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Pulp Testing: A Literature Review

Tahreem Fathima, Anjaneyulu, D. Ezhilarasan

Running title: Pulp testing- a literature review

Tahreem Fathima
Saveetha Dental College and Hospitals,
Saveetha Institute of Medical and Technical Sciences,
Saveetha University,
Chennai-600077, India
Email Id- 151801063.sdc@saveetha.com

Anjaneyulu K,
Reader, Department of Conservative Dentistry and Endodontics,
Saveetha Dental College and Hospitals,
Saveetha Institute of Medical and Technical Sciences,
Saveetha University,
Chennai-600077, India
Email Id- kanjaneyulu.sdc@saveetha.com

D. Ezhilarasan
Lecturer, Department of Pharmacology
Saveetha Dental College and Hospitals,
Saveetha Institute of Medical and Technical Sciences,
Saveetha University,
Chennai- 600077, India
Email Id- ezhilarasand.sdc@saveetha.com

Corresponding Authors*
Anjaneyulu,
Reader, Department of Conservative Dentistry and Endodontics,
Saveetha Dental College and Hospitals,
Saveetha Institute of Medical and Technical Sciences,
Saveetha University,
Chennai-600077, India
Email- kanjaneyulu.sdc@saveetha.com
Mobile No: +919666151527

ABSTRACT

Pulp vitality test plays a fundamental role in regulating the health of dental pulp particularly after injury. The dental pulp is the innermost part of the tooth. It is housed in a hard chamber. It is composed of enamel and dentine. Dental pulp testing is practical and crucial diagnostic aid in

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endodontics. Pulp sensibility tests include thermal and electrical tests which extrapolate the health of pulp from the sensory responses. DWLS is a method which is independent of a pulsatile circulation. Pulse oximetry is considered to be a non-invasive oxygen saturation monitoring device widely used to record blood oxygen saturations level. All the articles were collected from various search engines like PUBMED, Google scholar etc. The articles were based on the review topic. More than 50 articles were used for review**.** The pulp testing follows 2 techniques that include pulp sensibility testing and pulp vitality testing. The results are carefully interpreted and closely scrutinised for both the techniques. There should be more researched to collaborate and assess the development of newer devices.

Keywords: Dental pulp testing, sensibility testing, vitality testing, dental, thermal , electric

INTRODUCTION

The significant challenge in dental practice is to accurately assess the pulp status in different age groups of people. It becomes further more complicated in many cases of paediatric dentistry where the practitioner is faced with a developing dentition and traumatized teeth etc (Cohen and Hargreaves, 2006); (Ramanathan and Solete, 2015). Dental pulp is an unmineralized oral tissue which is composed of certain soft connective tissue, vascular, lymphatic and nervous elements which occupy the central part of pulp cavity (Iohara *et al.*, 2016). Dental pulp tests are investigations that provide valuable diagnostic and treatment planning to the dental clinician and information regarding it (Rowe and Pitt Ford, 1990).The presence of pathosis can be determined by pulp testing when it is combined with other investigations such as radiographs, history, examination would lead to diagnosis of the underlying disease (Chen and Abbott, 2009). The nerve vessels enter and leave the tooth through foramen. Dental pulpal testing devices are used in clinical as well as diagnostic purposes in the field of dentistry to establish the health of the dental pulp, within a pulp chamber and root canals of any tooth in the oral cavity. The pulp testing devices function in two manners: pulp vitality testing which assesses the blood supply to the tooth and pulp sensitivity testing which assesses the sensory supply to the tooth (Abd-Elmeguid and Yu, 2009). Routine methods rely on stimulation of A-delta nerve fibers and give no direct indication of blood flow within the pulp that include thermal stimulation, electrical or direct dentine stimulation. The testing methods have the potential to produce an unpleasant and occasional pain and inaccurate results. In addition the test is a subjective test that depends on the patients perceived response to a stimulus as well as the dentist's interpretation of that response (Noblett *et al.*, 1996). The uses of pulp testing in oral diagnosis as discussed by (Ehrmann, 1977) are prior to operative procedures. Pulp testers should be carried out on a teeth prior to restorative or orthodontic work even if the teeth is symptomless as it is known that there can be loss of periapical bone associated with a non-vital pulp before it is detectable in a radiograph, diagnosis of pain is due to oral pain in pulp but pain may be localized and require range of tests, investigations of the radiolucent areas as they are the periapical extension of pulpal pathology. The mental foramen and the incisive canal are two normal structures which may present as

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periapical radiolucencies. Recent studies have proved that blood circulation inside the pulpal chamber is the most accurate determinant in assessing pulp vitality (Robertson, 1977). This factor helps in providing an objective which enables to differentiate between necrotic and vital pulp tissues. This review article highlights tests relying on passage of light through the tooth to detect pulp vitality with greater objectivity in the longer run. They rely on the detection of changes in the light absorption as it passes through the tooth in photoplethysmography (Hargreaves, Goodis and Tay, 2012). Assessment of the pulp's sensory response is necessary as it is the ability of pulp to respond to stimulus, and hence it would be an appropriate and accurate term for typical and common clinical pulp tests such as thermal and electrical tests (Modaresi, Dianat and Soluti, 2008). Therefore, this review summarizes the pulp testing of teeth.Our team has rich experience in research and we have collaborated with numerous authors over various topics in the past decade (Ariga *et al.*, 2018; Basha, Ganapathy and Venugopalan, 2018; Hannah *et al.*, 2018; Hussainy *et al.*, 2018; Jeevanandan and Govindaraju, 2018; Kannan and Venugopalan, 2018; Kumar and S. D. P. Antony, 2018; Menon *et al.*, 2018; M. P. Manohar and Sharma, 2018; Nandakumar and Nasim, 2018; Nandhini, Babu and Mohanraj, 2018; Ravinthar and Jayalakshmi, 2018; Seppan *et al.*, 2018; Teja, Ramesh and Priya, 2018; Duraisamy *et al.*, 2019; Gheena and Ezhilarasan, 2019; Hema Shree *et al.*, 2019; Rajakeerthi and Ms, 2019; Rajendran *et al.*, 2019a; Sekar *et al.*, 2019; Sharma *et al.*, 2019; Siddique *et al.*, 2019; Janani, Palanivelu and Sandhya, 2020a; Johnson *et al.*, 2020; Jose, Ajitha and Subbaiyan, 2020).

MATERIALS AND METHODS

All the articles relevant to the topic of the review i.e, pulp testing of teeth are collected from search engines such as PUBMED, Google scholar etc. All the articles collected had information about pulpal tissue, pulp sensitivity, pulp vitality, principle of newer pulpal testing devices, pulpal vasculature etc. All the articles which were irrelevant to the topic were excluded from the list.

RESULTS AND DISCUSSION

Dental Pulp

The dental pulp is the innermost part of the teeth. It is housed inside the hard chamber of the tooth which is composed of enamel and dentin. It is made of living connective tissues.The pulpal tissues is the neurovascular bundle central to each tooth that comprises pulp chamber, pulp horns and radicular canals due to deposition of dentine the pulp chamber becomes smaller with age (Anderson, Keith and Novak, 2002). Radicular pulp canals start to extend from the cervical region of the crown to the root apex of a tooth. The mean volume of a single adult human pulp is 0.2CC (Morse, 1991). They are 4 layers of pulp from innermost to outermost aspect as described by (Dhaduk, 2012) they are

1. Pulp core- present in center of pulp chamber with many cells and vascular supply
2. Cell rich zone- consists of fibroblasts and undifferentiated mesenchymal cells

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3. Cell free zone- it is also called zone of weil's which is rich in capillaries and nerve networks
4. Odontoblastic layer- contains odontoblasts and it lies between mature and pre-dentin (outermost layer)

Nerve plexus of raschkow is located central to the cell rich zone (Gronthos *et al.*, 2000).

Recent study states that during the use of EndoActivator, the tip frequently produces a cloud of debris that can be observed within a fluid-filled pulp chamber in primary and secondary teeth. The primary or basic function of the EndoActivator is to produce vigorous intracanal fluid agitation through acoustic streaming and cavitation (Ramamoorthi, Nivedhitha and Divyanand, 2015). Another useful technique that is Cone-beam Computed Tomography to take the endodontic radiography, Cone-beam computed tomography (CBCT) is a valuable tool for the diagnosis in endodontics. It has shown higher accuracy in detecting root perforations than digital periapical radiography. Periapical periodontitis can be detected by this (Ramanathan and Solete, 2015) . The increase in bacterial count leads to various lesions in the oral cavity. There are certain antibacterial agents used for infected pulp. These include chlorhexidine with sodium hypochlorite, neem, and tulsi. Alternative to these irrigants, 3% sodium hypochlorite is also being used (Siddique and Jayalakshmi, 2019) (Noor and Others, 2016) It has been proved that the Natural tooth remineralisation occurs simultaneously after any damage to the tooth surface. It occurs on a daily basis after attack by acids from food, through the presence of calcium, phosphate and fluoride found in saliva. Saliva also acts as a natural buffer which helps to neutralise acid, preventing demineralisation in the first place (Rajendran *et al.*, 2019b). Acid erosion also takes place at times. Acid erosion initially begins in the enamel, causing it to become thin, and can progress into dentin, giving the tooth a dull yellow appearance and leading to dentin hypersensitivity. Erosion is commonly caused by acidic foods and drinks. The herbal use of grape seed and cranberry extract may prevent corrosion (Nasim and Nandakumar, 2018); (M. Manohar and Sharma, 2018). GIC protects the pulp and prevents microleakage (Hussainy *et al.*, 2018)

The next drawback is the calcified tooth.Calcific deposits of the pulp chamber cause the darker hue, translucency is completely lost in this and the yellowish appearance of the tooth's crown is seen. Locating the canal and negotiating it to full working length may lead to iatrogenic errors most of the time even by skilled full dentists like that of fractured instruments and perforation (Kumar and S. Antony, 2018). Painful inflammation of pulp can cause a condition called pulpitis

Pulpitis is caused due to invasion of bacteria in tooth pulp that causes swelling and also it occurs in one or more teeth.(Teja, Ramesh and Priya, 2018). By the usage of laminates and veneers the chance of irreversible pulpitis is being enhanced (Ravinthar and Others, 2018). Pulp consists of blood supply and nerve supply to the tooth. . The most serious and compli- cated consequences of fracture to tooth is the injuries are pulp. This leads to pulp necrosis and infection of the root

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canal system, external inflammatory root resorption, external replacement root resorption, ankylosis, bone resorption, loss of attachment and gingival recession followed by subse- quent tooth loss (Jose and Subbaiyan, 2020) (Teja and Ramesh, 2019).

Pulp Nociception Mechanism

Brannstroms hydrodynamic theory (Brannstrom, 1986) proposed that pulp pain is a result of nociceptors activated by fluid movement with possible other irritants through the patent dentinal tubules (Pierce, 1998). The fast conducting myelinated A-delta fibres are known to be responsible for acute sharp shooting pain whereas the slower conduction unmyelinated C-fibres are attributed to burning pain with slower onset. An anecdotal observation, using pulpitis resulting from rapidly progressing caries as examples that there seems to be more likelihood of having pain because there is less time for dental pulp to react and protect itself by occluding dentinal tubules (Bjørndal and Mjör, 2001). This finding partly explains the pain associated with pulpitis that differ greatly in quality, severity, duration, onset and trigger and it also explains poor localization of it (Ngassapa, 1996). With progression of caries into dentine, the no. of dentinal tubules being permeable is a major determinant to degree of pain. The persistent pain undergoes physiological modulation along with up and down regulation by inflammatory mediators which are either endogenous or exogenous in origin. Changes in intrapulpal pressure affects sensory nerves with increase in pressure selectively blocking larger diameter A-delta fibres and activating smaller C-fibers. The lack of total response to a stimulus indicates pulp necrosis has advanced (Fuss *et al.*, 1986).

PULP VITALITY

The ideal pulp test should provide a simple, objective, standardized, reproducible, non-painful, non-injurious, accurate and inexpensive way of assessing the condition of pulp tissue. In endodontics, pulp testing strategies may involve sensitivity tests which assess response to stimulus. The other form of pulp testing is to evaluate the tooth's vascular supply by using laser doppler flowmetry or pulse oximetry. Pulp vitality testing is the assessment of pulp’s blood supply. Pulp tissue is not directly assessed and this is exemplified by clinical observations (Bhaskar and Rappaport, 1973) that traumatized teeth can have no response to a stimulus for a period of time following injury.

Laser Doppler Flowmetry (LDF)

Research into the application of LDF to traumatized teeth has been extensive (Mesaros and Trope, 1997). The aim of the technique is to objectively measure the true vitality of the pulp i.e, the pulp blood flow rather than its sensory function with invasive procedures (Kim and Dörscher-Kim, 1990) such as intra vital microscopy and gas desaturation. The LDF was first described in dental literature in 1986 by Gazelius (Gazelius *et al.*, 1993). It is an electro optical technique that uses laser source that aims at pulp and laser light travels to pulp using dentinal tubules as guides (Matthews and Vongsavan, 1993). The back scattered reflected light from

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circulating blood cells is doppler shifted and has a different frequency to static surrounding tissues. The total backscattered light is processed to produce an output signal (Ingolfsson *et al.*, 1993). The signal is commonly recorded as the concentration and velocity (flux) of cells using perfusion units where 2.5 volts of blood flow is equivalent to 250 PU (Vongsavan and Matthewst, 1996). A stabilisation splint made of polyvinyl siloxane or acrylic is usually used in order to record the doppler shift of blood cells.

Technical Considerations to be considered for LDF

Various studies have been performed to investigate the testing parameters for lasers. Doppler flowmetry. The laser beam that is produced in LDF is a low power beam ranging from 1-2 mW. Different wavelengths of lasers can be produced by different sources: 633nm through helium-neon lasers or 780 and 810nm by semiconductor diode laser (Kimura, Wilder-Smith and Matsumoto, 2000). In reference to (Odor, Pitt Ford and McDonald, 1996), found that the laser light sources with longer wavelengths have better sensitivity to moving red blood cells due to deeper penetrating into pulp vasculature. The later studies (Roebuck *et al.*, 2001) noted extensively scattered light with longer wavelength of lasers contributes to the problem of signal contamination. Different ranges of bandwidth are set to filter the reflected signal with a wider frequency being more sensitive to moving red blood cells with a wider range of velocity (Barnett, Dougherty and Pettinger, 1990).

Limitations of LDF

Contamination noise due to back scattered light from periodontal tissues (Akpinar *et al.*, 2004) is impossible to eliminate in LDF even if it's covered with PVS splint. It has been considered that the closer the probe is positioned to the gingival margin, the higher the signal output due to greater pulp tissue volume will be but the potential gingival contamination is also higher (Ramsay, Artun and Martinen, 1991). Studies have suggested that 2-3 mm from the gingival margin would be the ideal position for probe tip as it creates a balance between minimizing the noise and having a recognizable signal volume (Emshoff *et al.*, 2004). In reference to (Polat, Er and Polat, 2005) compared teeth that had pulpectomy with contralateral health. pulp as controls. It was found that approximately 70% of LDF readings from teeth with pulp removed are non-pulpal in origin. Heithersay (Marin, Bartold and Heithersay, 1997) reported a case where traumatized upper central incisor teeth had stained and subsequently returned to normal colour, it was noticed that LDF readings were zero while the tooth was discoloured by blood products.

Accuracy of LDF to be used as a Pulp Test

There are differing views with regards to accuracy of pulp testing using LDF given that false results suggesting no blood flow are possible when the laser pathway is interfered or obstructed. The amount of signal contamination from non-pulp sources (Soo-ampon *et al.*, 2003) (Teja, Ramesh and Priya, 2018) primarily the periodontium can lead to false readings showing the presence of pulp blood flow.

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Pulse Oximetry

It is considered to be a non-invasive oxygen saturation monitoring device widely used to record blood oxygen saturations level (Munshi, Hegde and Radhakrishnan, 2003).Pulse oximeter is a standard equipment in operating rooms, including intensive care units, emergency rooms etc. where sedation & analgesia are provided (Kahan *et al.*, 1996). This device is currently under investigation in case of dental practice to detect pulpal blood circulation by virtue of its non-invasive design.

Principle: The principle of this is based on Beer's law which relates the absorption of light; by a solute to its concentration and optical properties at a given wavelength. In the red region, oxyhaemoglobin absorbs less light than deoxyhemoglobin and vice versa incase of infra-red region (13). The system has a probe which contains a diode that limits light in two different wavelengths.

1. Red Lights (660mm)
2. Infra-red light (850mm)

There is a silicon photodetector diode which is placed on the opposing surfaces of the tooth. This is connected to a microprocessor. Ideal placement of the probe is in the middle third of the crown (Janani, Palanivelu and Sandhya, 2020b). Many dentists approve pulse oximetry to be an effective manner of pulp testing. It is also very evident in the time of "impact injury" where the blood supply remains intact but the nerve supply is being damaged. Gingival circulations can also be used to detect the pulse based on this device (Pozzobon *et al.*, 2011).

Limitations- include the background absorption associated with venous blood and tissue constituents. Addition to this there are chances for refraction and reflection of light that may add on to its disadvantage.

Dual Wavelength Spectrophotometry

DWLS is a method which is independent of a pulsatile circulation. This method completely ensures the measure of oxygenation changes in cases of the capillary bed rather than in the supply vessels and hence does not depend on the pulsatile blood flow (R, Rajakeerthi and Ms, 2019) . DWLS basically depends on the presence or absence of oxygenated blood at 760mm and 850mm. DWLS helps to differentiate reproductive readings between a pulp chamber of a vital and non-vital tooth. In young children, where there are avulsed and replanted teeth with open apices, the blood supply is regained within the first 20 days after replantation but nerve supply lags behind. Repeated readings are taken in such cases upto 40 days to ensure an increase in blood oxygenated level that means the healing process has occurred ; the pulp of such teeth has also started to recover (Kayalvizhi and Subramaniyan, 2011) (R. Rajakeerthi and Ms, 2019). The instrument is comparatively small, portable, relatively inexpensive and suitable for usage in clinical practice.

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Thermography/Crown Surface Temperature

Thermography is a test that uses an infrared camera to detect blood flow in the pulpal body tissue. It is effective in recording heat patterns as wheels. It has become an important diagnostic tool because of accurate measurement of regional temperature and differentiation of temperatures while doing dental procedure. (Fanibunda, 1986). It is a non-invasive, and highly accurate method of measuring body's temperature. The teeth that need to be assessed must be isolated using rubber dams. The technique is complex and requires the subjects to be at rest for 1 hour period to test (Pogrel, Yen and Taylor, 1989).

Transmitted Light Photo Thermography (TLP)

It is a non-invasive technique used to monitor pulpal blood flow, and has been successfully applied in human studies. It has been suggested that TLP incurs less signal contamination from the periodontal blood flow than the other devices (Sarkela *et al.*, 1995)

Spectrophotometry

It uses dual wavelength lights in an effort to ascertain the contents of enclosed spaces such as pulp chamber has been tested with optimistic but only initial experimental results (Nissan *et al.*, 1992) .

Transmitted Laser Light

It is an experimental variation to LDF, aimed at eliminating the non-pulpal signals as it uses similar sending-receiving probes as conventional LDF but the probes are separate. The laser beam is passed through the labial or buccal side of the tooth of the receiver probe which is situated on the palatal or lingual side of the tooth (Sasano *et al.*, 1997).

Photoplethysmography

It is an analysis of optical properties of a selected tissue and was developed for pulp testing in an attempt to improve pulse oximetry by adding a light with a shorter wavelength (Schmitt, Webber and Walker, 1991).

PULP SENSIBILITY

Pulp sensibility testing is assessing the pulps sensory responses

Thermal Tests

The commonly used modality for testing of pulp is through thermal conduction which would stimulate sensory pulpal responses with the application of agents that would increase or decrease these responses (Mumford, 1967).

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Cold Tests

Ethyl chloride and ice have been popular in the past (Davies and Rawlinson, 1988) but Co2 snow and refrigerants such as dichlorodifluoromethane (DDM) have been shown to be effective and superior to ice and ethyl chloride (Dachi, Haley and Sanders, 1967).

1. **Ice-** simplest cold testing agent requiring practically zero cost to prepare and it can be made in a standard household freezer. The most common way to make ice depending upon the sizes and dimensions involves freezing water in empty local anesthetics cartridges. Clinical handlings of infection, controlling of infection and direct application of ice can be difficult.
2. **Refrigerant Spray-** they are widely used in clinical settings due to ease of storage, cheap cost and simple application technique. Most effective agents like DDM have superseded traditional refrigerants that contain ethyl chloride. DDM being a chlorofluorocarbon has decreased in popularity and availability due to atmospheric ozone layer depletion (Miller *et al.*, 2004).
3. **Carbon Dioxide Snow (co2)/ Dry Ice-** it is prepared from a pressurized liquid. CO2 cylinder using a commercially available apparatus known as odontoblast. It involves liquid co2 being forced through a small orifice such that when it comes under atmospheric pressure most of the liquid is converted to dry ice. The co2 gets collected in a hollow removable carrier, encased in a thin plexiglass tube. The dry ice gets collected in a pencil stick that is applied to one tooth at a time with aid of a supplied plunger.

Heat Tests

Typical methods used include gutta percha or compound material heated to melting temperature and directly applied to teeth being tested with lubricant in order to facilitate removal of material. Heated balls ended metallic instruments placed near the tooth, battery powered controlled heating instruments such as touch and heat and hot water bathing with teeth isolated by rubber dam (Rickoff *et al.*, 1988). The temperature of the melting GP used in pulp testing is approximately 78 degree Celcius but it has been reported upto 150 degree Celsius.

Electric Pulp Testing

It works on promise that electrical stimuli cause an ionic change across the neutral membrane thereby inducing an action potential with a rapid happening action at nodes of ranvier in myelinated nerves (Kleier, Sexton and Averbach, 1982).

Test Cavity Preparation

This test may be served as a last resort in testing for pulp vitality. It is only considered to be used when the results of all other tests have proved inconclusive (Ziskin and Wald, 1938).Its value in dental clinical practice has been largely anecdotal as there is no evidence base to support its effectiveness. The test cavity is made by drilling through the enamel–dentine junction of an unanesthetized tooth with good isolation. This may be achieved under a rubber dam with a small round diamond bur in a high-speed handpiece with adequate coolant. The patient is asked to

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respond if any painful sensation is felt during the drilling procedure. If the patient feels pain once the bur contacts the sound dentin, the procedure is terminated and cavity is restored

Local Anaesthetic Test

When dental symptoms are poorly localized or referred, an accurate diagnosis is extremely difficult. Sometimes, patients may not even be able to specify whether the symptoms are from the maxillary or mandibular arch. In such cases, and where pulp testing has proved inconclusive, an anaesthetic test may be helpful. The technique is as follows: using either infiltration or an intraligamentary injection, the most posterior tooth in the area suspected of causing the pain is anaesthetized. If pain persists once the tooth has been fully anaesthetized, the tooth immediately mesial to it is then anaesthetized, and so on, until the pain disappears. If the source of the pain cannot be even localized to the upper or lower jaw, an inferior alveolar nerve block injection is given; cessation of pain indicates involvement of a mandibular tooth. This approach has an advantage over a test cavity, which may incur iatrogenic damage (Certosimo and Archer, 1996).Our institution is passionate about high quality evidence based research and has excelled in various fields ((Pc, Marimuthu and Devadoss, 2018; Ramesh *et al.*, 2018; Vijayashree Priyadharsini, Smiline Girija and Paramasivam, 2018; Ezhilarasan, Apoorva and Ashok Vardhan, 2019; Ramadurai *et al.*, 2019; Sridharan *et al.*, 2019; Vijayashree Priyadharsini, 2019; Chandrasekar *et al.*, 2020; Mathew *et al.*, 2020; R *et al.*, 2020; Samuel, 2021)

Comparative studies of Pulp Testing

TESTS	**Sensitivity**	**Specificity**
CPT (cold pulp test) (Kim et al., 2015**)**	**0.86**	**0.84**
HPT (heat pulp test) (Kim et al., 2015**)**	**0.77**	**0.66**
EPT (electric pulp test) (Evans et al., 1999**)**	**0.72**	**0.92**
LDF (Laser Doppler flowmetry) (Kim et al., 2015**)**	**0.92**	**0.95**
Heated GP (Evans et al., 1999**)**	**0.86**	**0.41**
Ethyl Chloride (Evans et al., 1999**)**	**0.83**	**0.93**

Table 1- Comparison between Pulp Vitality tests and Pulp Sensibility tests in references to the studies.

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1) Comparison of LDF, ethyl chloride and EPT- In reference to (Evans *et al.*, 1999) , it was examined that 67 injured anterior teeth that had necrotic pulps or pulpless and infected canal systems in 55 patients whose age ranged from 8 - 34 years and 84 teeth with healthy pulps in 84 patients. The study indicates that the LDF test was technique sensitive and time consuming. Validity of cross sectional studies on comparisons between the performance of pulp tests is essential and to be dealt with caution.

2) Comparison of heated GP, ethyl chloride and EPT- In reference to (Peterson *et al.*, 1999) estimated cold and heat tests along with EPT by calculating the relevant sensitivity, specificity, positive predictive value, negative predictive value and accuracy for each test was disease pervasive (Kim *et al.*, 2015).

CONCLUSION

Pulp sensibility test despite its limitations, has been helpful aid in endodontic diagnosis. As of now, there have been no vitality tests that have been demonstrated to be superior in all aspects compared to pulp sensibility tests. Further research is required to improve the reliability and accuracy of diagnostic dental pulp tests.

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