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Original Article

Pulp-test responses in orthodontic patients

S. G. Cave
BDS, MDSc
Specialist practice, Orthodontics
Newcastle
Australia

T. J. Freer
BDSc, DipORTH, FDS, FRACDS, FICD, PhD
Professor of Orthodontics
Dental School
The University of Queensland
Australia

H. M. Podlich
BSc(Hons), PhD
School of Land and Food Sciences
The University of Queensland
Australia

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-test stimuli. Thirty-three subjects commencing fixed orthodontic treatment and another 15 subjects not undergoing orthodontic treatment were used in this study. Cold and electrical stimuli were applied to the maxillary incisor teeth prior to treatment, after the placement of fixed appliances and at regular intervals for both groups for up to 252 days. At baseline, response thresholds to electric testing were typically higher for orthodontic subjects, particularly for the lateral incisors. For the non-orthodontic group, the response threshold over the 252 days was relatively constant. For the orthodontic group, application of force immediately increased the response threshold to electric pulp testing, which peaked after two months. By day 252, response means for lateral incisors still remained elevated. Responses to thermal testing were more consistent and reliable. The results of this study indicate that dental practitioners should interpret responses to electric pulp testing cautiously in orthodontic patients and that thermal testing with carbon dioxide snow may be more reliable.
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Introduction

The health and integrity of the dental pulp is of major importance to the orthodontist and general practitioner alike. The diagnosis of orofacial pain is often challenging and is particularly difficult in the patient undergoing orthodontic treatment. Pulp "vitality" testing, both electric and thermal, is an invaluable aid to the clinician in the assessment and diagnosis of pulpal pathology, though false results may be obtained.[1-3] Prior knowledge of the circumstances that are likely to produce erroneous results would be of great benefit.

Sensory innervation of the pulp is provided by myelinated "A" fibres, and unmyelinated "C" fibres. The A fibres include both β and δ types. βδ fibres may be slightly more sensitive and convey pressure and touch sensations, whereas δ fibres transmit pain and temperature as well as touch. In the dental pulp, these fibres may only be involved in dentinal sensitivity[4] and are principally found at the pulpal-dentinal junction. 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 five years post-eruption.[5] This is thought to be one reason for the unreliability of electric pulp testing (EPT) in immature teeth.[6] 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. The pulpal horns are known to have the greatest density

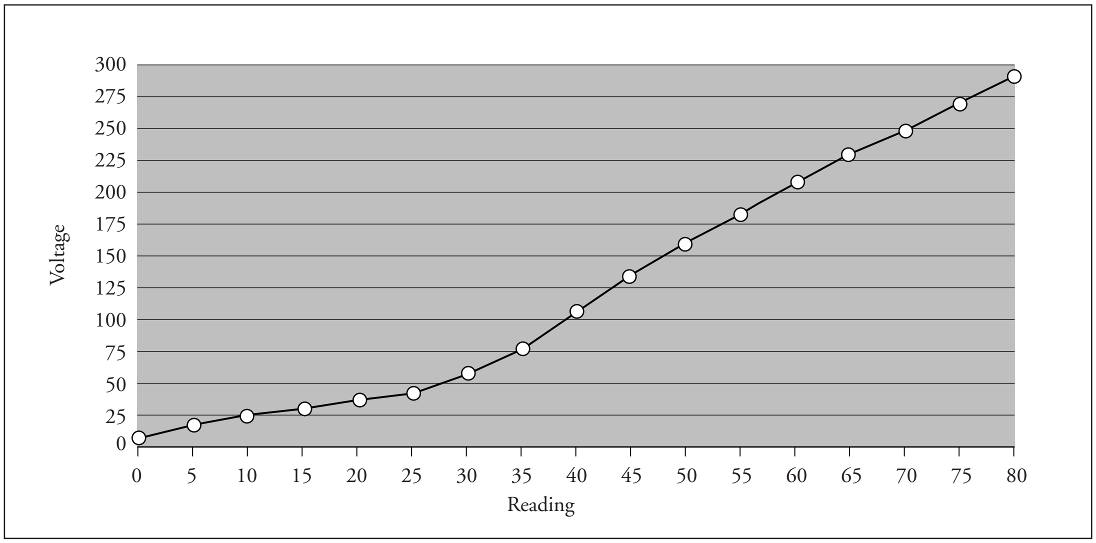

Figure 1. Reading on Analytical Technology vitality scanner scale graphed against voltage output (volts).

of nerve endings[7] and the incisal edges have been shown to be one of the most responsive places to test electrically.[8]

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 will be given before the C fibre threshold is reached.[9]

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.[10] Moreover, C fibres might still be able to respond in a diseased pulp in the presence of hypoxia,[11] and would actually be stimulated by inflammatory mediators such as histamine and bradykinin.[12]

Recently traumatised teeth are known to be unresponsive to EPT shortly after the insult, but the responsiveness often returns over time.[13] The duration may depend on the type of injury and it has been empirically stated that a latency period of up to six weeks should be allowed before assuming loss of vitality based on a negative response to EPT.[14]

Orthodontic movement of teeth has been shown to produce changes in tissue respiration within the pulp[15] as well as an inflammatory process within the periodontium. One study suggests that within the pulp, there is an initial decrease in blood flow upon force application, followed by a reactive hyperaemia 30 minutes later before returning to normal after 72 hours.[16] During orthodontic treatment, the testing of pulpal vitality is also thought to be unreliable,[17,18] but no studies have documented the long-term changes in pulpal response from pre-treatment values. Studies thus far have demonstrated a decreased or total lack of response to EPT during orthodontic force application;[17,18] however, there is little evidence to suggest that orthodontic treatment routinely alters pulpal physiology permanently.[19] Such information would be of value to the practitioner faced with the challenge of diagnosing pathology in a tooth concurrently 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 compare the efficacy of both thermal testing and EPT in determining tooth vitality and to investigate if the application of orthodontic force with fixed appliances could alter a tooth's responsiveness to pulp tests in a predictable manner.

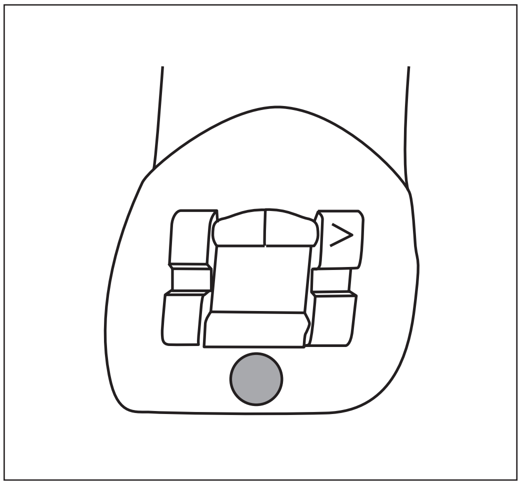

Figure 2. The point of application of electrical pulp tester and Odontotest dry-ice unit.

Materials and methods

A younger group of orthodontic patients was compared and contrasted with an older non-orthodontic group at various stages of treatment for a period of 252 days. The orthodontic group consisted of 33 subjects: 12 males and 21 females ranging in age from 9.8 to 29 years (mean 14.4 years) about to commence fixed orthodontic treatment at the Dental School of the University of Queensland, Australia*. Each subject underwent electric and thermal testing of the four maxillary incisor teeth as they are single rooted, easily accessible and have been shown to be most at risk of traumatic injury or loss of vitality in the general population.[20] The tests were performed immediately prior to bonding of orthodontic brackets (Time 0), immediately after bonding and ligation of the initial archwire (Time 1), then 28 ± 7 days (Time 2), 56 ± 7 days (Time 3), 100 ± 14 days (Time 4), 168 ± 14 days (Time 5) and 252 ± 14 days (Time 6) after initiation of tooth movement.

The non-orthodontic group consisted of 15 subjects: 7 male and 8 female ranging in age from 14 years to 27.3 years (mean 21.7 years) not undergoing orthodontic treatment. These subjects were tested at Times 0, 2, 4 and 6.

A total of 192 teeth were tested (132 orthodontically-treated and 60 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.

Electrical stimulation was provided by an Analytical Technology vitality scanner† using toothpaste as the conduction media. The technical specifications of this device are described elsewhere.[21,22] This electric pulp tester was chosen because of its ease of use, its clinical popularity and because it has been shown to produce threshold sensations that are not painful.[23] It is activated when the probe tip is placed upon the patient's tooth and a circuit is created when the patient contacts the mantle with the 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 upwards on the 0-80 EPT unit scale (Figure 1). The slower increase at the beginning is believed to be important for patient comfort.[21] The sweep rate controls the rate of increase of the stimulus intensity, but not the intensity itself. For this trial the rate was set at 3, at which it takes 35 seconds to achieve peak voltage and therefore gives the subject ample time to recognise the stimulus before it becomes painful. It has also been shown that a slow and consistent increase in stimulus intensity is important for accurate and reproducible readings.[24] 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.

All testing was carried out with the same EPT unit. Each tooth was carefully isolated with cotton rolls and dried thoroughly prior to testing to ensure pulpal not periodontal nerve fibre stimulation. The tip of the probe was coated with toothpaste and applied to the labial surface of the tooth in the incisal third, mid-way mesio-distally (Figure 2). This has been shown to be the most effective site to test electrically because of its close proximity to the highly innervated pulp horns[8] 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 worn incisal edges of any teeth or the orthodontic brackets in the orthodontic group. The patient was instructed to grasp the probe mantle to complete the circuit and initiate the test and to release the EPT device when a sensation was felt. 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 Figure 1. The order of testing was the upper right lateral incisor first, then the upper right central incisor, the upper left central incisor and finally the upper left lateral incisor (teeth 12, 11, 21 and 22). Testing was repeated after a 2-minute rest interval to reduce subject fatigue

* This project received approval from the University of Queensland Ethics Committee. All subjects gave their informed consent to participate in the project.

† Analytical Technology Corporation, Redmond, Washington, USA.

Table I. Incidence of negative response to electric testing at each time interval: orthodontic group.

Time (day)	Tests*	Teeth	Negative responses					
			Centrals		Laterals		Total	
		Tests	Teeth	Tests	Teeth	Tests (%)	Teeth (%)	
0 (0)	264	132	0	0	2	1	2 (0.76)	1 (0.76)
1 (0)	264	132	7	2	14	5	21 (7.95)	7 (5.30)
2 (28)	240	120	10	2	17	5	27 (11.25)	7 (5.83)
3 (56)	240	120	19	7	27	10	46 (19.17)	17 (14.17)
4 (100)	216	108	14	5	23	9	37 (17.13)	14 (12.96)
5 (168)	240	120	11	2	27	10	38 (15.83)	12 (10.00)
6 (252)	232	116	3	0	18	6	21 (9.05)	6 (5.17)

* Each tooth was tested twice with the EPT at each time interval.

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

Time	Tooth 12 Mean	SE	Tooth 11 Mean	SE	Tooth 21 Mean	SE	Tooth 22 Mean	SE	Combined Mean	SE
0	27.40	1.5	24.93	1.5	27.43	1.4	29.33	1.2	27.28	0.7
2	26.63	1.3	22.83	1.9	26.43	1.2	27.93	1.3	25.96	0.7
4	25.92	1.6	25.33	1.8	26.88	1.3	28.29	1.6	26.60	0.8
6	28.27	1.5	25.50	2.2	27.50	1.5	29.77	1.5	27.76	0.8

and minimise the possibility of nerve accommodation. Each reading was recorded as Test 1 or 2. Teeth that failed to respond to electric testing were recorded as a reading of 80 EPT units.

Thermal stimulation was provided by a stick of compacted carbon dioxide crystals (CO_2) produced in an Odontotest‡ dry-ice pencil, the temperature of which was -78°C at the tip. The dry ice was also applied to the test teeth in the mid-incisal third. 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 minutes apart.

The data collected from the orthodontic and non-orthodontic groups were grouped by subject, tooth and time (day), and also EPT readings. An analysis of variance was performed on the EPT responses from both the orthodontic and non-orthodontic groups. The number of negative responses to thermal stimulation were also compared.

‡ Odontotest. Fricar, A G. Zurich, Switzerland.

Results

The significance of the EPT responses on teeth in the orthodontic and non-orthodontic groups was tested using analysis of variance. There were 440 electric pulp-tester readings and 220 thermal vitality tests for the non-orthodontic group. All teeth tested positively to the EPT and CO_2 at all test intervals (Time 0, 2, 4, 6). For the orthodontic group, a total of 1696 electric tests were performed on 132 different teeth over the 252-day trial. The frequency of negative responses depended upon the time in treatment (Table I). At baseline (Time 0), only a single tooth in the entire orthodontic sample failed to elicit a response. After bonding of fixed appliances and ligation of the initial archwire, a further six teeth (5.3%) of the total teeth tested, were unresponsive to the electric pulp tester after the two applications (Tests 1 and 2). Fifty-six days (Time 3) after the application of orthodontic force on the maxillary incisors, 17 teeth (14.2%) of the total teeth tested, failed to respond. From this peak, responsiveness was seen

Table III. Mean response threshold at each test interval: orthodontic group.

Time	Tooth 12 Mean	SE	Tooth 11 Mean	SE	Tooth 21 Mean	SE	Tooth 22 Mean	SE	Combined Mean	SE
0	41.96	1.4	35.47	1.5	35.32	1.4	38.99	1.2	37.93	0.8
1	47.65	2.4	38.08	2.0	40.92	1.9	42.64	2.2	42.32	1.1
2	53.30	2.6	43.17	2.3	47.47	2.3	45.80	2.4	47.43	1.2
3	54.70	2.4	47.58	2.4	48.65	2.5	51.85	2.6	50.70	1.2
4	53.24	2.8	43.26	2.8	39.28	2.3	46.02	2.7	45.45	1.4
5	54.10	2.6	41.85	2.3	42.62	2.0	49.07	2.7	46.91	1.2
6	51.19	2.5	39.62	1.7	40.67	1.9	46.36	2.2	44.46	1.1

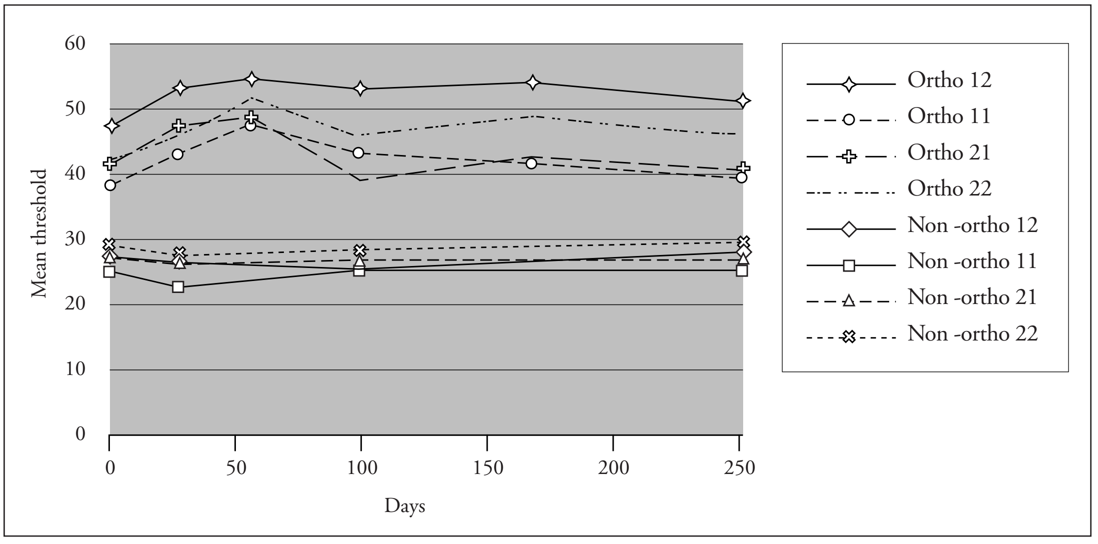

Figure 3. Relationship of EPT response to time.

to return at each time interval so that on day 252, only six teeth (5.2%) still tested negative to EPT. The number of lateral incisors failing to respond was greater than central incisors at all time intervals.

A total of 848 thermal tests were performed on 132 teeth in the orthodontic group. Only five negative responses were recorded, one at Time 0, three at Time 1 and one at Time 2. Four of these negative responses were found in the same patient, but the teeth in question responded positively to the CO_2 on later days of the trial, and appeared normal both clinically and radiographically and therefore were considered vital. On a per-tooth basis, the overall positive response rate to thermal testing was 99.41 per cent.

The analyses of variance show that there is considerably more variation apparent in the EPT responses of the orthodontic group, with root mean square errors between 1.5 and 2 times higher than that of the non-orthodontic group. At baseline, mean pulp tester values of subjects ranged from 13.9 to 58.8 EPT units (mean 37.9) for the orthodontic group and from 16.1 to 29.0 EPT units (mean 27.3) for the non-orthodontic group. Investigations within each group revealed the mean response threshold at baseline decreased with increasing subject age ($P < 0.01$) for the orthodontic group, but there was no correlation ($P > 0.05$) between age and threshold for the non-orthodontic group.

Statistical comparison of the mean EPT at baseline between the two groups, using the Error I mean squares, shows significant differences for each tooth type ($P < 0.0001$). The mean response thresholds are between approximately 8 and 15 EPT units higher in the younger orthodontic group (Tables II and III). The baseline means for lateral incisors tended to be higher than for central incisors in each group, but the difference was only significant for the orthodontic group.

The mean pulp-tester readings for the non-orthodontic group at each time interval differ by less than two EPT units over the 252-day trial (Table II). In contrast, the range of the overall time means for the orthodontic group is 12.8 EPT units (Table III). Also, the tooth-by-time interaction was significant for the orthodontic group ($P < 0.0001$), implying the time effect varies according to the tooth type. 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 2.6 and 5.7 EPT units (Table III, Figure 3). As treatment progressed, the means continued to rise for each tooth until day 56 (Time 3), where they peaked at between 12.1 and 13.3 EPT units higher than their pre-treatment levels (Time 0). By day 252 (Time 6), the central incisors approached their means after placement of fixed appliances, but the lateral incisors remained elevated.

Discussion

The results of this study indicate that both carbon dioxide snow and electric pulp testers are reliable when used to test the vitality of teeth in teenagers and young adults. For the older non-orthodontic group, all teeth tested positive to both forms of testing at all stages of the trial. For the younger orthodontic group, only two negative responses were recorded prior to the application of orthodontic force: one to electric, the other to thermal. In both these cases, the teeth did respond positively to the other form of testing. The findings are in general agreement with others.[2, 6] Fulling and Andreasen[2] and Fuss *et al.* found a 100 per cent response rate for electric testing, and over 97 per cent for thermal testing with CO_2 in patients of ages comparable to those in this study.[2,6]

Comparisons of baseline mean response thresholds as recorded using the electric pulp tester showed considerable variation among subjects in both the orthodontic and non-orthodontic groups. The concept that people have different 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 among these patients. Within the non-orthodontic group, more than 20 EPT units separated the most and least "sensitive" participants. The range for the younger orthodontic group was considerably larger, at over 44 EPT units. Comparison between the two groups at baseline showed significant differences between tooth-type means, with the overall mean for the orthodontic group 10 EPT units higher than that of the non-orthodontic group. This disparity may be partly due to the differences in the maturational status of the teeth between the two groups. Root formation for maxillary incisors is usually complete by 11 years of age, but narrowing of the apical foramen may continue for some time after that.[25] The dental pulp becomes progressively innervated during root formation and may not be fully developed until four or five years post-eruption,[5] even if the apex appears closed.[3] As a tooth's response threshold is positively correlated with neural density,[8] it is expected that younger subjects would require a greater stimulus to provoke a response. As the maturation of lateral incisors is somewhat later than centrals, this may also explain their higher response threshold, particularly in the younger orthodontic group.

The results of this study indicate that the application of an orthodontic force is a significant factor in determining a response threshold to EPT. Immediately 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. One explanation could be that the current from the pulp tester was allowed to drain off to the other teeth via the archwire. Fulling and Andreasen, however, found that, provided the probe was not in contact with the orthodontic appliances, the "electrometric pain threshold" of teeth did not change.[2] If contact was made, the threshold increased or no response was elicited, depending upon the type of electric tester used. In establishing the protocol for the present study, it was observed that 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 the orthodontic force has an immediate effect upon pulpal vascularity and consequently leads to hypoxia of the pulpal tissues.[15,16] Pulpal A-fibres have been shown to have an elevated response threshold in hypoxic conditions,[10] whereas C-fibres are much less affected. These C-fibres, however, always have an inherently higher response threshold.[26]

The continued rise in response threshold seen in the orthodontic group in this study after the application of force peaked at day 56. The number of teeth failing to respond at all also peaked at day 56. 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 thereafter. Lateral incisors appear to be affected to a greater magnitude and duration than central incisors. After 252 days of orthodontic treatment, the central incisor response threshold decreased towards the levels seen on the day of initial force application, whereas the lateral incisors' thresholds remained elevated. This may be due to the smaller size and root surface area of the lateral incisor, which equates to greater pressure at its apex.

Pulpal responses to thermal testing did not demonstrate the same degree of inconsistency. The worst response rate to carbon dioxide snow was noted immediately after orthodontic appliances were bonded and archwire ligated; however, 97.7 per cent 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 among young adults. Comparisons with the orthodontic treatment group in this study, however, were not optimal. Ideally, the two groups should at least contain the same number of subjects matched for age and measured at all time intervals. The reproducibility of responses given by these teeth for both same-day tests and for tests up to 252 days later demonstrates very little variation due to instrument or procedural error.

Conclusions

The threshold response to EPT varied depending on the type of tooth, the age of the patient and the presence of orthodontic appliances. Maxillary lateral incisor teeth had a higher response threshold than maxillary central incisor teeth.

The application of an orthodontic force dramatically increases the maxillary incisor's response threshold to EPT, to the extent that many teeth are completely unresponsive. The effect is almost instantaneous and is maximally demonstrated two months after force application, but thresholds may still be elevated up to nine months later, particularly for lateral incisors. Tooth responses to thermal testing with carbon dioxide snow are 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 carbon dioxide snow may provide a more reliable means 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.

Address for correspondence and reprints:

Professor T. J. Freer
The University of Queensland
School of Dentistry
200 Turbot Street,
Brisbane
Queensland 4000
Australia
Email: t.freer@mailbox.uq.edu.au

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