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Responses of pulp sensibility tests during orthodontic treatment and retention

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Abstract

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Aim To investigate the effect of orthodontic tooth movement involving the six maxillary anterior teeth on the pulp response to both thermal and electric stimuli during active orthodontic treatment and retention.

Methodology Forty-seven subjects who required fixed orthodontic appliances were used as a study group with 23 non-orthodontic subjects recruited as a control group. Cold and electrical stimuli were applied to the maxillary incisors and canines immediately before and after the placement of fixed appliances and at regular intervals for both groups during active treatment and 12 months into retention. The numbers of negative responses for each tooth at each time interval were recorded for both groups. The data were collected and tabulated, and chi-square tests were used to determine significant difference between the numbers of negative responses for the two types of tests used on the same tooth and between different teeth. The mean values of the electric pulp testing (EPT) thresholds were also obtained and used to assist in analysing the results.

Results In the control group, all teeth tested positively to the EPT and thermal pulp tests at all time intervals. In the orthodontic group, two teeth failed to respond to EPT and only one tooth to thermal testing at baseline (Time 0). After that, the number of negative responses to both tests increased gradually at each time interval reaching a peak after 2 months of active treatment (Time 3) and then declined gradually towards the end of observation period (Time 14). At baseline, response thresholds to electric testing were typically higher for orthodontic subjects, particularly for the maxillary lateral incisor tooth. For the control group, the response threshold over the study period was relatively constant. For the orthodontic group, application of force immediately increased the response threshold to EPT (Time 1), which peaked after 2 months (Time 3) and then gradually reduced. At the end of the active treatment, response thresholds remained elevated, but they returned to pre-treatment values towards the end of the retention phase.

Conclusion Dental practitioners should interpret responses to electrical pulp testing cautiously in orthodontic patients; thermal testing may be more reliable.

Keywords: electric test, pulp vitality, thermal test.

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Introduction

The health and integrity of the dental pulp is of major importance for tooth survival. The diagnosis of orofacial pain is complicated in the orthodontic patient as treatment-induced alterations to pulpal physiology may result in altered responses to pulp sensibility tests. Pulp testing, both electric and thermal, is an invaluable aid to the clinician in the assessment and diagnosis of pulpal pathosis, although false results may be obtained (Fulling & Andreasen 1976, Ehrmann 1977, Klein 1978). Prior knowledge of the circumstances that are likely to produce unreliable results would be of great benefit.

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Sensory innervation of the pulp is provided by myelinated 'A' fibres and unmyelinated 'C' fibres. The A fibres include both β and δ types, which are primary nociceptors. In the dental pulp, these fibres may only be involved in dentinal sensitivity and are principally found at the pulpal–dentinal junction (Byers 1984). C fibres have a relatively high stimulation threshold, transmit pain only, and are thought to be distributed throughout the pulp.

During odontogenesis, nerve fibres enter the tooth through the forming apex. The unmyelinated C fibres reach their maximal number shortly after tooth eruption, whereas the number of myelinated A fibres will increase up to 5 years post-eruption(Johnsen 1982). This is thought to be one reason for the unreliability of electric pulp testing (EPT) in immature teeth (Fuss *et al.* 1986). Once the nerve fibres reach the coronal pulp, they branch and form the plexus of Raschkow, just beneath the cell-rich zone adjacent to the dentine. Nerve endings may terminate in the pulp or may extend into the dentinal tubules (Lilja 1979). The pulpal horns are known to have the greatest density of nerve endings (Lilja 1979) and the incisal edge and have been shown to be one of the most responsive places to apply electric tests electrically (Bender *et al.* 1989).

Clinical pulp testing procedures aim to stimulate a response from pulpal neural elements. Electric and thermal stimuli first evoke a response from fast-acting myelinated A fibres. With prolonged application, these electric and thermal tests will also stimulate the slow-acting, relatively high-threshold, unmyelinated C fibres, but ordinarily, a pain response can be achieved before the C fibre threshold is reached (Narhi *et al.* 1992). Pulp tissue is much more sensitive to electrical stimulation than gingival or periapical tissues. Most modern pulp testers cannot produce sufficient current to stimulate periradicular tissues. In thermal pulp testing, although the levels of cold or heat used are extreme, the health of the pulp is not jeopardized if testing is carried out with care (Narhi 1985). An understanding of the pain response to thermometric pulp testing is based on the hydrodynamic theory of the sensitivity of dentin because the pulp has no thermosensing nerve endings. Therefore, a response requires the existence of intact pulp tissue. In other words, the cold- or heat-induced sensation depends on the presence of a morphologically intact pulp (Rickoff *et al.* 1988).

Conditions within the pulp can affect the excitability of nerve fibres. A reduction in blood flow is known to reduce the excitability of A fibres, whereas C fibres are affected to a much smaller degree (Narhi *et al.* 1984). Moreover, C fibres might still be able to respond in a diseased pulp in the presence of hypoxia and would actually be stimulated by inflammatory mediators, such as histamine and bradykinin (Narhi 1985).

Traumatized teeth are known to be unresponsive to EPT shortly after the injury, but the responsiveness often returns over time (Pileggi *et al.* 1996, Strobl *et al.* 2005). The duration may depend on the type of injury, and it has been empirically stated that a latency period of up to 6 weeks should be allowed before assuming loss of vitality based on a negative response to EPT (Andreasen 1986, Sano *et al.* 2002).

Orthodontic movement of teeth has been shown to produce changes in tissue respiration within the pulp as well as an inflammatory process within the periodontium (Hamersky *et al.* 1980). It was suggested that, after initiation of orthodontic force, there was an initial decrease in blood flow upon force application, followed by a reactive hyperaemia 30 min later before returning to normal after 72 h (McDonald & Pitt Ford 1994). During orthodontic treatment, the testing of pulpal sensibility is also thought to be unreliable (Burside *et al.* 1974, Cave *et al.* 2002), but there have been no reports on the changes in pulpal response during the retention phase. Studies thus far have demonstrated a decreased or total lack of response to EPT during orthodontic force application (Burside *et al.* 1974, Hall & Freer 1998); however, there is little evidence to suggest that orthodontic treatment routinely alters pulpal physiology permanently (Popp *et al.* 1992). Such information would be of value to the practitioner faced with the challenge of diagnosing pathosis in a tooth being subjected to an orthodontic force. If the level of tooth sensitivity were a measure of pulpal respiration, then the magnitude and duration of these appliance-induced effects would also be of great interest to the orthodontist.

The purpose of this study was to investigate the long-term effect of orthodontic force application on the response and reliability of both thermal and EPT during active orthodontic treatment and retention phase and to compare the efficacy of both thermal testing and EPT in determining pulp status during that time.

Materials and methods

A group of orthodontic patients was compared and contrasted with a non-orthodontic group at various stages of active treatment and during the retention phase. The orthodontic group consisted of 47 subjects:

21 men and 26 women. The mean age was 15.1 years (range 12.1–17.3 years) about to commence fixed orthodontic treatment at the Dental Department of Princess Aisha Medical Complex in Amman, Jordan. Treatment included maxillary and mandibular fixed appliances of Roth prescription, which is a commonly used prescription with specific tip and torque values built in the brackets. None of the subject had extractions as part of orthodontic treatment plan. The duration of treatment ranged from 14.3 to 18.1 months (mean 16.1 months). After finishing the active phase of treatment, removable Howley retainers were used full time for 6 months and overnight for another 6 months.

Each subject underwent electric and thermal testing of the maxillary central incisors, lateral incisors and canines as they are single rooted and easily accessible. The tests were performed immediately prior to bonding of orthodontic brackets (Time 0), 2 h after bonding of the brackets and insertion of the initial archwire (Time 1), then 30 ± 3 days (Time 2), 60 ± 3 days (Time 3), 120 ± 7 days (Time 4), 180 ± 7 days (Time 5), 240 ± 7 days (Time 6), 300 ± 10 days (Time 7) and 360 ± 10 days (Time 8), after initiation of tooth movement. All pulp tests were performed after the archwires were removed even at Time 1. Additionally, teeth were tested just after debonding (Time 9), 1 month after the fitting of Howley retainers (Time 10), 3 months into retention (Time 11), 6 months into retention (Time 12), 9 months into retention (Time 13) and 12 months into retention (Time 14).

The non-orthodontic group consisted of 23 subjects: 11 men and 12 women ranging in age from 13.7 to 18.1 years (mean 16.2 years) not undergoing orthodontic treatment. These subjects were tested at equivalent times to the Times 0–14 of the orthodontic group. All the tests were undertaken with understanding and written consent from the subjects and parents. Additionally, the study was reviewed and approved by the Ethical Committee of The Royal Medical Services.

A total of 420 teeth were tested (282 orthodontically treated and 138 non-orthodontic). Only non-carious teeth with small or no restorations were tested, and none had a history of significant trauma or were root filled. The teeth with no response had not been root filled as confirmed by periapical films.

Electric pulp testing was undertaken using an Analytical Technology Vitality Scanner (Analytical Technology Corporation, Redmond, WA, USA) using toothpaste as the conduction media. The technical specifications of this device are described elsewhere (Dummer *et al.* 1986, Dal Santo *et al.* 1992). All testing was carried out with the same EPT unit. Each tooth was isolated with cotton rolls and dried thoroughly with cotton pellets prior to testing to ensure pulpal rather than periodontal nerve fibres stimulation. The tip of the probe was coated with toothpaste and applied to the labial surface of the tooth in the incisal third, midway mesiodistally.

The patient was instructed to grasp the probe handle to complete the circuit and initiate the test and to release the EPT device when a sensation was felt. All subjects were informed about the difference between pre-pain and actual pain and asked to respond to the pre-pain only. The numerical values on the digital display on the machine were recorded after each test. The corresponding output voltage for each EPT unit is displayed in Fig. 1. The order of testing was the maxillary right canine, the maxillary right lateral incisor, the maxillary right central incisor, the maxillary left central incisor, the maxillary left lateral incisor and finally the maxillary left canine (teeth 13,12, 11,21, 22,23). Testing was repeated after a 2-min rest interval to minimize the possibility of nerve accommodation. Each reading was recorded as Test 1 or 2, and teeth that failed to respond to electric testing were recorded as a reading of 80 EPT units.

Thermal stimulation was provided by Endo Ice® (Endo Ice Hygienic Corp., Akron, OH, USA). Endo Ice was also applied to the test teeth in the mid-incisal third using a cotton pellet tightly wrapped around the tip of a tweezer. Response times were not recorded for thermal testing but simply recorded as a positive/negative (yes/no). A negative result was recorded if a tooth failed to elicit a response after two 15-second applications of the dry ice, 2 min apart.

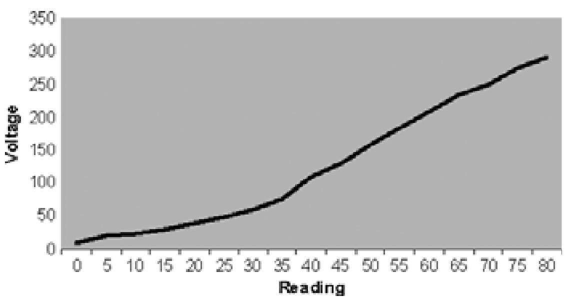

Figure 1 Reading on Analytical Technology Vitality Scanner scale plotted against voltage output (Analytic Technology Corporation).

The data collected from the orthodontic and non-orthodontic groups were grouped by subject, tooth and time (day), and also EPT readings. Statistical Package for Social Sciences, version 11 (SPSS-V11, Chicago, IL, USA) software, was used for the analyses. For statistical analysis, the results of electric and thermal pulp tests were recorded as negative or positive. The numbers of negative responses for both tests for each tooth at different intervals were grouped before using chi-square and Fisher's exact tests to find any statistically significant differences between the number of negative responses for each group of teeth in the same pulp test and between both tests.

Results

In the non-orthodontic group, there were 4140 electric pulp tester readings and 2070 thermal test readings for the 138 teeth. All teeth tested positively to the EPT and thermal testing at all test intervals (Time 0–14). For the orthodontic group, a total of 8460 electric tests and 4230 thermal tests were performed on 282 teeth on 15 occasions (Time 0–14). The frequency of negative responses depended upon the time into treatment (Table 1, Fig. 2). At baseline (Time 0), two teeth in the entire orthodontic sample failed to elicit responses. After bonding of fixed appliances and ligation of the initial archwire, a further ten teeth (4%) of the total teeth tested were unresponsive to the electric pulp tester after the two applications (Test 1 and 2). Two months (Time 4) after application of orthodontic force, 56 teeth (20%) of the total teeth tested failed to respond. From this peak, responsiveness was seen to return at each time interval so that on the day of debonding (Time 9), 17 teeth (6%) gave negative responses to EPT. After debonding and fitting of

Table 1 Incidence of negative response to electric and thermal testing at each time interval: orthodontic group

	Negative response			Total	
Time	Centrals (*n* = 94) EPT (TT)	Laterals (*n* = 94) EPT (TT)	Canines (*n* = 94) EPT (TT)	Number (*n* = 282) EPT (TT)	% EPT (TT)
0	1 (0)	1 (1)	0 (0)	2 (1)	0.71 (0.35)
1	3 (0)	9 (1)	0 (0)	12 (1)	4.26 (0.35)
2	5 (1)	16 (1)	1 (0)	21 (2)	7.59 (0.71)
3	14 (1)	38 (3)	4 (0)	56 (4)	19.9 (1.4)
4	13 (1)	32 (3)	3 (0)	48 (3)	17.0 (1.1)
5	10 (1)	29 (2)	3 (0)	42 (3)	15.9 (1.1)
6	9 (1)	25 (2)	3 (0)	37 (3)	13.1 (1.1)
7	9 (1)	23 (1)	3 (0)	35 (2)	12.4 (0.71)
8	6 (1)	19 (1)	2 (0)	27 (2)	9.6 (0.71)
9	4 (0)	12 (1)	1 (0)	17 (1)	6.0 (0.35)
10	4 (0)	11 (1)	0 (0)	15 (1)	5.3 (0.35)
11	2 (0)	7 (1)	0 (0)	9 (1)	3.2 (0.35)
12	2 (0)	3 (1)	0 (0)	5 (1)	1.8 (0.35)
13	1 (0)	3 (1)	0 (0)	4 (1)	1.4 (0.35)
14	1 (0)	2 (1)	0 (0)	3 (1)	1.1 (0.35)

EPT, electric pulp test; TT, thermal test.

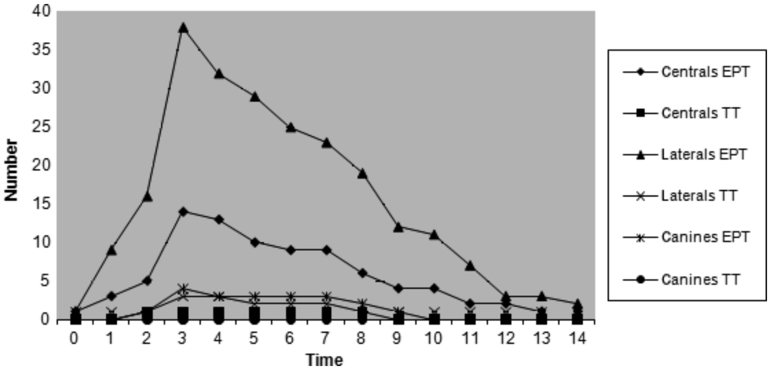

Figure 2 The relationship between number of negative readings and time for both electric pulp test (EPT) and thermal test with Endo Ice® (TT) for experimental group.

Table 2 Results of chi-square and Fisher's exact test: orthodontic group

Groups	Number of valid cases	Pearson chi-square	Fisher's exact sig. Two-sided	Fisher's exact sig. One-sided
Centrals EPT–Laterals EPT	2632	77.926	<0.001	<0.001
Centrals EPT–Canines EPT	2632	41.005	<0.001	<0.001
Laterals EPT–Canines EPT	2632	1.949E2	<0.001	<0.001
Centrals TT–Laterals TT	2632	7.075	0.012	0.04
Centrals TT–Canines TT	2632	7.019	0.016	0.008
Laterals TT–Canines TT	2632	21.169	<0.001	<0.001
Centrals EPT–Centrals TT	2632	86.769	<0.001	<0.001
Laterals EPT-Laterals TT	2632	1.924E2	<0.001	<0.001
Canines EPT–Canines TT	2632	20.153	<0.001	<0.001

EPT, electric pulp test; TT, thermal pulp test.

retainers, the responsiveness was progressively reduced at each time interval so that at Time 14, only two teeth failed to respond to EPT, one of them the same tooth that failed to respond at Time 0. The number of lateral incisors failing to respond was greater than central incisors and canines at all time intervals.

A total of 4230 thermal tests were performed on 132 teeth in the orthodontic group. A total of 27 negative responses were recorded. At Time 0, only one tooth (a lateral incisor) failed to respond. After that, the number of teeth with negative response increased gradually reaching a total of four at Time 3; this number declined gradually towards the end of active treatment. At the end of observation period (Time 14), only one tooth did not respond (Table 1, Fig. 2).

In the orthodontic group, chi-square tests revealed statistically significant differences between the number of negative responses for each tooth compared with other teeth tested in this study using both thermal and EPT ($P < 0.001$) (Table 2). In the control group, the results were insignificant. Statistical comparison between both groups showed statistically significant differences for both tests at all time intervals ($P < 0.0001$).

The mean threshold of the EPT responses showed that they were considerably higher in the orthodontic group than the control group. At baseline, mean pulp tester values of subjects ranged from 12.2 to 52.8 EPT units (mean 34.9) for the orthodontic group and from 14.1 to 27.1 EPT units (mean 29.2) for the control group. The mean response thresholds were approximately five EPT units higher in orthodontic group. The baseline means for the lateral incisors tended to be higher than for central incisors, which was again higher than for the canines both in orthodontic (Table 3) and in control groups (Table 4).

The mean pulp tester readings for the non-orthodontic group at each time interval differ by <2 EPT

Table 3 Mean response threshold at each test interval: orthodontic group

Time	Tested teeth: Tooth 13	Tooth 12	Tooth 11	Tooth 21	Tooth 22	Tooth 23	Combined
0	23.66	42.21	29.96	29.12	41.11	22.88	34.99
1	29.13	47.55	35.22	33.89	47.11	27.97	41.77
2	35.57	53.54	41.35	39.64	51.77	31.88	48.01
3	39.12	57.97	44.43	41.41	56.62	37.43	50.12
4	37.33	56.64	42.20	40.11	54.13	36.66	48.42
5	37.87	57.34	41.29	40.25	55.43	36.84	47.49
6	35.11	54.54	39.00	39.64	51.17	31.18	47.01
7	32.41	49.23	37.43	36.23	48.29	29.81	45.48
8	31.57	46.54	36.35	34.64	46.77	27.45	43.81
9	26.26	43.34	33.20	32.13	43.45	25.37	41.91
10	25.80	42.16	33.35	32.44	41.08	24.88	41.01
11	25.10	42.67	32.55	31.62	41.91	23.73	39.21
12	24.99	41.89	31.65	30.49	40.78	23.17	37.71
13	23.81	41.16	30.55	29.45	41.02	22.91	35.40
14	23.10	42.23	29.14	29.34	40.88	22.17	35.42

Table 4 Mean response threshold at each test interval: non-orthodontic group

	Teeth tested						
Time	Tooth 13	Tooth 12	Tooth 11	Tooth 21	Tooth 22	Tooth 23	Combined
0	22.20	37.32	24.76	24.21	38.12	22.32	29.22
1	22.45	37.04	25.03	24.77	37.32	21.99	31.76
2	21.99	37.72	25.21	25.03	38.02	22.44	31.23
3	21.75	36.79	24.87	25.32	37.67	21.55	30.44
4	21.54	37.09	25.23	24.78	38.40	21.69	30.08
5	21.07	37.19	25.22	24.38	38.46	21.99	30.08
6	21.29	37.72	25.88	25.03	38.42	22.14	31.04
7	21.99	38.11	25.65	24.73	37.09	22.93	31.33
8	22.79	37.17	25.21	25.00	38.17	23.14	30.23
9	23.09	37.02	24.90	25.68	37.02	22.73	31.89
10	22.00	36.72	26.11	26.03	37.17	21.74	31.23
11	22.23	36.22	26.93	25.08	38.11	22.26	30.11
12	23.03	37.33	24.78	25.27	37.90	21.49	29.91
13	22.69	36.92	24.31	24.13	38.11	22.24	29.20
14	22.12	37.71	23.97	25.09	37.67	21.93	30.23

units over the trial period (Table 4). In contrast, the range of the overall time means for the orthodontic group is 15.13 EPT units. After bonding of fixed appliances and ligation of the initial archwire (Time 1), the mean threshold of each tooth increased from baseline measurements by between 1.77 and 6.44 EPT units (Table 3). As treatment progressed, the means continued to rise for each tooth until day 60 (Time 3), where they peaked at between 12.3 and 15.8 EPT units higher than their pre-treatment levels (Time 0). At debonding (Time 9), the mean threshold was still approximately 2 units higher than the pre-treatment values. After 1 year into retention (Time 14), these values almost returned to their pre-treatment values for all the teeth tested (Table 3, Fig. 3).

Discussion

For the non-orthodontic group, all teeth gave a positive response to both forms of testing at all stages of the trial. For the orthodontic group, only three negative responses were recorded prior to the application of orthodontic force: two to electric, one to thermal. In both these cases, the teeth did respond positively to the other form of testing. The findings are in general agreement with several other studies (Fulling & Andreasen 1976, Fuss *et al.* 1986).

The electric pulp tester used in this study was chosen because of its ease of use, its clinical popularity, its small probe tip to allow testing without touching the brackets and because it has been shown to produce threshold sensations that are not painful (Kleier *et al.* 1982). It is activated when the probe tip is placed upon the patient's tooth, and a circuit is created when the patient contacts the handle with their hand. The intensity of the stimulus begins to increase automatically along a pre-programmed curve that is designed such that the rate of voltage increase is slower at the lower end of the scale but is linear from approximately 25 upward on the 0–80 EPT unit scale (Fig. 1).

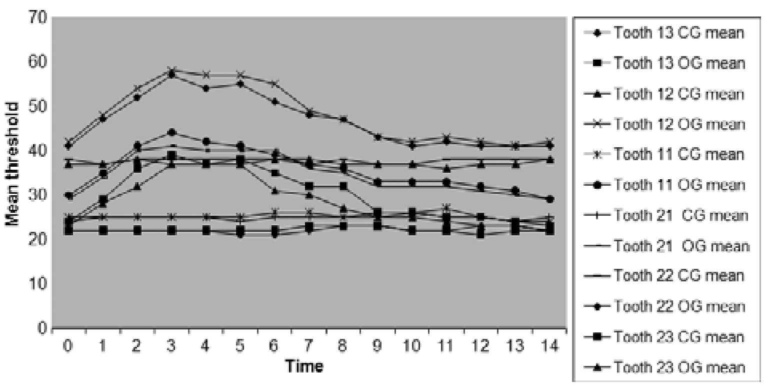

Figure 3 Relationship of electric pulp test (EPT) to time for both experimental and control groups.

The slower increase at the beginning is believed to be important for patient comfort (Dummer *et al.* 1986). The sweep rate controls the rate of increase in the stimulus intensity, but not the intensity itself. For this trial, the rate was set at 3, at which it takes 35 s to achieve peak voltage and therefore gives the subject sufficient time to recognize the stimulus and release the handle especially for the teeth that are expected to produce a rapid response, such as teeth with an open apex. It has also been shown that a slow and consistent increase in stimulus intensity is important for accurate and reproducible readings (Abdel Wahab & Kennedy 1987). To break the circuit, the patient simply releases the handle, and the reading remains on the digital display for a few seconds for ease of recording.

The site of application of the tip of the probe was on the labial surface of the tooth in the incisal one-third, midway mesiodistally. This has been shown to be the most effective site to test electrically because of its close proximity to the highly innervated pulp horns and because it provides a readily reproducible position for testing at subsequent visits. Care was taken not to allow the probe tip or conduction medium to contact the orthodontic brackets in the orthodontic group.

Thermal stimulation was provided by Endo Ice® (Endo Ice Hygienic Corp., Akron, OH, USA). Endo Ice is a liquid refrigerant (1,1,1,2-tetraflouroethane) that lowers the tooth temperature down to −30 °C.

Previous attempts have been made to quantify the response to the EPT performed with the analytic pulp tester used in this study. Cave *et al.* (2002) used this method when evaluating pulp test responses in orthodontic patients and reported that the response threshold increased after the application of force. A recent study could not verify these findings (Muller 2005). Changes in test results might not necessarily reflect changes in the pulp tissue. Even minute changes in test probe positioning will give different numerical values in the same tooth, and the condition of the battery might also play a role (Mickel *et al.* 2006, Lin *et al.* 2007). Therefore, for statistical analysis, it appears prudent to use all pulp tests, electric and thermal, as yes or no tests whilst the EPT readings were used for descriptive analysis. Comparisons of baseline mean response thresholds as recorded using the electric pulp tester showed considerable variation amongst subjects in both the orthodontic and non-orthodontic groups. The concept that people have different pain or pre-pain thresholds is certainly not new, but variations in the relative size, morphology and condition of the teeth in regard to enamel quality and quantity may also be factors that caused variations amongst these patients, although these variations were not within the scope of this study. Within the non-orthodontic groups, more than 25 EPT units separated the response levels reported by the participants. The range for the orthodontic group was considerably large, at over 39 EPT units. Comparison between the two groups at baseline showed considerable differences between the mean values for tooth type, with the overall mean for the orthodontic group 5.8 EPT units higher than that of the non-orthodontic group. This disparity may be partly attributed to the fact that the control group was slightly older than the orthodontic group reflecting differences in the maturational status of the teeth between the two groups. Root formation for maxillary incisors and canines is usually complete by 11 and 16 years of age, respectively, but narrowing of the apical foramen may continue for some time after that (Moorrees *et al.* 1963). The dental pulp becomes progressively innervated during root formation and may not be fully developed until 4 or 5 years post-eruption (Johnsen 1982) even if the apex appears closed (Klein 1978). As a tooth's response threshold is positively correlated with neural density, it is expected that younger subjects would require a greater stimulus to provoke a response (Bender *et al.* 1989). As the maturation of lateral incisors is somewhat later than centrals, and canines are later than both, this may also explain their higher response threshold, particularly in the younger orthodontic group. The mean age of the control group was higher than the orthodontic group because the younger patients seeking orthodontic treatment in the Royal Medical Services centres have the priority for treatment than older patients, that is why the control group was selected from other dental specialties clinics.

The application of the orthodontic force was a significant factor in determining a response threshold to EPT. At Time 1, 2 h after the bonding of orthodontic appliances and ligation of the initial archwire, the mean response threshold increased, as did the number of teeth failing to respond at all. Fulling & Andreasen (1976), however, found that, provided the probe was not in contact with the orthodontic appliances, the 'electrometric pain threshold' of teeth did not change. If contact with the orthodontic bracket was made, the threshold increased or no response was elicited depending upon the type of the tester used.

In establishing the protocol for the present study, if the probe of the Analytical Technology Vitality

Scanner or the conductive medium were allowed to contact the orthodontic bracket, the response was always negative. The change in response threshold experienced in this study group may be the result of pressure or tension on apical nerve fibres. Others have found that orthodontic force has an immediate effect upon vascularity leading to hypoxia of the pulpal tissues (Hamersky *et al.* 1980, McDonald & Pitt Ford 1994). Pulpal A fibres have been shown to have an elevated response threshold in hypoxia conditions, whereas C fibres are much less affected. These C fibres, however, always have an inherently higher response threshold (Jyvasjarvi *et al.* 1986). The continued rise in response threshold seen in the orthodontic group in this study after the application of force peaked at day 60 (Time 3). The number of teeth failing to respond also peaked at day 60. Clinically, this appears to coincide with the time required to achieve initial levelling and alignment of the arches, and perhaps, force levels on the teeth begin to dissipate after that. Lateral incisors appear to be affected to a greater magnitude and duration than central incisors, whilst canines appear to be the least affected. This may be attributed to the smaller size and root surface area of the lateral incisors, and the bigger root surface area of the canines.

Pulpal responses to thermal testing did not demonstrate the same degree of variation. The more negative response rate to Endo Ice® was noted after 60 days of orthodontic force application; however, 97% of teeth still responded positively.

The control group used in this study provided useful information about the normal range and mean response threshold for different teeth and the variability that exists amongst young adults. Comparisons with the orthodontic treatment group, however, were not optimal. Ideally, the two groups should at least contain the same number of subjects matched for age. The reproducibility of responses given by these teeth for both same-day tests and for tests carried out throughout the trial demonstrated very little variations.

Conclusions

The application of an orthodontic force increased the response threshold to EPT, to the extent that many teeth were completely unresponsive. The effect was almost instantaneous and was demonstrated maximally 2 months after force application. Thresholds gradually returned to the pre-treatment values towards the end of the observation period.

Tooth responses to thermal testing with Endo Ice® were much less affected. For the dental practitioner seeking to evaluate the pulpal status of a tooth concurrently receiving orthodontic treatment, results from electric pulp testers should be interpreted cautiously. Negative responses may be positively correlated with pulpal necrosis in the general population, but not for the orthodontic patient. Thermal testing with Endo Ice® would provide a more reliable mean of assessing pulp vitality. For the orthodontist, it is apparent that the application of a sustained force to the teeth not only results in an inflammatory reaction within the periodontium but also has a significant effect on pulpal neural responsiveness, possibly for the entire duration of orthodontic treatment.

A further study to record the response times will be conducted in the near future in an attempt to evaluate the conduction velocities and to indicate the type of the responding fibres.

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