Pulp and Periradicular Testing

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Abstract

Pulp and periradicular testing is crucial to the initial trauma evaluation and to subsequent monitoring of the traumatized teeth and supporting structures. An accurate diagnosis serves as the basis for therapeutic intervention and helps to ensure that destruction of the dental structures will be minimized and function will be regained. The purpose of this review is to present the current best evidence for accurate diagnostic testing of the pulp and periapex of traumatized teeth. Five databases were searched for literature pertaining to pulpal testing and trauma. Widely recognized textbooks were also consulted. Currently used pulp vitality testing is constrained by its subjective character and by the fact that it is a measure of neuronal status and not true pulpal viability. Tests that measure tissue perfusion more accurately reflect pulpal vitality, but they are not available commercially. This review discusses the specificity, sensitivity, and accuracy of commonly used tests, with emphasis on the applicability of certain tests to specific patient presentations in trauma. Factors that influence test selection are discussed, and specific recommendations are made on the basis of best evidence. Although differences exist between the various studies as to the accuracy of commonly used pulpal and periradicular tests, most of these have acceptable predictive value. Pulpal and periradicular tests in the trauma patient should be used in conjunction with clinical and radiographic observations to arrive at a diagnosis and treatment plan. (J Endod 2013;39:513–519)

Key Words

Dental trauma, electric pulp test, laser Doppler flowmetry, pulse oximetry, sensitivity testing, thermal tests, vitality tests

A proper diagnosis is the basis for any successful treatment in dentistry. This is particularly important in the treatment of traumatic injuries to the dentition in which proper assessment of the conditions of the affected tissues can limit the invasiveness of therapy or substantiate an aggressive approach to treatment to limit further destruction of biological structures.

A variety of diagnostic tests are used in endodontics to assess pulpal and periradicular health. These tests vary in their sensitivity, specificity, and predictive values. Sensitivity is defined as the ability of a test or technique to identify teeth that are diseased. Specificity is defined as the ability of a test to identify healthy teeth. The predictive value of a test particularly in the trauma patient where damage to the periodontium and psychological factors interfere with the perception of any stimulus. It is for this reason that tests that evaluate the pulpal tissue directly have become a focus of interest. The accuracy of tests used to determine pulpal status concluded that no studies reached high quality (6). A number of studies have provided “best evidence” for the use of existing tests. Selected best evidence data for pulpal vitality tests are shown in Table 1.

A review of diagnostic testing shows that most of the currently used tests are subjective in nature. That subjectivity is both patient and operator dependent. Data obtained from thermal and electrical tests are dependent on the patient’s subjective perception and description of a response to the applied stimulus. The application of a testing stimulus by the operator is dependent on the length of time it is applied, where and how it is placed on the tooth, as well as the physical character of the stimulus (degree of heat, cold, pressure, etc) (1). Such subjectivity limits the predictive value of a test particularly in the trauma patient where damage to the periodontium and psychological factors interfere with the perception of any stimulus. It is for this reason that tests that evaluate the pulpal tissue directly have become a focus of interest in the field of trauma. These tests bypass patient perception and directly gauge the condition of the pulp. They offer a significant advantage over conventional pulpal testing, which has been documented to have a poor correlation with the histologic status of the tissue tested (7, 8). Presently these modalities are not readily available to the clinician. A meaningful and clinically cogent discussion therefore should focus on those tests presently used in everyday dental practice. The purpose of this review is to discuss currently used pulpal and periradicular tests in the traumatized tooth and to show their role in case management. This will include a discussion of experimental diagnostic technologies, but only from a theoretical perspective.

Periradicular Testing of the Traumatized Dentition

Immediately after trauma the purpose of periradicular testing is primarily to assess the degree of injury to the tooth and periodontium. It is expected that the traumatized tooth will be sensitive to manipulation initially. The persistence or recurrence of sensitivity in the posttrauma period can indicate pathology and direct further treatment of the dental structures involved (9). The primary tests for evaluating the periradicular tissues after trauma include mobility, percussion, and palpation testing.
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TABLE 1. Sensitivity and Specificity of Various Vitality Tests on Mature Permanent Teeth Taken from Recent Studies by Using a Clinical Gold Standard (2, 18, 45)

<table>
<thead>
<tr>
<th>Clinical presentation</th>
<th>Cold test</th>
<th>Heat test</th>
<th>EPT</th>
<th>LDF</th>
<th>Pulse oximetry</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sensitivity</td>
<td>0.81–0.92</td>
<td>0.86</td>
<td>0.71–0.87</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>Specificity</td>
<td>0.89–0.93</td>
<td>0.41</td>
<td>0.71–0.87</td>
<td>1.0</td>
<td>0.95</td>
</tr>
<tr>
<td>Accuracy (%)</td>
<td>97*</td>
<td>—</td>
<td>97.7</td>
<td>96.3</td>
<td>—</td>
</tr>
</tbody>
</table>

*O3, ice pencil.

Mobility Testing
Tooth mobility is an important indicator of how severely the tooth has been dislodged from its normal position in the tooth socket. The degree of mobility is directly proportional to the physical stretching or tearing of the vasculature of the pulp. Likewise, a lack of physiological mobility can indicate intrusion in one or more dimensions, resulting in crushing injuries to the vasculature (9). Recovery appears to be related to the amount of force the tooth sustains as well as the maturation level of the apex. The former may be gauged by the degree of tooth displacement, and the latter is apparent with proper radiographs and patient age (10).

The mobility of several teeth in unison is indicative of an alveolar fracture. Tooth vitality within the segment may be unaltered, but stabilization of the broken segment is necessary, and it influences the splitting time (11). Tooth mobility can also indicate an unfavorable type and location of horizontal root fracture. Transverse root fractures in the cervical area of the tooth are associated with higher mobility of the coronal segment and a higher rate of healing complications (12).

Mobility at the time of luxation injury does not appear to have a significant effect on prognosis (13).

Percussion Testing
Sensitivity to percussion is an indication of mechanical allodynia, which is defined as a reduction in the mechanical pain threshold. It is a reflection of inflammation of the periodontal ligament, and as a clinical test it shows a high sensitivity for detecting periradicular pain (14, 15).

The technique for percussion testing is variable. The most typical method is to use a gloved finger or the blunt end of a dental instrument to percuss teeth in the quadrant of interest and a contralateral tooth. This method, however, is not quantitative. The use of bite force transducers and digital force transducers have been shown to be reliable instruments for quantitatively measuring mechanical allodynia in the teeth of patients, but these devices are not widely clinically available (14, 15).

The results of percussion testing in the traumatized dentition can have different implications depending on the length of time since the injury. Percussion sensitivity immediately after trauma reflects inflammation of the attachment apparatus as a result of the trauma and is a result of tissue damage. Percussion sensitivity at follow-up visits can indicate infection or an undetected alveolar fracture. It has been reported that sensitivity to percussion after luxation injuries is the only sign significantly related to pulp necrosis (16).

In addition to the subjective response of the patient to percussion of a traumatized tooth, the clinician’s perception of the tone of percussion is significant. A high-pitched or metallic percussion tone immediately after injury can indicate that the injured tooth is locked in bone as in a lateral or intrusive luxation injury. Andreasen et al (11) discuss in depth the art of auscultation of the tooth during percussion. They note that if a tooth is lodged in the socket, the percussion of the tooth will not be felt by the examiner’s finger on the lingual. After the initial healing of a trauma, high-pitched or metallic tone is indicative of ankylosis.

Palpation
Palpation of the alveolus can indicate the presence of an alveolar fracture as well as the direction and degree of a luxation injury in the peritrauma period. It can also indicate if a luxation has been appropriately reduced. A comparison to contralateral tissues can aid in the determination of altered anatomy or soft tissue swelling as well. At the follow-up visits palpation sensitivity can indicate that pulp necrosis and infection have ensued, and the infection has eroded through the cortical plate. This finding is confirmed with vitality testing and radiographic evaluations. Last, persistent palpation sensitivity can indicate that osseous healing from an (undiagnosed) alveolar fracture has not resolved.

Existing tests for evaluating the periradicular tissues after trauma have not been systematically evaluated for sensitivity, specificity, and predictive value. In routine endodontic evaluation that uses traditional techniques, they do not appear to consistently differentiate between pulpal and periodontal diseases (1). In the trauma patient they can yield valuable information regarding the tissues involved, the extent of involvement, and responses to healing.

Pulpal Testing of the Traumatized Dentition
Numerous studies have been designed to study the accuracy of pulp vitality testing. Although their results are of interest, their applicability to the traumatized tooth must be cautiously interpreted. The traumatized tooth often suffers from paresthesia as a result of the injury, and this altered neurologic response can take up to 9 months to resolve (13, 17–19). Andreasen et al (11) and Skjellerup (20), citing classic literature, report that immediately after trauma, up to one-half of all luxation injuries will have no response to sensibility testing. Despite the lack of neurologic response to testing, studies with laser Doppler flowmetry (LDF) and pulse oximetry consistently show signs of pulpal blood flow in the absence of a response to thermal or electric testing after trauma (18, 21). The converse is also true; teeth that respond to vitality testing immediately after trauma may subsequently undergo pulpal necrosis. It is for this reason that conventional vitality testing is considered only in concert with other findings and “prior probabilities,” particularly in the immediate posttrauma period.

The most significant predictors of continued pulpal vitality after trauma are the type of injury and the developmental status of the tooth (13) (Figs. 1 and 2). In mature permanent teeth after luxation injuries and certain types of fractures, a continued negative response to vitality tests after 3 months is considered a strong indication of pulp necrosis (22). Because of the revascularization abilities of the pulp in a tooth with an open apex (>1.0 mm), cautious continued monitoring is advocated (22, 23).

Baseline vitality testing should be conducted at the earliest possible time. Although optimal, this may not be at the initial trauma treatment where the patient has sustained considerable physical and psychological trauma. Vitality testing should be completed for all teeth in the maxillary and mandibular field of trauma. Although this is most commonly the anterior region, this may not always be the case. All testing results should be recorded and repeated at 2, 4, and 6–8 weeks and then 6 and 12 months. Follow-up after that depends on the type of
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Electric Pulp Testing

The electric pulp tester (EPT) has been available for many years for pulp vitality testing. Its accuracy has been debated largely because of its high rate of false positives (25). EPT indicates the presence of functional neurons but does not indicate pulp health (26, 27). It functions by using a low-grade current to stimulate the peripherally situated myelinated A\textsuperscript{δ} nerve fibers in the dentin-pulp complex. Centrally located, pulpal C fibers do not react because their firing threshold is higher and requires a much stronger electrical current (28). A\textsuperscript{δ} nerve fibers are particularly vulnerable to trauma where a compromise in blood flow is the principal cause of pulpal demise. This is because the A\textsuperscript{δ} nerve fibers are the most sensitive to oxygen deprivation and will cease to function before pulp necrosis ensues. The clinical implication is that the EPT may not elicit a response despite a vital pulp in traumatized teeth. Likewise, in the immature permanent tooth the developmental ingress of A\textsuperscript{δ} fibers in the periphery of the pulp tissue is relatively late and can result in a higher rate of false-negative responses (5, 24, 29, 30). For this reason it is not the vitality test of choice for immature traumatized teeth (4).

Conversely, the EPT has been shown to be superior to cold testing in older teeth or teeth that have undergone pulp canal obliteration/mineralization because it does not rely on dentinal fluid flow to elicit a pulpal response. Studies have shown that with age, the dentinal tubules decrease in size, and the amount of dentin fluid is reduced, making teeth less sensitive to thermal changes (31, 32). The same changes could be expected in the younger traumatized tooth that has undergone pulp canal mineralization. Thus, in the assessment of an “old” trauma where there has been pulp canal mineralization, the EPT may be the most accurate test for pulp vitality (4, 33, 34). It is noted that pulp canal mineralization results in higher threshold readings with EPT in postruama observation periods greater than 5 years (35).

Consistent with other vitality tests, EPT is technique sensitive. Tooth isolation, probe placement, and conduction medium have been shown to have an impact on accuracy (21). Moisture on the tooth surface and contacting metallic restorations can conduct current to adjacent teeth or the gingiva, giving a false-positive reading (36). An interproximal insulating material or even rubber dam placement can facilitate proper isolation and minimize this. Probe placement for the EPT has been debated. From a theoretical perspective, the placement of the probe should be where the maximum concentration of A\textsuperscript{δ} nerve fibers exists, and the overlying enamel and dentin thickness is minimal (21, 37). This allows a summation effect where the maximum number of nerve terminals is stimulated by the current (28). In the young tooth this would be a pulp horn (38–40). In the older tooth it may be closer to the cervical one-third of the crown. This optimal position also varies depending on the type of tooth tested; for anterior teeth the area of high neural density would be the incisal edge, and for posterior teeth it would be the middle third (21, 40). Conduction medium is necessary for proper probe contact with the tooth surface. One study concluded that K-Y lubricating gel (Johnson & Johnson, New Brunswick, NJ) and Crest baking soda and peroxide toothpaste (Procter & Gamble, Cincinnati, OH) provided the optimal conduction for EPT (41). Previous studies had indicated no difference in conduction media (42, 43). Last, EPT cannot be used on teeth where there is no exposed natural tooth surface.

In the majority of studies the specificity of EPT is consistently high. The sensitivity is more variable. EPT has a lower dependability for detecting a necrotic pulp, but the ability to confirm vitality is the same as that of the cold test (2, 44, 45). The accuracy of the EPT is highest where there is no response to the current at any level. Stated another way, a negative response to EPT has a high positive predictive value (5, 7, 18). Information obtained from EPT indicates the presence or absence of vitality, but it gives no information on the health status of the pulp. An EPT reading cannot differentiate between reversible or irreversible pulpitis.

Thermal Sensitivity Tests

There are several techniques for thermal testing of the traumatized tooth. Unlike the EPT, thermal tests work by stimulating expansion or contraction of dentinal fluid within the patent tubules, resulting in a rapid fluid movement. This movement of dentinal fluid results in the stimulation of A\textsuperscript{δ} fibers in the pulp/dentin complex (37). Of the thermal tests, cold testing is the most commonly performed. The most popular modes of cold application are CO\textsubscript{2} pencil, refrigerant spray, and ice. The physical properties of each cold stimulus are different as are their respective accuracies in controlled clinical trials (45, 46).

Pencils made of compacted carbon dioxide crystals have a temperature of −69°C, but when used clinically, they can only
achieve a temperature of $-56^\circ$C (47). Even though CO$_2$ has an extremely low temperature, it has been shown that vitality testing with CO$_2$ snow is safe for the pulp tissue and enamel (48). Furthermore, it has been shown to be one of the most accurate and reliable vitality tests (45).

Despite the effectiveness of CO$_2$ pencils, the necessity for the acquisition, maintenance, and storage of a cumbersome CO$_2$ tank makes it impractical for many dental offices. A more convenient yet effective cold test was introduced by the adaptation of refrigerant spray for pulp testing (49). Original formulations of the spray were dichlorotetrafluoromethane (DDM) and had a temperature of $-50^\circ$C. Environmental concerns resulted in a reformulation of the sprays to allow zero ozone depletion. The currently available ones are 1,1,1,2-tetrafluoroethane (TFE). TFE has a temperature of $-26.2^\circ$C and is most effective when applied to the tooth by saturating a #2 cotton pellet and placing it on the midfacial aspect of the tooth or crown (50). Comparisons between refrigerant sprays and CO$_2$ ice have shown them to be equivalent to each other in their accuracy and equivalent to or superior to EPT (4).

Common ice pencils, which are made by filling spent anesthetic carpules with water, have been widely used for cold testing; however, they are consistently shown to be less accurate than either CO$_2$ pencils or spray refrigerant (4, 45). This could be attributed to the fact that frozen water is not as cold as CO$_2$ snow or DDM/TFE. It could also be due to the difficulty of confining the cold stimulus to the target tooth because cold water from the melting stick can flow onto adjacent teeth, confounding interpretation of the patient’s response.

Heat testing is another form of thermal testing. It is often used in routine endodontic evaluations when the patient’s chief complaint is pain to hot food/liquids. It is not typically performed as an initial evaluation in the traumatized tooth; however, it may be indicated if a report of heat sensitivity develops subsequently. A heat stimulus can be applied to a tooth by using a variety of techniques. These include heated gutta-percha stopping, hot water, and frictional heat by using a rubber cup or application of a heated instrument. In current practice the use of a controlled heat source or hot water are the most commonly used methods. Both of these have the advantage of controlling the temperature, which is important because excessive heating can damage the pulp (51).

The accuracy of heat testing has been shown to be low when simply evaluating vitality. Petersson et al (2) showed that the lack of sensation to heat was not a reliable indicator of pulp necrosis. Likewise, a positive response to heat was more accurate but still less reliable than that achieved with cold or EPT.

Unlike the electric pulp test, thermal testing can be used to evaluate the health of the pulp. The character of the response has been shown to correlate with the potential for healing or necrosis (52). In the monitoring of traumatic injuries, distinguishing between reversible or irreversable pulpitis may result in a less invasive therapy or a more aggressive one that prevents infection, a known stimulator of inflammatory root resorption (53).

Factors That Affect Patient Response to Sensitivity Testing

Numerous factors have been identified as having an impact on vitality testing results. Immediately after trauma, teeth are often unresponsive to testing. This is due to neuronal degeneration that is characterized by intramyelin edema, axonal swelling, and a partial loss of the myelin sheath (54). Concurrent dental treatment such as orthodontics can alter the response to EPT by increasing the threshold of response (55). This has been attributed to a change in tissue respiration and blood flow that can affect vulnerable A$\delta$ nerve fibers (56). Medications, alcohol use, and psychological disorders have also been shown to decrease the response to EPT (57). Psychological factors such as fear of pain can influence the patient’s perception of a stimulus or even motivate a false response in an attempt to avoid pain.
Experimental Vitality Tests

Vitality Tests That Measure Blood Flow

Conventional vitality tests assess the integrity of the neuronal supply of the pulp, yet vascular supply is the most accurate determinant of pulpal vitality (58). An understanding of this has stimulated interest in diagnostic modalities that focus on blood supply rather than innervation. LDF and pulse oximetry are noninvasive technologies that directly evaluate blood flow in the target tissue. Both have been investigated as diagnostic tools to assess pulpal vitality, and both offer great potential (59, 60). Despite this, there are practical limitations that must be overcome before either test becomes part of the routine pulpal assessment after trauma.

Laser Doppler Flowmetry. Soft tissue perfusion injuries and digit replants have been monitored with LDF for years (61). Adaptation of this technology to teeth has posed more of a challenge and has so far precluded a commercially available device. Numerous investigators have evaluated the efficacy of LDF for determining pulpal blood flow in a laboratory setting or isolated patient trials (19, 62, 64, 65). The findings of these studies consistently support the accuracy of LDF in determining pulpal vitality.

LDF works by measuring the number and velocity of particles in the microcirculation. It does this by emitting an infrared light beam from a laser diode that is deflected by moving red blood cells but not stationary ones. This deflection is called a Doppler shift, and it is recorded by a photodetector in the flowmeter that interprets the interference pattern by using an algorithm. The result is a semiquantitative assessment of blood flow termed the flux signal that is expressed as the number of moving erythrocytes per second multiplied by their mean velocities (66).

A major drawback for LDF in the determination of pulpal vitality is background interference from the surrounding tissues. In some studies it was found that a major portion of the signal detected from teeth came from the periodontium (67, 68, 69). Some of the background can be reduced by using a probe and holder that better adapts to the tooth surface and by tooth isolation with a rubber dam or other nonconducting material. Another approach is to increase the intensity of the detection beam by using high-powered transmitted laser light. This appears to reduce background noise, while increasing the sensitivity to pulpal blood flow in thicker teeth (70). Probe placement and angulation of the beam are additional factors that influence the accuracy of LDF readings for teeth (71, 72).

Experimental data suggest that LDF is well suited for the determination of pulpal vitality and offers great promise for the evaluation of traumatized teeth. It does not appear to be useful in differentiating a normal from an inflamed pulp because of the nonlinear relationship between signal output and blood flow rate in small volumes (73). Clinical studies evaluating accuracy show that LDF has superlative specificity and sensitivity when compared with conventional vitality tests (46).

A variety of LDF units have been tested on teeth through the years. The use of laser diodes that emit a longer wavelength of light proved to penetrate enamel and dentin better (74). More recently, ultrasound Doppler imaging has been evaluated for its use in determining pulpal vitality (75).

Pulse Oximetry. Whereas LDF measures the actual flow of blood through the vasculature, pulse oximetry measures the oxygen saturation of arterial blood in a tissue. It has been used in the medical field for several decades and only recently has found applicability in the evaluation of tooth vitality. Pulse oximetry detects the amount of oxygenated blood in circulation by registering the differential light absorption of oxygenated hemoglobin versus deoxygenated hemoglobin and calculating the $O_2$ saturation. Initial studies evaluating the applicability of the pulse oximeter to vitality testing have been fraught with the frustration of accommodating the instrument to the size and shape of teeth, while maintaining the relationship between the photoreceptor and light-emitting diode sensor. In recent years progress has been made with prototypes of pulse oximeters suitable for dental use (76).

Studies examining the applicability of pulse oximetry to vitality testing have been promising. A comparison of readings from a custom-made pulse oximeter and conventional vitality tests performed on teeth slated for endodontic treatment revealed the pulse oximeter was more reliable than the EPT, heat, and cold test (76). The sensitivity and specificity of pulse oximetry were superior to all tests. The gold standard for the study was confirmation of pulpal status on endodontic access (Table 1). These findings have exciting implications for the development of a unit that could be available in a routine clinical setting.

Dual-Wavelength Spectrophotometry. Dual-wavelength spectrophotometry can also be used to measure oxygen saturation in the pulpal blood supply. Animal studies have shown that dual-wavelength spectrophotometry can differentiate between a necrotic pulp space and one filled with oxygenated blood (77). A commercially available unit suitable for dental use is not available.

Thermography. A relationship between surface temperature and tooth vitality has been shown (78). The vital tooth derives its temperature externally from the periodontium and the oral environment and internally from the pulpal circulation and metabolism. The nonvital tooth has only an external source of heat, so surface temperature is a function of heat conductance (79). Theoretically, this should allow differentiation between the vital and nonvital pulps either by differences in baseline temperature or by the speed of rewarming after cooling. Although a simple concept, actual measurement is fraught with confounding variables. A diagnostic temperature differential has been investigated by the use of thermocouples, infrared thermometers, miniature thermometers, thermists, infrared thermography, and cholesteric liquid crystals (80). It holds promise as a noninvasive vitality test, but as yet, there are no commercially available devices.

Conclusions

In summary, a variety of periradicular and pulp vitality tests exist to evaluate and monitor the trauma patient. Presently, commonly available pulp vitality tests all depend on the presence of intact nerve endings. Their selection and interpretation are highly dependent on several predictive factors or prior/pretest probability such as the age of the patient, the time since the initial trauma, the type of trauma sustained, the degree of root-end development, and the presence of pulp canal mineralization (Fig. 3). Taken in concert with the radiographic and clinical findings, they provide a basis for therapies designed to preserve the dentition. Klausen et al (15) reported that the cumulative data from the patient examination and testing were accurate predictors of disease that led to an accurate pulpal diagnosis in 82% of cases. Newer methods of testing pulpal vitality promise to increase our diagnostic accuracy in the trauma patient to even higher levels.

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References


