The use of dental pulp tests in children with dental trauma: a national survey of the British Society of Paediatric Dentistry's members

N. Ghouth,*[1,4] M. S. Duggal[2] and H. Nazzal[3]

Key points

- Provides insight into the use of dental pulp tests.
- Suggests there is a need to encourage vitality testing, including possibly the use of LDF in clinical practice for a better evaluation of the dental pulp.
- Shows that the use of pulp sensibility tests for the assessment of traumatised teeth was relatively high within the cohort selected for this study.

Background Careful long-term monitoring of pulp vitality has been recommended by all dental trauma guidelines. It is essential to explore the methods and techniques used by UK dental practitioners in assessing pulp sensibility and vitality. **Aim** To study the use of dental pulp tests by paediatric dentists and general dental practitioners in children with dental trauma to permanent teeth. **Design** A cross-sectional study utilising an 18 item questionnaire that was developed using the Bristol Online Survey (BOS) tool and circulated electronically to the members of the British Society of Paediatric Dentistry between June and August 2017. **Results** One hundred and forty-one respondents were included in the analysis, paediatric dental specialists (56%) and GDPs (44%). Almost all specialists (93.7%) reported using sensibility tests routinely in comparison to 80.6% of GDPs. Child perception and cooperation were the most commonly reported barriers. GDPs mainly used cold testing, while specialists used cold and electric pulp tests equally. Due to inconsistencies in recording, as well as documentation, the results varied among respondents. Only a few specialists reported having some experience in using laser doppler flowmetry. **Conclusions** The use of pulp sensibility tests was relatively high among respondents while those of vitality tests were very low. Barriers and inconsistencies in the technique and recording of the results of sensibility tests were evident. The frequency and timing of using sensibility tests in line with international guidelines were stressed. The use of standardised techniques involving methods considered to improve reliability was highlighted.

Introduction

Dental trauma affecting incisors has been shown to affect 12% and 10% of the UK's 12 and 15-year-old children, respectively.[1] Complications such as loss of pulp vitality and root resorption could develop as a consequence of such injuries leading to long-term irreversible damage or even tooth loss.[2] The risk of pulp necrosis after crown fractures ranges between 0.2% and 6%, increasing with concomitant luxation injuries.[3,4] Pulp necrosis after luxation injuries ranges between 15% and 59% with the highest frequency associated with intrusive luxation. The least occurrence of pulpal necrosis, on the other hand, is following concussion and subluxation injuries.[5,6] Consequently, accurate diagnosis and monitoring of the pulp status and periodontal tissues of traumatised teeth are essential.

The use of dental pulp sensibility/vitality tests is an integral part of the pulp assessment process following dental trauma.[7] An ideal pulp test should provide a 'simple, objective, standardised, reproducible, non-painful, non-injurious, accurate and inexpensive' way of assessing the condition of the pulp tissue.[8] Several diverse sensibility and vitality pulp diagnostic tests are available.

Sensibility tests offer an assessment of pulp health through the stimulation of pulp nerve fibres. Vitality testing, on the other hand, involves assessing the tooth's blood supply; offering an objective approach to assessing pulp vitality that is not reliant on patients' understanding and response to stimuli. Among vitality tests, laser doppler flowmetry (LDF) has been developed for the assessment of pulp blood flow. Studies suggest that LDF is able to determine pulp vitality (blood supply), offering a better pulp evaluation of traumatised teeth in comparison to other dental pulp tests.[9]

Thermal and electric pulp testing (EPT) are the most commonly used pulp sensibility tests. The use of these conventional pulp tests in assessing pulp sensibility of children's teeth is subjective and relies on patients' understanding and cooperation which can be challenging, especially in the child population. Thus, false positive/negative results are often associated with the use of sensibility tests which can sometimes be misleading in clinical situations.[10]

[1]School of Dentistry, University of Leeds, Leeds, UK; [2]Discipline of Orthodontics and Paediatric Dentistry, National University Health System, Singapore; [3]Hamad Medical Corporation, Doha, Qatar; [4]College of Dentistry, Taibah University, Al-Madinah Al-Munawarah, Saudi Arabia
*Correspondence to: Nahar Ghouth
Email: Ghouth_nn@hotmail.com

Refereed Paper.
Accepted 24 August 2018
Published online February 1 2019
DOI: 10.1038/sj.bdj.2019.99

Fig. 1 Bar chart showing the number of children with traumatised permanent teeth per group of respondents seen in a month

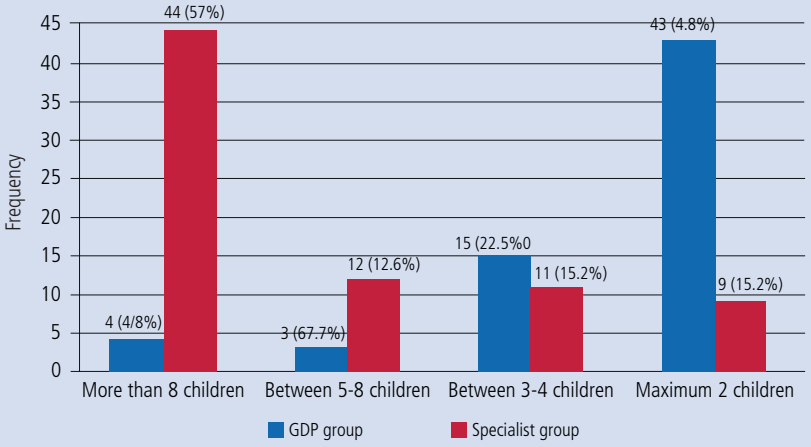


Table 1 General use of dental pulp tests

The overall frequency of using dental pulp tests		Frequency	Percentage %
Yes, routinely	GDPs	50/62	80.6
	Specialists	74/79	93.7
Sometimes	GDPs	12/62	19.4
	Specialists	5/79	6.3
No	GDPs	0	0
	Specialists	0	0
The timing of using dental pulp tests following traumatic dental injuries			
On initial presentation and at specific intervals	GDPs	52/62	83.9
	Specialists	78/79	98.7
At review appointments	GDPs	5/62	8.1
	Specialists	0	0
Only initially at the time of trauma	GDPs	3/62	4.8
	Specialists	0	0
Only when new symptoms arise	GDPs	2/62	3.2
	Specialists	1/79	1.3

There are recommendations and techniques to overcome some of the limitations of sensibility tests.[10,11] Therefore, it was considered important to explore the methods and techniques used by UK general dental practitioners (GDPs) and paediatric dental specialists in assessing pulp sensibility and vitality, especially in the child population following dental trauma. This would also help understand compliance, limitations and barriers to the use of the tests in complying with current guidelines. This survey aimed to investigate paediatric dentists' and GDPs' use of sensibility/vitality tests and the barriers to routinely using such tests in assessing dental trauma to permanent teeth in children.

Methods

This was a cross-sectional study utilising an 18 item questionnaire aiming to investigate the use of sensibility and vitality tests in the management of dental trauma in children among UK paediatric dentists and GDPs. Institutional ethical approval was obtained from the University of Leeds Research Ethics Committee before the commencement of the study (300,317/NG/226). The questionnaire was developed using the Bristol Online Survey (BOS) tool, now known as online surveys, and piloted on a small group of ten dentists (specialist paediatric dentists, specialist registrars in paediatric dentistry and GDPs) for ease of understanding and reduction of the ambiguity of questions before administration. An invitation email explaining the aims of the survey questionnaire was circulated to the members of the British Society of Paediatric Dentistry (BSPD) between 23 June 2017 and 15 August 2017 with a reminder email sent on 18 July 2017. Individual follow-up correspondence with non-respondents was not carried out due to the anonymity of the survey. The UK-based paediatric dental specialists, paediatric dental trainees, GDPs working in the capacity of specialists in paediatric dentistry, such as non-specialist senior dental officers in paediatric dentistry, lecturers in paediatric dentistry or GDPs with advanced training in paediatric dentistry, and GDPs were included in the study. Non-UK based practitioners, retired dentists and specialists were excluded. Information collected in the questionnaire included the following:

- Part A: Demographic data including positions held and frequency of treating children with traumatised permanent teeth
- Part B: General questions on the clinical use of dental pulp tests
- Part C: Specific questions on the use of cold sensibility testing
- Part D: Specific questions on the use of EPT
- Part E: Specific questions on the use of the LDF.

Data collected were entered into a statistics programme (IBM SPSS version 22). Descriptive statistics analysing participants' responses were computed.

Results

Participants

The email invite was sent to all 732 BSPD members, the membership of which included both UK registered paediatric dentistry specialists and GDPs who have an interest in children's dentistry. A total of 149 respondents completed the survey; of which eight respondents were excluded (two retired dentists, two special care dentists and four dentists who did not treat children with dental trauma).

The remaining 141 respondents were split into paediatric dental specialists (79, 56%)

Official journal of the British Dental Association.

and GDP groups (62, 44%). The paediatric dental specialist group included 68 registered paediatric dental specialists, eight paediatric dental trainees and three speciality dentists. Consequently, a specialist response rate of 35% (68 BSPD registered specialists out of 192 BSPD registered specialists) was achieved in this survey and an overall response rate of 20.3% (149 out of 732). The GDP group included ten community dental practitioners and 52 GDPs. A GDP response rate could not be calculated as the BSPD does not hold an overall number of GDP members.

Dental trauma experience

More than half of the specialists (45/79, 57%) reported seeing more than eight patients a month, while the majority of GDPs (42/62, 67.7%) reported seeing a maximum of two children with a history of dental trauma a month (Fig. 1).

General use of dental pulp tests

The majority of the respondents (124/141, 87.9%), with almost all specialists (74/79, 93.7%) reported using sensibility pulp tests routinely in the management of traumatised teeth in children in comparison to (50/62, 80.6%) of GDPs (Table 1).

Different barriers to the use of sensibility testing among those who reported not using the tests routinely were cited, with child perception and cooperation being the most reported barriers among both groups. Other barriers were also reported, including the cost of the tests, the time-consuming nature of the tests, and that they do not provide any additional information.

On average, most of the respondents reported using dental pulp testing at initial presentation and then at specific intervals (128/141, 90.8%). Almost all of the specialists (78/79, 98.7%) reported using dental pulp tests on initial presentation and specific intervals, in comparison to 83.9% of GDPs (52/62) (Table 1).

Type of sensibility/vitality tests used

The most common type of sensibility/vitality tests used by all respondents was cold testing (137/141, 97.2%), followed by EPT (94/141, 66.7%). None reported using LDF. Six respondents (4.2%) reported the use of heat testing.

GDPs mainly used cold testing 60/62 (96.8%) rather than other tests such as EPT (28/62, 45.2%), while specialists used cold and EPT tests equally (77/79, 97.5% and 76/79, 96.2% respectively) (Fig. 2).

Fig. 2 Bar chart showing types of sensibility/vitality tests used by respondents per group

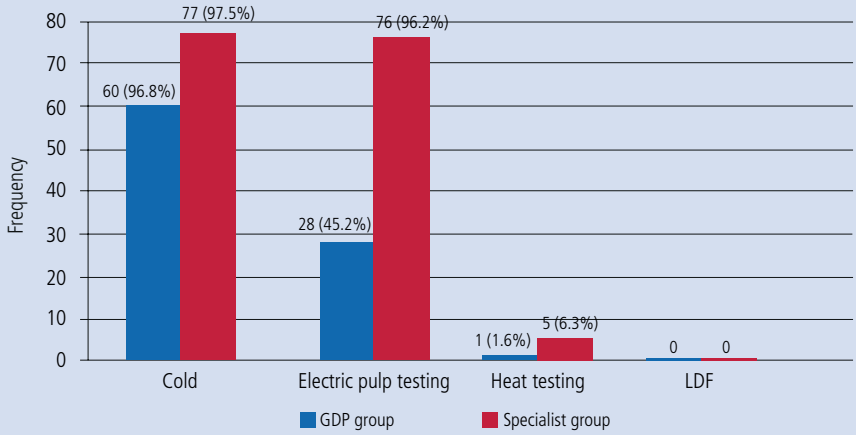


Table 2 Reliability of sensibility tests

Perception of the reliability of sensibility tests by respondents		Frequency	Percentage%
Yes,	GDPs	16/62	25.8
	Specialists	18/79	22.8
Sometimes	GDPs	32/62	51.6
	Specialists	50/79	63.3
No	GDPs	14/62	22.6
	Specialists	11/79	13.9
Practical techniques performed by respondents in improving the reliability of sensibility tests			
I use a control tooth for the child to experience the desired sensation	GDPs	56/62	90.3
	Specialists	69/79	87.3
I repeat the test on each tooth	GDPs	40/62	64.5
	Specialists	57/79	72
I apply a false positive reading such as applying a dry cotton pledget.	GDPs	17/62	27.4
	Specialists	37/79	46.8
I do not do anything in specific	GDPs	1/62	1.6
	Specialists	2/79	2.5

Reliability of sensibility tests

The reliability of dental pulp tests was considered inconsistent with almost half the number of GDPs (32/62, 51.6%) and almost two-thirds of the specialist group (50/79, 63.3%) considering these tests to be sometimes reliable (Table 2). Different reasons for such inconsistency of reliability were reported including children's understanding and cooperation, anxiety and stress, age, root formation, tests are not reliable in the early stage of trauma, and issues with sensitivity and specificity of the tests. Techniques used in improving test reliability in children are shown in Table 2.

Different techniques have been used by the respondents in order to improve reliability of dental pulp tests such as using a control tooth for the child to experience the desired sensation, repeating the test on each tooth, and applying a false positive reading such as applying a dry cotton pledget (Table 2). The most commonly used single method by both the GDP and specialist groups was the use of a control tooth, while the least commonly used method was applying a false positive reading.

Cold test use among respondents

Almost all respondents reported using cold tests (139/141, 98.6%) with ethyl chloride being

reported as the most commonly used cold testing agent with comparable use between the two groups (Fig. 3). Three-quarters of all respondents (106/139, 76.2%), of which 80.3% (49/61) and 73% (57/78) were GDPs and specialists, respectively, did not apply the cold test for a specific period on each tooth. Those who did, however, used a range of time between one and 20 seconds per tooth.

Inconsistencies in recording the results of the cold test were also observed with the majority of GDPs (43/61, 70.5%) and specialists (55/78, 70.5%) recording the results as positive and negative with no record of reliability of results.

EPT use among respondents

Almost half of the GDPs (30/62, 48.4%) and the majority of the specialists (67/79, 85%) reported using EPT when treating traumatised permanent teeth in children.

Documentation of the results of the EPT varied among respondents with most specialists (48/67, 71.6%) and just over half of GDPs (17/30, 56.6%) documented the numerical values of the EPT rather than whether the results were reliable or unreliable. Approximately 20% of both groups equally reported recording whether the results were reliable or not (Fig. 4a and b). There were differences in the recording of sensibility test results as detailed in Figure 4b with more than half of all participants 52/97 (53.6%) recording only the most reliable/consistent EPT reading, of which 22/30 (73.3%) were recorded by GDPs and 30/67 (44.8%) were recorded by specialists.

LDF use among respondents

Only 9/141 (6.4%) respondents reported having some experience in using LDF, of which all were specialists. The main reason reported for using LDF was the need for a test able to assess tooth vitality (blood flow) rather than sensibility (nerve supply).

Different barriers to the use of LDF were reported as the lack of knowledge of the technique among GDPs (29/62, 46.7%), compared to the lack of training as reported by the specialist group (33/70, 47%) (Fig. 5).

Fig. 3 Bar chart showing types of cold tests used

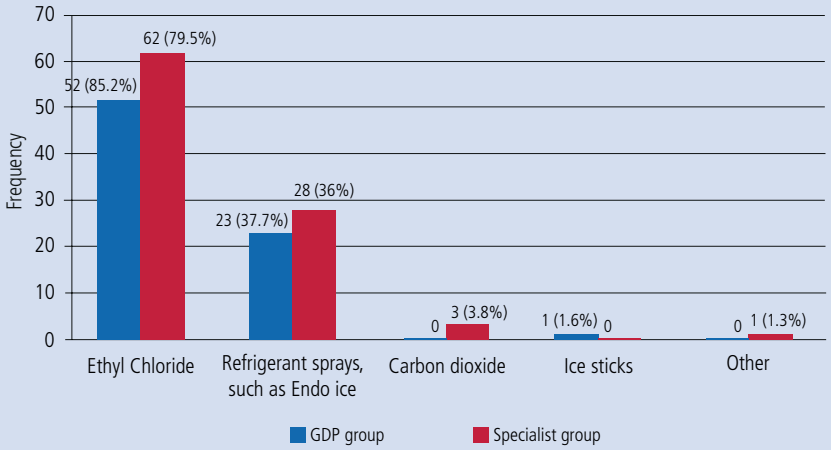
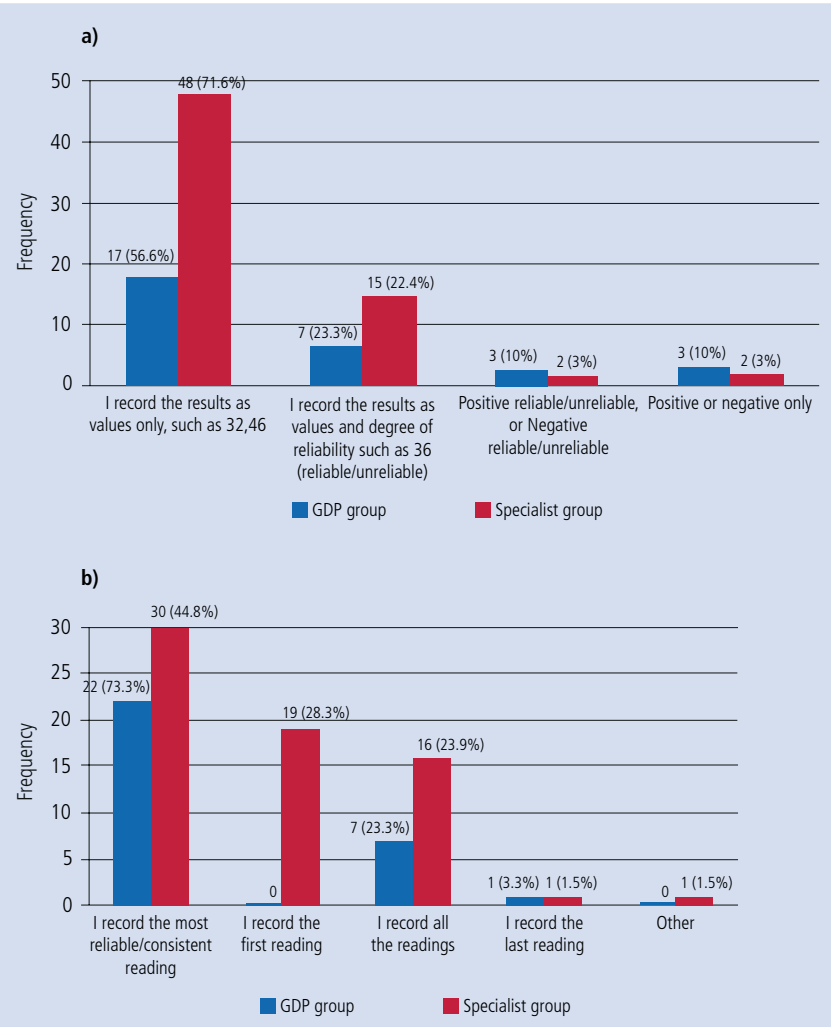


Fig. 4 Bar chart showing a) different methods used in documenting the results of the EPT per group, and b) different techniques in choosing the EPT value reading recorded



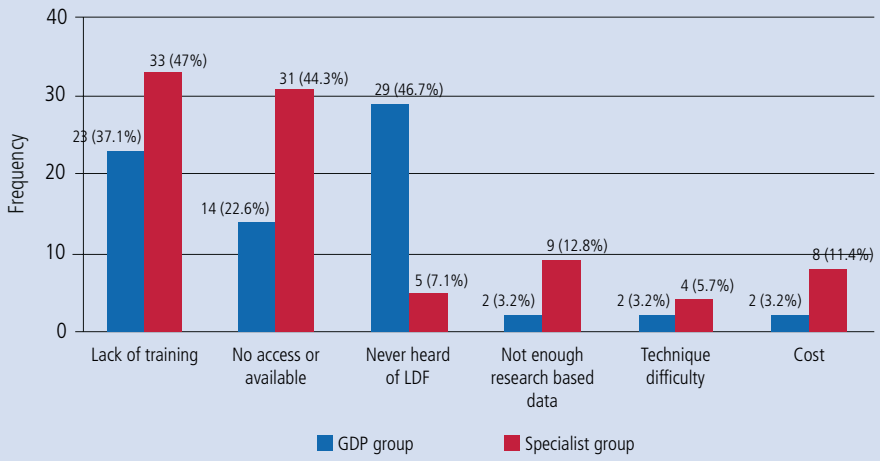
Discussion

Loss of tooth vitality is one of the sequalae of dental trauma, and careful long-term monitoring of pulp vitality has been recommended by all dental trauma guidelines in order to avoid unwanted complications.[12–14] Different pulp sensibility and vitality tests are available, however, to date no one test has been shown, based on high quality evidence, to be superior in terms of sensitivity and specificity.[15] It has been argued that the use of LDF, whereby pulp blood flow is measured, is more appropriate and accurate in assessing pulp vitality than sensibility, therefore, reducing false negative and false positive results.[9]

The authors acknowledge that few UK based

Official journal of the British Dental Association.

Fig. 5 The reasons/barriers in using LDF in dental trauma



specialists may not be members of the BSPD. That being said, the results included the participation of a large number of UK based specialists and practitioners working in the capacity of paediatric dental specialists, with a reasonably good representation of paediatric dental specialists across the country. Also, such a cohort of GDPs might not fully represent UK GDPs, as those BSPD GDP members are likely to be more interested in managing children with dental trauma than the average GDP population.

An attempt was made initially to get a wider sample of GDPs and paediatric dentistry specialists by contacting the GDC. Unfortunately, due to a recent change in the GDC's published members' information, such data were no longer available online. In addition, the GDC was neither able to share their members' addresses nor willing to forward electronic surveys to their members. Furthermore, attempting to distribute the survey to all practitioners in the Yorkshire and Humber region through contacting the Local Professional Network (LPN), was also unsuccessful. The BSPD was not able to share their members' contact details, but agreed to forward an electronic survey to all their registered members. The survey was distributed through the mailing list.

The results of this survey showed a reasonable exposure of both specialists and GDPs to children with traumatised permanent teeth, with the specialists expectedly reporting more exposure than GDPs. Such difference in exposure to this group of children is understandable since UK GDPs refer most trauma cases, especially severe traumatic injuries, to paediatric dental specialists for management.[16] It is essential that general dental practitioners have a sound knowledge about managing dental trauma, especially the initial treatment and management.[17]

Despite their limitations, sensibility tests are extremely useful tools in assessing and monitoring pulp status and should be used as part of clinical examination at initial trauma time and review appointments as recommended by the International Association for Dental Traumatology (IADT). Lauridsen *et al.*[18–20] showed the importance of using EPT at initial trauma in identifying teeth at increased risk of pulp necrosis. Therefore, the routine use of sensibility tests by most respondents, especially at initial trauma, was in line with published guidelines. More exposure of specialists to children with dental trauma could explain the discrepancy in the routine use of sensibility tests by the two groups, with more specialists than GDPs using these tests routinely. Around 1.3% of specialists reported using sensibility tests only when symptoms arise, and around 5% of GDPs reported using sensibility tests only at initial trauma.

The overwhelming use of cold tests and EPT among all respondents could be attributed to the availability, ease of use, cost-effectiveness, and high accuracy reported of these tests.[21] The lack of use of vitality tests such as LDF among respondents could be attributed to the higher cost and lack of high-quality evidence supporting the superiority of this technique over other sensibility tests.[15] In addition, very few specialists have reported having a previous experience using LDF mainly in research.

Ethyl chloride and refrigerant spray cold agents have been used by most respondents. Ethyl chloride has a temperature of –12.3°C, while the temperature produced by different refrigerant sprays such as Endo-Ice, Green Endo-Ice and Endo-Frost ranges from –20°C to –50°C.[10] The sensitivity of ethyl chloride has been reported to range between 53% and 92% while that of Endo-Ice refrigerant spray ranges between 81% and 100%. Specificity, on the other hand, ranged between 89–100% and 76–100% for ethyl chloride and Endo-Ice, respectively.[23]

The correct use of cold tests is important in improving accuracy, reliability and reproducibility of these tests. Patients need to fully understand the feeling of cold tests as well as when and how to respond to the stimulus. Applying the cold stimulus to unaffected teeth before using the tests on affected teeth (with questionable pulp status) so that patients are aware of the cold stimulus sensation is important in reducing false results. The use of dry cotton pellets to test patient compliance and understanding of the test is also recommended.[10]

The application of cold tests requires a carrier such as a cotton pellet saturated with the sprayed agent applied with direct contact to the tooth tested.[22] Larger pellets have larger surface areas than smaller cotton pellets, thus allowing better thermal conduction. Cotton buds with wooden handles and small cotton pellets have smaller surface areas and are therefore less efficacious in thermal conduction.[23] The application of the cotton pellet to the middle third of the labial/buccal surface of the crown for five to eight seconds is recommended.[24,25] Avoiding contact with the gingival tissues is also important to reduce false positive results.

When using EPT, a positive response is the result of an ionic shift in the dentinal fluid within the tubules causing local depolarisation and thus the generation of action potential from intact nerves.[26] A positive response simply indicates that there are sensory fibres present within the pulp that can respond to the electrical stimulus. However, necrotic pulp tissue can leave electrolytes in the pulp space, which are able to conduct the electricity to the nerves further down the pulp space, simulating a normal pulp response.[27] In general, EPT is more reliable in detecting vital teeth than non-vital teeth. The sensitivity of EPT ranges between 67% and 100% while the specificity ranges between 88% and 100%.[21]

Applying the EPT on unaffected teeth before use to enhance patient understanding is also needed. Drying the tooth is essential in preventing false positive results due to electrical conduction to the adjacent teeth, or periodontium.[28] If possible, the contralateral tooth should be tested in order to establish a baseline response. Teeth should be tested at least twice

to confirm the results and ensure consistency.[29] Changing the sequence of the teeth being tested has been reported to increase the reliability of EPT.[11] Another method is to apply a faster current. However, the numerical values of EPT have significance only if there is a high difference between the traumatised tooth and the vital control teeth. The numerical value of the responses should be recorded for each tooth. The electrode should be applied to the middle third of the facial/labial surface of the tooth with direct contact to the tooth structure.[30]

The value of sensibility tests is highly dependent on a number of factors including the patient's understanding, compliance and cooperation, and the degree of root development. These factors limit their use in children, patients with learning disabilities and patients with limited communication. Such limitations were reported by respondents showing good understanding and appreciation of these limitations. Therefore, recording the results of such techniques with a comment on the reliability of the results and/or any limiting factors should be encouraged.

The ability of LDF in measuring the tooth's pulp blood flow rather than innervation lead to its use as a pulp vitality tester. The objectivity of this test (lack of dependence on the patient's response) further supported its use.[31] The laser light reaches the pulp through the dentinal tubules acting as a guide. When light enters the tissue, it gets absorbed and scattered by the moving and circulating red blood cells. Laser photons are then shifted against moving red blood cells and reflected back into a photodetector leading to a signal production.[32]

It has been reported that LDF is able to determine pulp vitality and offers a better chance of evaluating traumatised teeth than other pulp tests. Clinical studies have shown that LDF has higher sensitivity and specificity when compared to other pulp tests.[33,34] However, the cost of the equipment is considered to be high when compared to other pulp tests. Moreover, it is technique sensitive. Thus, careful interpretation of the results should also be considered.[9]

Recommendations

Although the use of pulp sensibility tests was relatively high within the cohort selected for this study when assessing traumatised teeth in children, GDPs and specialists should:

- Routinely use sensibility tests with all traumatised teeth, mainly at baseline and key review appointments as per IADT guidelines[12,13]
- Use a standardised technique, able to reduce false results as described above, in order to be accurately compared with future pulp test results
- Record the reliability of the results depending on their assessment of patient understanding, cooperation and response to contralateral healthy teeth and repeated measurements
- Interpret the results of the sensibility tests within the overall clinical assessment due to the inherent limitations of these tests.

Conclusion

The use of pulp sensibility tests was relatively high, but inconsistency in technique and recording of results was evident within the cohort selected for this study. Several barriers usually associated with the child patient, including cooperation, understanding and age were identified. The use of vitality tests and especially LDF was extremely low. It appears that there is a need to encourage vitality testing, including possibly the use of LDF in clinical practice for a better evaluation of the dental pulp. The high cost, the difficulty of the technique, and training, as well as limited knowledge about LDF are certainly limiting factors in its widespread use.

Acknowledgements

The authors would like to thank the BSPD for distribution of the questionnaire survey to their members and all BSPD members who took the time to complete the survey.

1. Pitts N, Chadwick B, Anderson T. Children's dental health survey 2013. Report 2: Dental disease and damage in children: England, Wales and Northern Ireland. 2015. Available at https://files.digital.nhs.uk/publicationimport/pub17xxx/pub17137/cdhs2013-report2-dental-disease.pdf (accessed January 2019).
2. Yu C Y, Abbott P V. Responses of the pulp, periradicular and soft tissues following trauma to the permanent teeth. *Aust Dent J* 2016; **61**: 39–58.
3. Robertson A. A retrospective evaluation of patients with uncomplicated crown fractures and luxation injuries. *Endod Dent Traumatol* 1998; **14**: 245–256.
4. Robertson A, Andreasen F M, Andreasen J O, Noren J G. Long-term prognosis of crown-fractured permanent incisors. The effect of stage of root development and associated luxation injury. *Int J Paediatr Dent* 2000; **10**: 191–199.
5. Andreasen F M. Pulpal healing after luxation injuries and root fracture in the permanent dentition. *Endod Dent Traumatol* 1989; **5**: 111–131.
6. Andreasen F M, Paedersen B V. Prognosis of luxated permanent teeth–the development of pulp necrosis. *Endod Dent Traumatol* 1985; **1**: 207–220.
7. Sigurdsson A. Pulpal diagnosis. *Endod Topics* 2003; **5**: 12–25.
8. Chambers I G. The role and methods of pulp testing in oral diagnosis: a review. *Int Endod J* 1982; **15**: 1–15.
9. Jafarzadeh H. Laser Doppler flowmetry in endodontics: a review. *Int Endod J* 2009; **42**: 476–490.
10. Jafarzadeh H, Abbott P V. Review of pulp sensibility tests. Part I: general information and thermal tests. *Int Endod J* 2010; **43**: 738–762.
11. Jafarzadeh H, Abbott P V. Review of pulp sensibility tests. Part II: electric pulp tests and test cavities. *Int Endod J* 2010; **43**: 945–958.
12. Andersson L, Andreasen J O, Day P *et al.* Guidelines for the Management of Traumatic Dental Injuries: 2. Avulsion of Permanent Teeth. *Paediatr Dent* 2017; **39**: 412–419.
13. Diangelis A J, Andreasen J O, Ebeleseder K A *et al.* Guidelines for the Management of Traumatic Dental Injuries: 1. Fractures and Luxations of Permanent Teeth. *Paediatr Dent* 2017; **39**: 401–411.
14. Albadri S, Zaitoun H, Kinirons M J. UK National Clinical Guidelines in Paediatric Dentistry: treatment of traumatically intruded permanent incisor teeth in children. *Int J Paediatr Dent* 2010; **20 (Spec Iss):**1–2.
15. Mejare I A, Axelsson S, Davidson T *et al.* Diagnosis of the condition of the dental pulp: a systematic review. *Int Endod J* 2012; **45**: 597–613.
16. Maguire A, Murray J J, al-Majed I. A retrospective study of treatment provided in the primary and secondary care services for children attending a dental hospital following complicated crown fracture in the permanent dentition. *Int J Paediatr Dent* 2000; **10**: 182–190.
17. Jackson N G, Waterhouse P J, Maguire A. Management of dental trauma in primary care: a postal survey of general dental practitioners. *Br Dent J* 2005; **198**: 293–297.
18. Lauridsen E, Hermann N V, Gerds T A, Ahrensburg S S, Kreiborg S, Andreasen J O. Combination injuries 1. The risk of pulp necrosis in permanent teeth with concussion injuries and concomitant crown fractures. *Dent Traumatol* 2012; **28**: 364–370.
19. Lauridsen E, Hermann N V, Gerds T A, Ahrensburg S S, Kreiborg S, Andreasen J O. Combination injuries 2. The risk of pulp necrosis in permanent teeth with subluxation injuries and concomitant crown fractures. *Dent Traumatol* 2012; **28**: 371–378.
20. Lauridsen E, Hermann N V, Gerds T A, Ahrensburg S S, Kreiborg S, Andreasen J O. Combination injuries 3. The risk of pulp necrosis in permanent teeth with extrusion or lateral luxation and concomitant crown fractures without pulp exposure. *Dent Traumatol* 2012; **28**: 379–385.
21. Alghaithy R A, Qualtrough A J. Pulp sensibility and vitality tests for diagnosing pulpal health in permanent teeth: a critical review. *Int Endod J* 2017; **50**: 135–142.
22. Fuss Z, Trowbridge H, Bender I B, Rickoff B, Sorin S. Assessment of reliability of electrical and thermal pulp testing agents. *J Endod* 1986; **12**: 301–305.
23. Jones D M. Effect of the type carrier used on the results of dichlorodifluoromethane application to teeth. *J Endod* 1999; **25**: 692–694.
24. White J H, Cooley R L. A quantitative evaluation of thermal pulp testing. *J Endod* 1977; **3**: 453–457.
25. Dachi S F, Haley J V, Sanders J E. Standardization of a test for dental sensitivity to cold. *Oral Surg Oral Med Oral Pathol* 1967; **24**: 687–692.
26. Pantera E A Jr, Anderson R W, Pantera C T. Reliability of electric pulp testing after pulpal testing with dichlorodifluoromethane. *J Endod* 1993; **19**: 312–314.
27. Apfel F R, Gerstein H. Response of periodontium to pulp tester. *J Am Dent Assoc* 1973; **87**: 30.
28. Pitt Ford T R, Patel S. Technical equipment for assessment of dental pulp status. *Endod Topics* 2004; **7**: 2–13.
29. Bender I B, Landau M A, Fonsecca S, Trowbridge H O. The optimum placement-site of the electrode in electric pulp testing of the 12 anterior teeth. *J Am Dent Assoc* 1989; **118**: 305–310.
30. Matthews B, Searle B N, Adams D, Linden R. Thresholds of vital and non-vital teeth to stimulation with electric pulp testers. *Br Dent J* 1974; **137**: 352–355.
31. Gazelius B, Olgart L, Edwall B, Edwall L. Non-Invasive Recording of Blood Flow in Human Dental Pulp. *Endod Dent Traumatol* 1986; **2**: 219–221.
32. Lee J Y, Yanpiset K, Sigurdsson A, Vann W F. Laser Doppler flowmetry for monitoring traumatized teeth. *Dent Traumatol* 2001; **17**: 231–235.
33. Evans D, Reid J, Strang R, Stirrups D. A comparison of laser Doppler flowmetry with other methods of assessing the vitality of traumatised anterior teeth. *Endod Dent Traumatol* 1999; **15**: 284–290.
34. Karayilmaz H, Kirzioglu Z. Comparison of the reliability of laser Doppler flowmetry, pulse oximetry and electric pulp tester in assessing the pulp vitality of human teeth. *J Oral Rehabil* 2011; **38**: 340–347.