Pulp diagnosis: current guidelines, shortcomings, and future developments

Learning outcomes

- To develop an understanding of the basis of pulpal diagnosis;
- to understand the limitations of contemporary diagnostic tools and systems; and,
- to be aware of the future of pulpal diagnostic tests and technology.

Introduction

Accurate and reliable diagnosis is at the core of operative dentistry and endodontics, as without it over- or undertreatment will ensue. Current diagnostic tools should aim to differentially diagnose not only whether the pulp is vital or non-vital, but also the threshold between reversible and irreversible pulp damage. Identifying this inflammatory threshold will help determine whether the pulp can be preserved in its entirety, in part, or not at all.

Current endodontic diagnosis relies on the use of proxy measures that elicit the symptoms experienced by the patient and can indicate the condition of the dental pulp.[1] The primary means of obtaining a pulpal diagnosis involves the use of pulp sensibility tests,[2] accompanied by clinical history, examination and radiographs. The responses to thermal and electrical stimuli and their relative severity indicate the condition of the pulp; however, inflammatory processes affecting the pulp are dynamic, with signs/symptoms changing based on the degree of inflammation present.[3] Therefore, tests should be able to reproduce the symptoms of pulpal inflammation and determine the degree of inflammation present in the pulp.

However, as in medicine, endodontic diagnostic procedures are associated with some degree of uncertainty. To formulate an accurate pulpal diagnosis, practitioners should be aware of the diagnostic value (sensitivity and specificity) of available pulp tests and how their results should be interpreted, have a working understanding of the limitations associated with their use, and be aware of future trends in the area in order to provide more biologically based, conservative treatments. The aim of this review is to analyse current diagnostic systems, discussing their use and limitations as well as highlighting future areas of development.

Classification of pulpal disease

Diagnostic systems should be capable of correlating biological conditions within the dental pulp to clinical and radiographic findings in order to arrive at a correct diagnosis, which subsequently informs treatment options.

The currently accepted classification of pulpal and periapical disease, as endorsed by the American Academy of Endodontology (AAE), is a binary system of diagnosis based on the perceived ability of the pulp to repair following insult, and relies solely on patient symptoms and subjective responses to tests.

Pulpitis of a reversible nature represents a vital pulp associated with the initial inflammatory reaction in response to the progression of carious lesions through the tooth without bacterial colonisation within the pulp chamber or root canal system. Pathognomonic symptoms classically include short, sharp, non-lingering pain brought about only through stimulation of the affected tooth. Reversible pulpitis can be treated effectively with the removal of this irritating stimulus and appropriate restoration without the need to remove pulpal tissue. Irreversible pulpitis is characterised by a range of symptoms, most commonly describing persistent, spontaneous, and often nocturnal pain. This is histologically associated with bacterial colonisation of the tertiary dentine and pulp. According to current guidelines, the irreversibly inflamed pulp, although still vital, cannot be repaired and is not amenable to vital therapies, necessitating its extirpation followed by root canal treatment.

Currently, terminology to diagnose pulpal pathology, although universally employed, has been criticised by authors due to its limitations in ascertaining the true pulpal status. While the differentiation between health and necrosis is relatively straightforward,[4] accurately diagnosing the degree of pulpitis (or threshold) along the inflammatory continuum with current gold standard methods is a challenge. The terms reversible and irreversible do not reflect the dynamic biological processes occurring within the inflamed pulp. Therefore, the clinical diagnosis reached with these terms can only ascertain the probable pulpal diagnosis, and is based on relatively crude measures to correlate clinical signs and symptoms with the inflammatory status of the pulp.

The level of insult/inflammation within the dental pulp determines the type of endodontic treatment and level of intervention required. The publication of recent guidelines by both the European Society of Endodontology (ESE)[5] and the AAE[6] emphasises the growing interest in minimally invasive, biologically oriented endodontics that preserve pulp vitality. However, current terminology does not facilitate these techniques, which are often successful even in teeth with signs and symptoms indicative of irreversible pulpitis. Therefore, proposals

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Table 1: False responses from sensibility tests.[10]

False negative	False positive
Calcified/sclerosed canals: the presence of sclerosed canals will impede fluid flow within the tubules, thus acting as an insulator to stimuli.	Multi-rooted teeth: teeth with multiple roots might have inflamed pulp tissue in a canal, while the pulp chamber and other canals might be necrotic and infected.
Trauma: recent trauma can result in a transient loss of response to pulp tests.	Metallic restorations: the electrical current might be conducted to adjacent teeth through contacting Class II restorations, especially if they are metallic.
Immature apex: young patients with large immature apices often have false negative responses. This is because the development of Raschkow's plexus lags behind the eruption of the tooth. Cold is recommended in place of electrical pulp testing (EPT).	Anxious or young patients.
Extensive restorations: similar to calcified pulps, large restorations act as insulators to external stimuli, thus resulting in false negative responses for some teeth.	Contact with gingival tissues.

have been made to update the current system of pulpal disease[7] to diagnose the pulp along a continuum from health to varying stages of inflammation.

Pulpal diagnostic tests

Diagnostic nomenclature relating to pulp pathology is based on classic studies of the histological state of the pulp as a measure of validity. Diagnostic accuracy systems utilise histology as a reference standard to define/verify clinical classifications. Histological verification is regarded as the gold standard in endodontics as there is no other objective measure of pulpitis currently available.[8] However, assessing the condition of the dental pulp clinically through histology is not feasible. In addition, the dentine-pulp complex is encased in a mineralised barrier of tooth structure, and therefore the pulp cannot be directly inspected until it is exposed. As a result, surrogate markers of pulpal health, such as an assessment of the condition of nerve supply (sensibility) and/or blood supply (vitality) are routinely employed.

The ideal pulp diagnostic test should be objective, easily completed, inexpensive, reliable, reproducible, standardised, painless, and non-invasive.[9] Although a myriad of diagnostic tests exist, they all have inaccuracies, leading to misdiagnosis at the time of testing and the creation of false positive and false negative results (**Table 1**).[10]

The diagnostic accuracy of any clinical test is based on its inherent ability to differentiate between health and disease. This can be quantified as sensitivity and specificity. Sensitivity is the ability of a test to detect disease in a patient who has a disease, while specificity is the ability to detect the absence of disease in those patients without that said disease or condition.[4] These values are given for teeth that have known diseased states. In unknown diseased states, positive predictive values (PPVs) and negative predictive values (NPVs) are used. PPV indicates the probability that a positive result represents a diseased tooth, whereas an NPV is the probability that a negative result indicates a disease-free tooth. Although these values can be used to compare to each other, their value is questioned due to the limitations of the tests, which will be discussed.

Table 2: Pooled diagnostic accuracy of five pulp tests.[4]

	Sensitivity	Specificity	Accuracy	PPV	NPV
Cold test	0.867	0.843	0.840	0.807	0.871
Heat test	0.778	0.665	0.723	0.619	0.785
Electrical pulp test (EPT)	0.720	0.928	0.817	0.888	0.804
Laser Doppler flowmetry (LDF)	0.975	0.950	0.971	0.937	0.997
Pulse oximetry (PO)	0.973	0.954	0.974	0.943	0.990

FIGURE 1: roeko Endo Frost (C) refrigerant spray.

The validity of each recognised sensibility and vitality test has been extensively researched in the literature. The pooled sensitivity/specificity for each type can be seen in **Table 2**. It is important to state that a diagnosis of the condition of the pulp cannot and should not be formed only on the basis of the results obtained from pulp tests. These diagnostic tests serve as adjuncts and must be combined with information gained from a thorough history, additional clinical tests, and radiographic analysis to formulate an accurate diagnosis for the pulp.

Current standards in pulpal diagnostics

Sensibility tests

Sensibility tests assess the neural response of pulpal tissue to an external stimulus by activation of A-delta fibres.[8] These tests indirectly assess the condition of the pulp via the integrity of these nerve fibres and aim to reproduce the symptoms experienced by the patient to reach a pulpal diagnosis. Therefore, the condition of the nerve supply is used as a surrogate marker of pulp vitality, i.e., blood supply.

Thermal stimuli, when applied to the surface of a tooth, result in the hydrodynamic movement of fluid within the dentinal tubules, acting on A-delta fibres within the dentine-pulp complex. A subjective evaluation of the response elicited gives a determination of the sensory innervation of the pulp. Cold testing (**Figure 1**) is the most common method used to assess the condition of the pulp. Heat testing is used less than cold testing and is less reliable and sensitive,[4] although it may have

FIGURE 2: Electric pulp test (EPT).

FIGURE 3: Laser Doppler flow (LDF) machine.

its uses in mimicking the symptoms of acute pulpitis. However, It is important to note that the application of heat on a tooth for greater than five seconds can result in biphasic stimulation of A-delta and C fibres, causing lingering pain.[2]

In contrast to thermal testing, electric pulp tests (EPTs; **Figure 2**) involve the direct stimulation of A-delta fibres to elicit a response measurable by a numeric value.[11] Application of the electric current elicits ionic shift within the dentinal fluid, causing depolarisation and formation of an action potential in the A-delta fibre. The numerical reading generated by the electrical pulp tester is not a quantitative measure of the condition of the pulp. Rather, it indicates that at least some A-delta fibres are functional and able to respond to the electrical current applied to the tooth. Generally, when applying an electric stimulus to the tooth, contralateral and adjacent teeth are also tested for comparison.

Limitations of current methods of diagnosis

Sensibility tests exhibit inherent limitations, as they do not measure true vitality, but sensibility, by determining whether the nerve supply can respond to a stimulus. The true indication of vitality is whether the vascular supply is intact. While patients' symptoms from such tests can differentiate health from disease, determining the exact degree of inflammation or threshold of irreversible damage of the pulp is more challenging. This is because pulpitis is diagnosed on arbitrary and subjective measures such as patient response to pain, which may be exaggerated by some, and underestimated by others. A systematic review by Mejàre *et al.*[12] examined the accuracy of the most common diagnostic tests and concluded that there is insufficient evidence to show that signs/symptoms and responses to stimuli accurately reflect true pulp status in the presence of inflammation.

The reproduction of symptoms of pulpal inflammation should allow clinicians to ascertain the degree/severity of insult in the dental pulp. This has not been shown to be the case, however; while symptoms have been accepted as an indication of the inflamed status of the pulp, it has been shown that we cannot confidently correlate clinical signs and symptoms with histological status.[13] This finding, however, has recently been disputed.[14]

The lack of correlation between signs and symptoms and histological status of the pulp, alongside diagnostic tests with relatively limited accuracy, culminates in a situation where accurately diagnosing the pulp along a continuum of disease with contemporary techniques is challenging.

Vitality testing

Sensibility tests use neural function as a surrogate marker for pulpal health but cannot directly ascertain the vascular supply to the tooth. Therefore, vitality testing is the most accurate measurement of the condition of the pulp.[15] In a bid to improve accuracy with pulpal diagnosis and reduce false positive and negative responses, vitality testing methods have been introduced.

These tests measure the blood flow in the pulp objectively, without any reliance on the patient's response to stimuli, thus resulting in improved accuracy in diagnosing the pulpal status. These tests aim to address the recognised limitations of sensibility tests and include pulse oximetry (PO) and laser Doppler flowmetry (LDF) (**Figure 3**).

LDF is an objective, non-invasive diagnostic test that measures the numbers and velocity of particles in circulation in the pulp to give a measurement of the health of the pulp. LDF has been shown to have greater sensitivity and specificity than conventional sensibility tests.[16] Therefore, LDF should be capable of assessing between a healthy and necrotic tooth. However, while this is of particular utility in traumatised sound anterior teeth, it is of less use in heavily restored or sclerotic teeth where false positives and negatives are common.

Pulse oximetry is a physiometric technique that measures the oxygen saturation of pulpal blood via catheter diodes.[17] This objective non-invasive technique is less vulnerable to the relative limitations associated with other sensibility tests. A recent systematic review and meta-analysis concluded that LDF and PO are

the most reliable means of determining the status of the dental pulp. When both methods of vitality testing were compared, PO was regarded as the gold standard. Although PO shows great promise, there is currently no commercially available kit on the market.

Despite the improved sensitivity and specificity associated with these pulpal diagnostic tests, they too are associated with limitations.[18] In LDF, differentiating between a healthy and inflamed pulp is not currently possible as a result of error margins due to the small volume of blood measured; therefore, it can only differentiate between health and necrosis and not along a continuum.[19] Background interference from surrounding tissues has been shown to lead to inaccuracies in results with LDF. The ability of LDF to penetrate the mineralised tissue of teeth has been questioned. The equipment has also been shown to be prohibitively expensive. On the other hand, failings with PO have occurred as the instrument is not designed for dental use, although an adaptation of a tooth-specific instrument has shown it to have higher sensitivity and specificity values than EPT and cold tests.[20]

Vital pulp treatment

Endodontics has seen a shift in recent times towards a more biologically centred treatment approach by employing vital pulp treatments (VPT) in teeth displaying even signs of advanced pulpal inflammation.[21] This comes from improved data on the reparative capacity of the pulp as well as the development and use of bioactive materials shown to promote superior mineralised bridge formation. In addition, there has been greater emphasis on the benefits of preserving some or all of the pulp, such as allowing for the continual formation of tertiary dentine and preserving proprioceptive functions that reduce overloading.[22]

While root canal treatment is a successful treatment modality, it is a technique-sensitive, invasive and costly approach to carry out to a high standard in general practice. The use of VPT to preserve some or all of the pulp represents a simpler, more cost-effective approach with documented success levels, comparable with conventional endodontics.[23] By employing minimally invasive treatment as a first-line therapy, the invasive options can be avoided, or delayed until their implementation is warranted.

That said, it is recognised that the success of VPT is dependent on an accurate diagnosis of the inflammatory status of the pulp. When using current gold standard diagnostic tests, this is currently not possible. Contemporaneous methods of assessing the condition of the pulp are relatively limited in their ability to assess, objectively and quantitatively, the severity and extent of pulpal inflammation. Current pulpal diagnostic terminology and the use of crude surrogate markers of the pulpal health do not facilitate or encourage the use of VPT as a first-line treatment option, despite our knowledge of the reparative capacity of the pulp, resulting in root canal treatment being completed on teeth that may benefit more from less invasive treatment.

An improvement in the accuracy of pulpal diagnostic tests and the development of objective point-of-care measures to assess the condition of the pulp are likely needed to ideally reflect the continuum of inflammation within the pulp to facilitate evidence-based, conservative treatment options being employed at varying stages of pulpal pathosis, with the primary aim of preserving some or all pulpal tissue where possible.

Future trends

Although it has been shown that accurate diagnosis can be achieved by current subjective diagnostic tools, new objective diagnostic methods show promise in improving accuracy, e.g., dual wave spectrometry and improvements in LDF. However, these diagnostic tests are not yet commercially available.

Research is ongoing to understand the role of inflammatory mediators that better indicate pulpal status.[24] Point-of-care analysis could use gingival crevicular fluid or dentinal fluid in situations where the pulp is not exposed, or blood could be sampled from the pulp in cases of exposure to discriminately assess the inflammatory condition of the pulp quantitatively, while preserving pulpal vitality and the integrity of the tooth. Analysis may allow for the detection of molecules associated with tissue degradation, such as matrix metalloproteinase or markers of cell death, thus allowing for assessment of the degree of inflammation in a pulp.

There have been efforts made to address the downfalls associated with our current system of pulpal diagnostic terminology. A biologically centred classification system for pulpal disease[3] advocates the staged use of VPT. Pulpitis is viewed along a continuum from initial pulpitis, represented by increased response to cold, to severe pulpitis, characterised by spontaneous nocturnal pain. Ricucci *et al.* (2019) have reported that no distinct boundary exists after which the pulp is rendered beyond repair.[25] Therefore, this system recommends minimally invasive, biologic therapies as a first-line treatment. Indirect pulp therapy is advocated when pulpitis is gauged to be in the initial and mild stages. Severe pulpitis could potentially be managed with pulpotomy in place of traditional pulpectomy procedures, although recent research has highlighted that success drops after partial pulpotomy if the symptoms are classed as severe.[26] However, despite some improvements, this and other updated classification systems all suffer from the same problem, which is the lack of a reliable reference standard.[27] With developments being made with pulpal biomarkers, future systems could incorporate one or several of these markers into an objective measure of the condition of the pulp to formulate a diagnosis and subsequently guide treatment.

Conclusion

Although a myriad of pulp diagnostic tests exist, none unfortunately are ideal. Operator use and an understanding of the drawbacks of each test are important to reduce inaccuracies. Despite the recognised limitations of pulpal sensibility tests, recent guidelines have highlighted that they remain a helpful and essential aid in endodontic diagnosis.

With an understanding of the limitations of pulpal sensibility tests, efforts to assess pulpal vitality directly with vitality tests have so far had mixed success. Currently, no such vitality tests are superior in all aspects when compared to sensibility tests.

Promising new objective diagnostic tests should improve the sensitivity and specificity, but more evidence-based research and non-cost-limiting equipment need to be produced. Future research is needed in the field of pulpal diagnostic technology in a bid to reduce inconsistencies, and improve accuracy and reliability.

An understanding of the diagnostic accuracy and relative limitations of pulp testing methods will aid practitioners in accurately diagnosing the degree of pulpitis, thereby facilitating the selection of the most appropriate and effective treatment for dental pulp.

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