Making sense of sensibility: part 2

Kasim Butt*[1] and Ian Harris[2]

Key points

- Enables a clinician to understand the mechanism of action of cold, electric and heat pulp testing.
- Provides a summary of the correct clinical technique for undertaking cold, electric and heat pulp testing.
- Provides the clinician with an understanding of scenarios which may give rise to false pulp testing results and an explanation of why these may occur.

Abstract

To reach an accurate endodontic diagnosis, it is important for clinicians to understand how to undertake pulpal sensibility tests correctly, how to interpret their results and how to understand their limitations. Part one of this series defined different terms relevant to pulp testing and detailed the diagnostic uses and diagnostic accuracy of pulp testing methods. This section describes clinical techniques for commonly used pulp tests and highlights their limitations and correct interpretation of their results. Applying these principles and techniques will enable accurate endodontic diagnosis in different clinical scenarios.

Introduction

Thermal and electric pulp sensibility tests are the most commonly used pulp testing methods when diagnosing endodontic disease.[1] These tests have inherent limitations, including a reliance on a patient's subjective response to the test and the dentist's interpretation of the patient's response.[2] Part one of this series defined different terms relevant to pulp testing and detailed the diagnostic uses and diagnostic accuracy of pulp testing methods. This paper describes clinical techniques for commonly used pulp tests and highlights their limitations and the correct interpretation of their results. Applying these principles and techniques will enable accurate endodontic diagnosis in different clinical scenarios.

[1]Specialty Registrar in Restorative Dentistry, Charles Clifford Dental Hospital, Sheffield, UK; [2]Specialist in Restorative Dentistry, Endodontics and Prosthodontics, Consultant in Restorative Dentistry, Charles Clifford Dental Hospital, Sheffield, UK.
*Correspondence to: Kasim Butt
Email address: kasim.butt1@nhs.net

Refereed Paper.
Accepted 20 September 2021
https://doi.org/10.1038/s41415-022-039-7

Cold thermal testing

Cold thermal testing is probably the most common pulp testing method used by practitioners to assess pulpal health.[3] It can be utilised as both a sensibility test, assessing the pulp's sensory response as a surrogate for pulpal vitality and as a sensitivity test when diagnosing pulpitis.[4] In cases where a clinician is seeking to differentiate between a diagnosis of reversible and irreversible pulpitis, cold stimuli can be used to assess whether there is a prolonged, lingering or painful response: in such cases, a diagnosis of irreversible pulpitis is likely. In cases where the pulpitic response subsides immediately upon removal of the stimulus from the tooth, a diagnosis of reversible pulpitis is more likely.

Mechanism of action

Cold testing involves the application of a cold stimulus to a tooth to assess the integrity of Aδ nerve fibres in the pulp-dentine complex. Upon activation, Aδ nerve fibres elicit an acute, sharp sensation.[5] When a cold stimulus is applied to a tooth there is contraction of fluid within the dentinal tubules and this results in a rapid outward flow of fluid within the patent tubules.[6] This hydrodynamic pressure change activates the Aδ mechanoreceptor nerve fibres, leading to a sharp sensation.[7]

Clinical technique

There are a variety of ways a clinician can carry out cold thermal testing. The most commonly used products include refrigerant sprays, frozen water as an ice stick, ice-cold water and carbon dioxide sticks (CO_2 snow). The main difference between these is the intensity of cold that is applied to the tooth. There is a consensus that the colder the stimulus, the more effective the investigation will be in assessing the status of the tooth's nerve supply.[8,9,10] Therefore, tests involving the use of ice sticks or ice-cold water may not be as effective or reliable as CO_2 snow or refrigerant sprays, due to not being sufficiently cold to elicit a nerve fibre response. Cold tests should be applied to the test tooth and control teeth until the patient responds to the stimulus or for a maximum of 15 seconds, whichever is shorter.[10]

Refrigerant sprays

These products are popular as they are relatively economical, easily stored and have a simple application technique. Products such as Endo-Frost (Roeko, Langenau, Germany) which is a propane/butane/

isobutane gas mixture[4] and Endo-Ice (Coltene Whaledent, Cuyahoga Falls, Ohio) which is a tetrafluoroethane gas[11] have largely superseded traditional refrigerant sprays such as ethyl chloride due to their capability to produce lower temperatures.

The application of the refrigerant spray involves a carrier, such as a cotton wool pellet, which is saturated with the substance to form ice crystals before direct contact with the tooth which is to be tested (Fig. 1).[12] Larger pellets have larger surface areas, thus allowing better thermal conduction to occur between the carrier and the tooth being tested.[4] Cotton buds with wooden handles and small cotton pellets have smaller surface areas available for contact and are, therefore, less efficacious in thermal conduction.[4] Cotton wool rolls are generally not recommended as the portion with the dry fibres serves as a wick, drawing refrigerant away from the tooth structure.[4]

A summary of commonly used refrigerant sprays and their boiling points is displayed in Table 1.[11]

Carbon dioxide snow

In this test, a stick of solidified carbon dioxide is prepared from a pressurised carbon dioxide cylinder using commercially available apparatus known as the Odontotest (Fricar A.G., Zurich, Switzerland).[4] The liquid CO_2 is forced through a small orifice so that when it comes under atmospheric pressure, most of the liquid is converted into dry ice. The dry ice is collected in a pencil stick form that can be applied to the buccal surface of the tooth to be tested. Due to the low boiling point of the CO_2, it can be particularly effective when attempting to assess the pulpal sensory response of teeth restored with full coverage metal restorations.[9] Concerns regarding possible damage to enamel and healthy pulps from this test appear to be unfounded.[13]

Ice sticks

'Pencils' of ice can be easily and inexpensively made in the dental surgery by a variety of methods, such as freezing a plastic straw filled with water in an upright position, or freezing water in local anaesthetic needle sheaths which have not been contaminated. When the ice stick is required for use, one half should be wrapped in gauze to act as a handle and then the other end may be applied to the tooth under investigation. When utilising ice sticks, it may be prudent to isolate each tooth individually with rubber dam to avoid thermal stimulation of adjacent teeth.

Fig. 1 Cotton wool pellet saturated with refrigerant spray applied to the mid-labial surface of 11 with tweezers

Table 1 Commonly used refrigerant sprays and their boiling point

Cold testing product	Boiling point temperature
Ethyl chloride	-4 degrees Celsius
Propane/butane/isobutane gas mixture (Endo-Frost, Roeko, Langenau, Germany)	-50 degrees Celsius
Tetrafluoroethane (Endo-Ice, Coltene Whaledent, Cuyahoga Falls, Ohio)	-26 degrees Celsius
Carbon dioxide snow (CO_2 snow/dry ice)	-72 degrees Celsius

Ice-cold water

This is another low-cost test which is especially useful when assessing teeth restored with full-coverage crown restorations. The tooth under investigation is isolated with rubber dam and then the whole tooth is bathed with ice-cold water from a syringe.

Electrical pulp testing

An electrical pulp tester consists of a battery-operated unit which is connected to a probe that is applied to the tooth under investigation (Figures 2 and 3). The electrical circuit is completed by the patient holding the rear end of the handle of the probe, or by placing a hook over the patient's lip.

Mechanism of action

Electric pulp testers produce a pulsating electrical stimulus. The intensity of the stimulus automatically begins at a very low level to avoid excessive stimulation and discomfort for the patient and increases steadily at a pre-determined rate. The objective of an electric pulp test is to stimulate intact Aδ nerves in the pulp-dentine complex by applying an electric current to the tooth surface.[14] A positive result from electric pulp testing is a result of an ionic shift in the dentinal fluid within the tubules, causing local depolarisation and subsequent generation of an action potential from the intact nerve fibres.[14] When the patient acknowledges a warm or tingling sensation, a positive response is recorded.

Clinical technique

Correct technique when using an electric pulp tester is very important for accuracy as the process can be technique sensitive.[15,16] The tooth to be assessed should be sufficiently dry to prevent electrical conduction to adjacent teeth, or to the periodontium.[17] A conducting medium should be applied to the electrode to ensure maximum current passes from the electrode to the tooth surface.[16] It is important to ensure that the electrode lies flat against

Fig. 2 Electric pulp tester – Pulppen DP2000 Digital Pulp Tester

Fig. 3 Electric pulp tester electrode tip applied to the mid-labial surface of 11. Note the use of toothpaste as a conducting medium and PTFE tape applied interproximally to avoid electrical conduction to adjacent teeth

the surface of the tooth (therefore maximising electrode contact area) as this also reduces the response threshold value.[16] An *in vitro* experiment using incisors and premolars found that placing the probe tip labially, within the incisal or occlusal two-thirds of the crown, gave more consistent results.[18] Direct contact with tooth tissue is required when using an electric pulp tester and this may be a problem with heavily restored or crowned teeth.[9] When there has been recession around a crowned tooth a small tip is available that may be used instead of the standard electrode tip. This allows probe-to-tooth contact below a crown margin or to a small area of tooth adjacent to an extensive restoration. It can be helpful to use cellulose strips, polytetrafluoroethylene (PTFE) tape, or rubber dam strips interproximally between adjacent teeth to prevent electrical conduction. This is especially important in teeth which have adjacent restorations in contact.

The numerical reading displayed on the electrical pulp tester is not a quantitative measurement of the health of the pulp and therefore does not indicate to what extent the pulp is healthy/unhealthy.[11] A response only implies that the Aδ fibres are sufficiently healthy to function. The threshold for response may be influenced by the thickness of the enamel and dentine overlying the pulp;[19,20] therefore, it has been suggested that the response threshold in healthy teeth may be lowest in incisors, slightly greater in premolars and greatest in molar teeth. Tooth surface loss may lower the response threshold due to increased exposure of dentine but, conversely, if tertiary dentine has been laid down within the pulp chamber or if there has been pulp space obliteration following trauma, the threshold for response may be increased.

Heat thermal testing

Heat thermal testing is most useful when a patient's chief complaint is intense sensitivity or dental pain on contact with hot liquids or foods. When a patient is unable to identify which tooth is sensitive, a heat test can be helpful.[8] Sequentially isolating teeth before thermal testing with heat has the potential to reproduce the patient's symptoms and therefore helps to identify the causative tooth, allowing further investigation or treatment.[1]

Mechanism of action

Thermal application of heat to a tooth stimulates intact Aδ nerves in the pulp-dentine complex. A response of short duration which is consistent in nature with control teeth implies that the Aδ fibres are functioning normally. Prolonged heat application will result in biphasic stimulation of initially Aδ fibres and then C fibres within the pulp, resulting in a lingering pain.[21] Heat tests should therefore be applied for no more than five seconds.[11] If the patient reports that the heat application to a specific tooth elicits the same intense pain as their reported symptoms then further investigation of the tooth in question can be undertaken.[1]

Clinical technique

A commonly reported method for heat thermal testing is to use a gutta-percha or impression compound stick, heated to melting temperature and applied directly to a tooth surface coated in Vaseline.[22] The Vaseline acts as a lubricant, facilitating removal of the hot gutta-percha or compound. It has been reported that a tooth surface temperature as high as 150 °C can be achieved with this technique;[23] gutta-percha softens at 65 °C and may be heated in delivery devices up to 200 °C.[11] The challenge with heat thermal testing is that it can be difficult to adequately control and maintain the temperature of the heated gutta-percha or impression compound. Inadequate heating will result in the stimulus

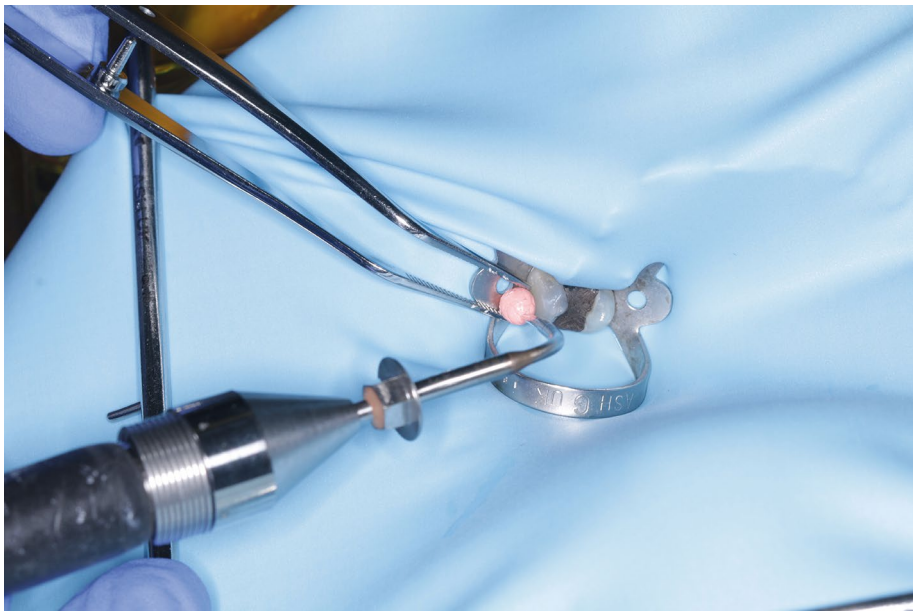

Fig. 4 System B plugger (SybronEndo, USA) used to heat gutta-percha ball applied to the buccal surface of 15 following rubber dam isolation

not being hot enough to elicit a response from the pulp or not being hot enough to mimic the temperature required to initiate the patient's painful symptoms.[24] Equally important to consider is that prolonged heat application can cause damage to the pulp.[25] It has been shown that an increase of 11 °C during restorative procedures without adequate cooling can harm the pulp.[26] In an *in vitro* study, it was found that heat testing using gutta-percha increased the pulp temperature by less than 2 °C, when applied for less than five seconds.[27] This temperature change is unlikely to cause pulp damage.

Other techniques described in the literature include generating heat by friction, using a dry rubber polishing wheel run at a high speed against the dry surface of a tooth,[28] or isolating suspected teeth sequentially with rubber dam and expressing hot water from a syringe of a similar temperature to that which would cause the patient's reported painful sensation.[11]

Another technique that can be used to localise a thermally-sensitive tooth involves the use of a heat-controlled plugger instrument such as a System B plugger (SybronEndo, Orange, USA) and a thermoplasticised gutta-percha delivery device such as Obtura (SybronEndo, Orange, USA), when available. In this technique, a 5 mm diameter ball is expressed from the thermoplasticised gutta-percha delivery device. Following sequential isolation with dental dam, starting with the most posterior tooth, the gutta-percha ball is then applied to the test teeth, sequentially and heated for no more than five seconds with a heat-controlled plugger instrument. The authors have found that this technique works well if a clinician has the necessary specialised equipment available. The System B (SybronEndo, Orange, USA) heat-controlled plugger is best used at a temperature of 200 °C and a power setting of 10, with application for no more than five seconds. The touch mode is considered the easiest setting to use[29] (Fig. 4).

Selective local anaesthesia test

When symptoms are poorly localised or when pain is referred, the diagnosis may be challenging. Sometimes the patient may not be able to specify whether the symptoms are from the maxillary or mandibular teeth. In these instances, when other pulp testing methods, radiographs, and clinical tests are inconclusive, selective anaesthesia may be helpful in assembling the diagnostic picture.

If a patient cannot determine which arch their pain is coming from, the clinician should first selectively anaesthetise the teeth in the maxilla on the relevant side.[8] This is best accomplished by delivering an intraligamentary injection to the most posterior tooth in the suspected sextant; the patient is then asked if the pain has been eliminated. If it has not, the next tooth in the sextant is anaesthetised with an intraligamentary injection and so on. Before subsequent intraligamentary injections, an assessment should be made of whether the patient's pain has been eliminated. If the pain has not been eliminated, once all the maxillary teeth in the suspected quadrant have been anaesthetised, then the clinician should repeat the same technique on the mandibular teeth. It should be noted that intraligamentary injections may anaesthetise an adjacent tooth[30] and thus this technique is more useful for identifying an arch or suspect teeth for further investigation, rather than confirming a specific tooth as the source of the pain.

Test cavity

The test cavity method for assessing pulpal response is not routinely used since it is an invasive and irreversible pulp test.[4] This method is used only as a last resort when all other test results have proved inconclusive or are not possible to undertake.[3] An example of a situation in which this method may be selected is where a tooth restored with a full-coverage crown is suspected to be the source of endodontic pain. If there is no exposed supragingival tooth structure available to use a small probe or bridging medium with the electric pulp tester on and the cold test results along with the clinical and radiographic findings are inconclusive, a small Class I cavity preparation can be made through the occlusal surface of the crown, following rubber dam isolation. The patient is not anaesthetised while this procedure is performed and is asked to report if any painful sensation is felt during the procedure. If the patient feels pain once the bur contacts sound dentine, the procedure is terminated and the Class I cavity preparation is restored. It is unlikely that this test will provide any more information than thermal or electric pulp sensibility tests[4] as the sensation signifies only that there is some viable nerve tissue remaining in the pulp, not that the pulp tissue is totally healthy. The limitation of this technique is that a positive response indicating vitality may be falsely obtained due to the vibration of the handpiece drill[30] or from a dentally anxious patient reacting to the procedure.[4] In scenarios where the test cavity method is employed to diagnose pulpal necrosis, the patient should be given a full explanation of the procedure before the test cavity is drilled and the reasons why it is being undertaken in order to obtain valid consent.

Factors to consider when interpreting pulp sensibility test results

Pulp sensibility tests are reliant on a patient's response and as previously stated, can produce false results. These can occur when a patient with a non-vital tooth reports a positive result or a patient with a vital tooth does not respond, suggesting a negative result. Therefore, it is recommended that teeth suspected of pulpal disease are tested using a combination of sensibility testing methods (for example, cold tests and electrical pulp tests), that tests are repeated on more than on occasion and responses are compared to control teeth. When making a pulpal diagnosis, the clinician should be aware that several scenarios can increase the likelihood of false pulp testing results (Table 2). This further highlights the need to consider the results of pulp testing alongside the other 'jigsaw pieces' of patient history and other important clinical and radiological information, as discussed in the first part of this series.

Conclusion

Accurately assessing pulpal health is of great importance in clinical dental practice. The consequences of an inaccurate diagnosis include ongoing pain and infection for the patient or a biologically unnecessary and financially costly root canal treatment. Even with its acknowledged limitations, pulp sensibility testing remains a beneficial aid in endodontic diagnosis. Clinicians must correctly undertake pulp sensibility tests and accurately interpret their results to aid in diagnosis and treatment planning.

Ethics declaration

The authors declare no conflicts of interest.

Author contributions

The original concept for the paper was devised by Kasim Butt and developed, jointly, in discussion between the two authors. Both authors wrote substantial parts of the paper, with Ian Harris revising successive drafts. Both authors contributed equally to the final approval of the version to be published.

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Table 2 Scenarios which can give rise to false pulp testing results

Scenario	Reason why a false result may be obtained
Multi-rooted teeth	Pulps in multi-rooted teeth may be partially necrotic and therefore part of the root canal system may still possess viable pulp tissue and functioning Aδ nerve fibres. A prospective study reported three previously root-treated maxillary molars responding positively to cold pulp sensibility testing and on root canal retreatment, uninstrumented second mesiobuccal canals were identified.[31] The authors concluded that viable tissue in the second mesiobuccal canal resulted in the positive response.[31]
Vital tissue still present in a partially necrotic root canal system	Localised breakdown products in one part of the root canal system may be able to conduct the electric current from an electric pulp tester to viable nerve tissue in adjacent areas, thereby resulting in a misleading result.[32]
Unpleasant sensation	A false-positive response may occur in anxious or young patients who are expecting to feel an unpleasant sensation.[16,33] For this reason, it is important to begin pulp sensibility testing on a control tooth which is thought to have a healthy pulp.
Sclerosed canals	Obliteration of the coronal pulp by dentine may act as a thermal insulator to cold tests, thereby leading to a false-negative result.[11]
Incomplete root development	In young patients, teeth erupt and become functional before completion of neural and root development.[34,35] These teeth have a higher response threshold to pulp testing compared to teeth with complete root development.[36] In these situations, cold testing with Endo-Frost (Roeko, Langenau, Germany) or CO_2 snow can be more reliable than electric pulp testing.[10,36] Sensibility testing of immature permanent incisors following trauma is recommended as it provides a baseline for comparison at later follow-up examinations.
Recently traumatised teeth	Following injury, traumatised teeth may have a temporarily reduced or negative response to thermal and/or electric pulp testing in comparison to control teeth.[33] This is thought to be due to injury, inflammation, pressure or tension to apical nerve fibres.[37] The pulpal blood supply of these teeth may remain intact, or revascularisation may take place. It may take eight weeks or longer before a normal pulp response can be elicited[37,38] and therefore, these teeth should be monitored clinically and radiographically at periodic intervals in accordance with International Association of Dental Traumatology guidelines.[39] The need for endodontic treatment should be considered if there are two or more signs of pulpal necrosis.[37]
Contact with metal restorations	During electric pulp testing, contact with metal restorations may result in conduction of the current to the periodontium, giving a false-positive result.[40]
Inadequate isolation from adjacent teeth and periodontium	During electric pulp testing, inadequate isolation or failure to adequately dry teeth may result in electrical conduction to the periodontium or to adjacent teeth, giving a false-positive result.[30,40] Drying and isolation with cellulose strips, rubber dam, or PTFE tape before electric pulp testing is recommended. Teeth which are part of a bridge prosthesis with more than one abutment tooth should not be tested with electric pulp testing as adjacent teeth cannot be adequately isolated. Instead, cold thermal testing should be used.
Recent orthodontic appliance activation	Teeth which have undergone recent orthodontic appliance activation have been found to have an increased response threshold to electric pulp testing.[41] This may be due to reduced blood flow and possible anoxia of Aδ nerve fibres associated with orthodontic tooth movement.[42] A lack of response to electric pulp testing has been observed for up to nine months following orthodontic movement; however, thermal testing appears to be more reliable.[34]
Patients with psychotic conditions and/or under the influence of sedative drugs/alcohol	Patients with psychotic conditions may not give reliable responses to pulp testing due to impaired mental capacity.[41] Individuals who are under the influence of sedative drugs or alcohol may either not respond or respond to stronger stimulation due to their increased threshold to nerve excitation.[43]

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