte H, et al. Effect of narcotic pain reliever on pulp tests in women. J Endod 2002;28:537–9. PMID: 12126385 [PubMed-indexed for MEDLINE] Type/Level of Evidence–RCT/Level 1

Subquestion #5: How Can We Standardize Radiographic Interpretation of Endodontic Pathosis in Everyday Practice, and What Can Contemporary Imaging Technologies Add to Our Understanding of Endodontic Diagnosis?

Periradicular/Periapical Pathosis

Radiographic interpretation of periradicular/periapical pathosis is controversial in the endodontic literature. When during the course of apical periodontitis can a lesion be detected on a radiograph or digital image is one question that is debated extensively.

Priebe et al (1) showed that radiographs should not be used to differentiate the nature of periapical pathosis and that a poor correlation exists between radiographic and histologic diagnosis. Bender and Seltzer (2) reported that in order for a lesion to be detected radiographically, the bone cortex must be affected and lesions of cancellous bone were not visible radiographically. Bony lesions cannot be visualized radiographically if they are confined within the cancellous bone. However, if the lesions erode the junction area of the cortex and cancellous bone, or perforate the cortex, they could be distinguished radiographically. The size of a rarefied area on a radiograph cannot be correlated with the amount of tissue destruction (3).

Shoha et al (4) found that the radiographic images were consistently smaller than the actual experimental bony defects. Lesions in the premolar area were only slightly larger than their radiographic images and were evident on the radiographs before their cortical plate was involved. LeQuire et al (5) showed that when a high kVp and long cone technique were used with a paralleling device, cancellous lesions were visible radiographically 84% of the time. In human cadaver jaws, Lee and Messer (6) showed that periapical lesions confined to cancellous bone were detected in 80% of cases, and the presence of a sclerotic border tended to enhance visualization.

Bender (7) reported that the amount of mineralized bone loss in cancellous bone does not significantly affect the radiographic results. The lowest percent of MBL in the direct path of the x-ray beam to create a radiolucent area in cortical bone was 6.6%.

Kaffe and Gratt (8) found that the lamina dura and periodontal ligament are radiographic features that were interpreted more consistently than other evaluated features, and diagnoses based on these features are more accurate than using other features. Cavalcanti et al (9) found that the loss of periapical lamina dura alone was not sufficient for most dentists to detect a change radiographically. Both lamina dura and trabecular bone must be lost before most dentists can detect a periapical change.

Brynolf (10) showed that when two or three films from different angles are used, the accuracy of the radiographic interpretation increases. Bohay (11) evaluated the sensitivity and specificity of posterior radiographic periapical diagnosis and found the sensitivity to be 0.65 and the specificity to be 0.78 (ie, periapical radiographs were better able to identify the teeth without periapical disease than to identify the teeth that have periapical disease).

Interpretation of Radiographs

Reading versus interpreting radiographs is another area of debate. Goldman et al (12) reported that when interpreting radiographs for outcomes assessment and the presence or absence of rarefaction, examiners agreed 47% to 73% of the time. In a follow-up study, they confirmed that radiographic interpretation is a very subjective process because examiners agreed with themselves only 75% to 83% of time (13). Similar to the often quoted Goldman et al studies, Bohay (11) reported that the reliability of interpretation was only fair when interobserver agreement was assessed, but improved when intraobserver agreement was considered.

Advances in Technology

Technology has advanced in the area of radiology to include F-speed or Insight (Eastman Kodak, Rochester, NY) conventional film, xeroradiography, digital radiography, subtraction radiography, phosphor images, ultrasound and now cone beam-computed tomography (CBCT), but improvement in our ability to interpret periradicular/periapical pathosis is still debatable with some of the methodologies. Comparing xeroradiography and E-speed conventional film, Barkhordar and Kempler (14) reported no difference in the detection of periapical bone pathosis.

Tyndall et al (15) found that digitally subtracted images were more sensitive for identifying cortical and cancellous bone changes than conventional films. In an in vitro model, Dove et al (16) found subtraction radiography capable of discriminating between health and disease, and Mikrogeorgis et al (17) found that the progress of chronic apical periodontitis can be followed predictably by their subtraction methodology. Digital subtraction radiography may also be useful in the evaluation of healing after endodontic therapy (18).

Kullendorpf et al (19) concluded that conventional film radiography performed slightly better for the detection of periapical bone lesions than direct digital radiography and that image processing did not improve the observer performance. Paurazas et al (20) reported that cortical bone lesions were identified with greater accuracy than trabecular bone lesions regardless of using digital radiography or conventional films. Folk et al (21) showed that there was no significant difference in the accuracy of detecting artificially prepared periapical lesions between Schick CDR (Schick Technologies, Long Island City, NY) and Trophy RVG (Eastman Kodak, Rochester, NY) direct digital radiography systems, and their results were in agreement with Bender and Seltzer regarding when a lesion can be seen on a digital image.

Cotti et al (22) introduced the potential of ultrasound real time imaging in endodontics and in a follow-up article found that the methodology was able to distinguish between granulomas and cysts (23). Gundappa el al (24) found that periapical radiographs and digital radiography were able to diagnose periapical disease and also found that ultrasound imaging agreed with the histopathological diagnosis in all 15 cases examined.

In a review article, Huumonen and Ørstavik (25) discussed the usefulness and limitations of the radiologic examination in periapical diagnosis. They concluded that"Systems for the training and calibration of observers may be used to improve diagnostic performance, and digital manipulations have great potential for the detection of more sophisticated radiographic techniques is still in the future." However, it appears that a number of investigators believe that the usefulness of CBCT is "now." Velvart et al (26) found that computed tomography scans provided more information for detecting apical lesions and for surgical treatment planning than conventional radiography. Lofthag-Hansen et al (27) found that CBCT provided more relevant information in the diagnosis of periapical pathosis compared with a periapical radiograph. Patel et al (28) felt that CBCT may have great use in endodontics in evaluating the outcomes of treatment. Estrela et al (29) used CBCT as the gold standard to evaluate the accuracy of detecting apical periodontitis when compared with periapical and panoramic radiographs. They found that apical periodontitis was correctly identified in 54.5% and 27.8% for periapical and panoramic radiographs, respectively.

Cotton et al (30) identified the following endodontic applications for cone beam volumetric tomography: diagnosis and canal morphology, nonendodontic pathosis, root fracture, internal resorption, invasive cervical resorption, presurgical anatomic assessment, and diagnosis of a failed implant (30). As the costs go down and the CBCT machines become more common in dental offices, CBCT may be the answer to more early and accurate diagnosis of periradicular/periapical pathosis and evaluation of the healing progress of endodontic therapy and may resolve the issue of inter- and intraobserver interpretation of radiographs/images.

Subquestion #5 References

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14. Barkhordar RA, Kempler D. A comparison between xeroradiography and conventional radiography in the diagnosis of endodontic lesions. Oral Surg Oral Med Oral Pathol 1988;66:489–93.
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