

A COMPARISON OF MONOPOLAR AND BIPOLAR ELECTRICAL STIMULI AND THERMAL STIMULI IN DETERMINING THE VITALITY OF HUMAN TEETH

A. B. MOODY,¹ R. M. BROWNE² and P. P. ROBINSON^{1,3*}

¹Department of Oral Surgery, Dudley Road Hospital, Birmingham B18 7QH, department of Oral Pathology, Birmingham Dental School, Birmingham B4 6NN and departments of Oral Surgery & Oral Medicine and Physiology, Birmingham Medical & Dental Schools, Birmingham B1 5 2TJ, England

(Received 1 September 1988; accepted 30 March 1989)

Summary —The sensory threshold was determined for 50 teeth in 31 patients using constant-current stimuli of 0.1, 1.0 and 10 ms duration at 10 Hz through both monopolar and bipolar electrodes. The teeth were also tested with a cold stimulus (ethyl chloride on cotton wool), then extracted, processed and examined by light microscopy. Histologically, 38 teeth were vital and 7 non-vital. The best prediction of vitality was from ethyl chloride (80% correct) or bipolar stimuli of 10 ms duration and up to 200 μ A (73% correct). The remaining 5 teeth had vital radicular pulps and necrotic tissue coronally, but a comparison between the results of monopolar and bipolar stimulation did not permit the detection of this group. There was no correlation between the electrical threshold and presence of caries, restorations, pulp stones or diffuse pulpal mineralization.

INTRODUCTION

A reliable method for determining the vitality of tooth pulps would be of immense value in the diagnosis of dental and facial pain, but none of the methods commonly used in clinical practice is entirely satisfactory as they may give misleading results. Attempts have been made to determine vitality by mean of tooth surface temperature (Fanibunda, 1986), transillumination (Hill, 1986), u.v. light photography (Foreman, 1983), or a Doppler flow probe (Gazelius *et al.*, 1986), but the most frequently used tests determine whether a sensation is evoked by a thermal or electrical stimulus to the tooth crown. Such thermal stimulation will excite nerves within the pulp but it may be difficult to exclude that it is not being detected by receptors in the gingival margin, periodontal ligament or adjacent teeth.

Electrical stimuli can be applied with a monopolar instrument (one electrode on the tooth and the indifferent electrode usually held in the patient's hand) or a bipolar instrument (in which the current is passed between two electrodes both on the crown of the tooth). With monopolar stimulation, current passes through the dentinal tubules beneath the electrode, the coronal pulp and the root pulp. Based on the expected current density in this pathway, Mumford and Newton (1969) have suggested that nerves may be excited at either the pulp-dentine junction or the apical foramen, although the density is likely to be highest in the dentinal tubules under the electrode and lowest in the root pulp (Matthews, Horiuchi and Greenwood, 1974a).

The criteria for the design of monopolar pulp testers have been described by Matthews and Searle (1976). Unfortunately many of the commercially available instruments do not fulfil these criteria (Matthews and Searle, 1974; Dummer, Tanner and McCarthy, 1986) and may give false positive results (indicating that a tooth is vital when it is not) from stimulation of nerves in the gingival margin or periodontal ligament (Matthews *et al.*, 1974b). A specially constructed constant-current monopolar stimulator with stimuli of less than 150 μ A has been found to give no false positive results (Matthews *et al.*, 1974b), but may, however, give false negative results if nerves are confined to regions of low current density, as in the root pulp; larger currents may carry the risk of exciting extra-pulpal nerves (Björn, 1946; Matthews, Baxter and Watts, 1976).

Bipolar electrical stimulation has been used only experimentally (Matthews *et al.*, 1974a; Hannam, Siu and Tom, 1974; Robinson, 1987); the current is largely confined to the tooth crown with little spread to either the root pulp or adjacent tissues. The highest current density is, once again, in the dentinal tubules. It seems likely, therefore, that larger currents could be passed with a bipolar stimulator (decreasing the incidence of false negatives) without risk of stimulating nerves outside the pulp, but this proposal has not been tested clinically.

The majority of studies on electrical stimulation of teeth have used stimuli of 10 ms at a frequency of 10 Hz (e.g. Björn, 1946; Matthews *et al.*, 1974b). In animal experiments stimuli of 0.1 or 1.0 ms are capable of exciting the majority of nerves within the pulp (Cadden, Lisney and Matthews, 1983; Virtanen, 1985). The possible advantage of using shorter stimuli for vitality testing has not been examined.

Many investigations into pulp testing methods have used normal anterior (e.g. Hannam *et al.*, 1974;

* Address correspondence to: Professor P. P. Robinson, Department of Oral and Maxillofacial Surgery, The Charles Clifford Dental Hospital, Wellesley Road, Sheffield S10 2SZ, England.

Abdel-Waheb and Kennedy, 1987) or premolar (Fuss *et al.*, 1986) teeth in young volunteers, rather than the carious or heavily restored teeth that frequently require testing clinically in patients of all ages. Accurate assessment of the results obtained from teeth of uncertain vitality must also be dependent upon histological inspection of the tooth pulp, but few studies have involved this method (Seltzer, Bender and Ziontz, 1963; Johnson, Dachi and Haley, 1970; Matthews *et al.*, 1974b; Fuss *et al.*, 1986; Hill, 1986). We have therefore now sought to compare the sensory thresholds of teeth using monopolar and bipolar electrical stimuli of different durations with the results of testing with a cold stimulus, and to correlate the findings with the histological appearance of the pulp.

MATERIALS AND METHODS

Fifty teeth that required extraction were studied in 31 patients (20 male, 11 female) with a mean age of 53 (range 20-80) years. Tests were carried out with the informed consent of each subject and after local Ethical Committee approval. For each tooth the presence of caries or any restoration was noted; the crown was then dried with either cotton wool or a brief stream of air and isolated with cotton-wool rolls. For electrical stimulation, a specially made constant-current stimulator of similar design to that described by Matthews and Searle (1976) was used. This instrument delivered rectangular pulses at a rate of 10 Hz and had a maximum available voltage of 300 V.

Monopolar cathodal stimuli were applied to intact enamel on the buccal tooth surface using a circular metal electrode of 3 mm diameter, smeared with a thin layer of toothpaste to ensure good electrical contact (Matthews *et al.*, 1974b). The indifferent electrode was held in the patient's hand. Bipolar stimuli were applied with electrodes similar to those illustrated by Matthews *et al.* (1974a). The 2 metal electrode tips (each 3 mm dia) were smeared with toothpaste and applied to enamel on opposite sides of the tooth crown. For both types of electrical stimulation the intensity was gradually increased until the patient reported a sensation. The mean of two threshold values was recorded for stimuli of 0.1, 1.0 and 10 ms.

The cold stimulus was applied to intact enamel, usually on the buccal surface, using a small pledget of cotton wool (approx. 4 mm dia) sprayed with ethyl chloride until it became frosted. Care was taken to avoid stimulating the gingival margin and adjacent teeth.

After the tests were completed, local anaesthetic was administered and the tooth was extracted and fixed immediately in 10% neutral buffered formalin. After demineralization in 10% formic acid, the tissue was paraffin-embedded and 9 μ m, haematoxylin- and eosin-stained, longitudinal sections cut. Representative sections covering the entire pulp cavity were examined under the light microscope. This examination was done without prior knowledge of the clinical tests; it assessed the vitality of the coronal and radicular sections of the pulp. Vitality was assumed

if the pulp cavity contained cellular pulp tissue. The presence of inflammatory changes, abscess formation and pulp calcifications was also noted.

RESULTS

Of the 50 teeth tested, 30 were clinically sound, 11 had been restored, 7 were carious and 2 were both restored and carious.

Histology

Although the preservation of the pulp was not always perfect, artefactual changes were never so marked as to prevent a simple evaluation. Of the 50 teeth tested, 38 contained vital tissue in the coronal and radicular pulp. In a group of 7 teeth, the entire pulp was necrotic and, in 5 others, extensive areas of the coronal pulp were necrotic but the radicular pulp contained vital tissue. For further analysis of the results the teeth were divided into those 3 groups. The pulps of 18 of the vital teeth contained either pulp stones or diffuse mineralizations and some of them showed varying degrees of acute and chronic inflammation. The extent of secondary dentine formation was extremely variable, sometimes occluding most of the coronal pulp chamber.

Monopolar electrical stimulation

The sensory thresholds to electrical stimulation are shown in Fig. 1. Predictably, the thresholds of individual teeth usually decreased as the stimulus duration increased (Fig. 2). Failure to observe this relationship, in some instances, may have resulted from slight repositioning of the electrodes between tests. Monopolar stimuli of 0.1 ms at 10 Hz failed to evoke any sensation from 5 of the vital teeth. Because of the high impedance of enamel and the limit of 300 V from the stimulator, it was not always possible to increase the stimulus intensity up to 1.0 mA in the teeth that failed to respond, and this was indicated by an overload light on the instrument. All of the vital teeth responded to stimuli of either 1.0 or 10 ms. Teeth with a non-vital coronal pulp but vital radicular pulp had a wide range of thresholds, and one sound upper central incisor with a completely necrotic pulp appeared to respond to monopolar stimuli of less than 150 μ A at all three stimulus durations. It was therefore not possible to set a limit to the stimulus intensity that would satisfactorily distinguish all of the non-vital teeth from the majority of the vital teeth, or discriminate those with necrotic pulps coronally. When a limit of 150 μ A was taken, the number of teeth that responded in each group is shown in Table 1. The correlation (using Pearson's correlation coefficient) between the teeth that responded below 150 μ A and the histological determination of vitality (omitting the teeth with partly vital pulps) was: 0.1ms— $r=0.21$, $p>0.1$; 1.0ms— $r=0.26$, $p>0.05$; 10 ms— $r=0.34$, $p<0.05$. There was no correlation between the threshold of the vital teeth to stimuli of 10 ms and the presence of pulp stones or diffuse mineralizations ($r=0.08$, $p>0.05$), or to the presence of caries or a restoration ($r=0.19$, $p>0.1$).

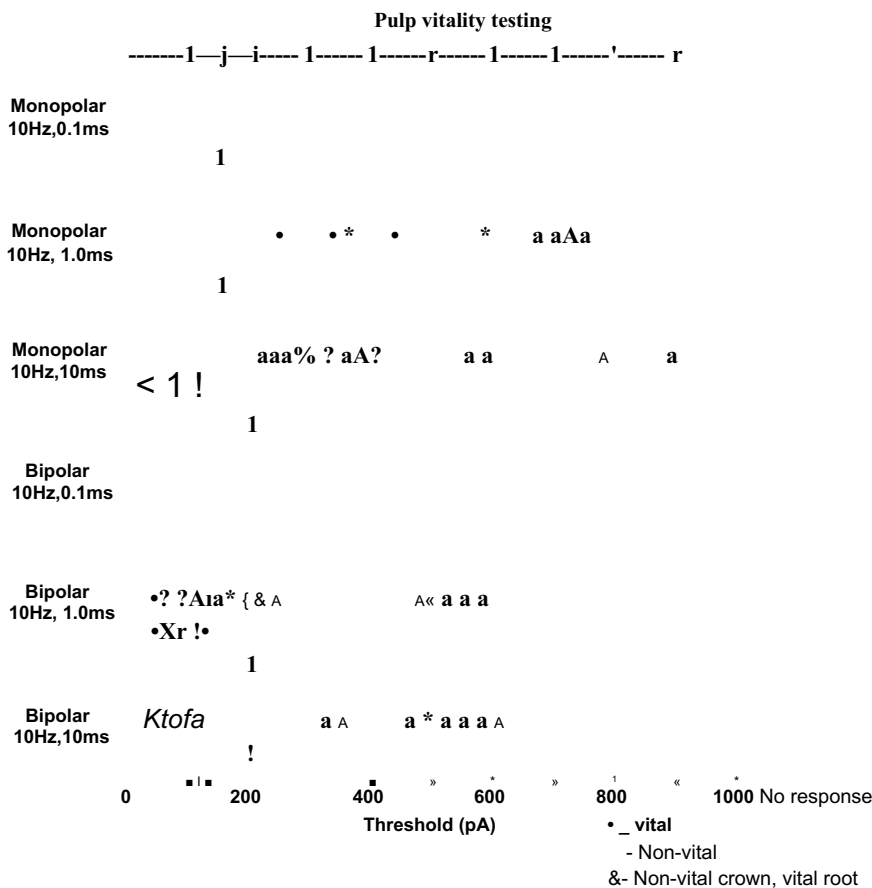


Fig. 1. The sensory thresholds of the vital, non-vital and partly vital teeth to each of the electrical stimuli. The number of teeth from which a response could not be obtained is indicated on the right. The dotted lines are the possible limits for monopolar (150/zA) or bipolar (200/zA) stimuli.

Bipolar electrical stimulation

The sensory thresholds to this are shown in Fig.1, and the relationship between threshold and stimulus duration for individual teeth is shown in Fig. 2. It was not always possible to increase the stimulus intensity up to 1.0 mA in teeth that failed to respond, but a current of at least 200 pA could always be passed. No sensation could be evoked from 9 of the vital teeth with stimuli of 0.1 ms or from 6 and 5 teeth with stimuli of 1.0 and 10 ms, respectively. Teeth with a non-vital coronal pulp but vital radicular pulp had a wide range of thresholds, some less than 200 pA, and one non-vital tooth (the same central incisor that responded to low-intensity monopolar stimulation) responded to bipolar stimuli of less than 200 pA at all three stimulus duration. As with monopolar stimulation, it was therefore not possible to set a limit to the stimulus intensity that would distinguish all of the non-vital teeth from most of the vital teeth, or discriminate those with necrotic pulps coronally. When a limit of 200 pA was taken, the number of teeth that responded in each group is shown in Table 1. The correlation between the teeth that responded below 200 pA and the histological determination of vitality (omitting the teeth with partly vital pulps) was: 0.1 ms— $r = 0.23$, $p > 0.1$; 1.0 ms— $r = 0.34$, $p < 0.05$; 10 ms— $r = 0.42$, $p < 0.01$. There was no correlation between the sensory threshold of those vital teeth that responded to stimuli of 10 ms

and the presence of pulp stones or diffuse mineralizations ($r = 0.01$, $p > 0.5$), or to the presence of caries or restorations ($r = 0.04$, $p > 0.5$).

Thermal stimulation

Of the 38 vital teeth, 31 responded to testing with ethyl chloride. Two of the 7 non-vital teeth and 1 of the 5 teeth with a non-vital coronal pulp also responded to the cold stimulus (Table 1). The correlation between the teeth that responded to this stimulus and the histological determination of vitality (omitting the teeth with partly vital pulps) was: $r = 0.43$, $p < 0.01$.

DISCUSSION

From electrical stimulation at 10 Hz, the best prediction of tooth vitality was obtained with bipolar stimuli of 10 ms duration and up to 200/zA in intensity. This test gave a correct prediction of vitality for 73% of the teeth. Monopolar stimulation with stimuli of 10 ms and up to 150 pA gave a correct prediction of vitality for only 64% of teeth, a value almost exactly the same as that reported by Matthews *et al.* (1974b) using a similar instrument. Bipolar stimuli of 1.0 ms and up to 200 pA gave a similar result, and the other electrical stimuli tested were less successful. The sensory thresholds of vital teeth were usually higher for shorter stimuli, as would be expected from a normal strength-duration relationship

Fig. 2. The relationship between sensory threshold and stimulus duration for 10 teeth, using monopolar and bipolar electrodes.

and as previously reported by Mumford (1965) and Virtanen (1985). There was no evidence to suggest that shorter stimuli of a higher intensity would be any better at discriminating between vital and non-vital teeth than the 10 ms stimuli that are more commonly used. Thus, our results confirm that electrical stimulation cannot always distinguish between vital and non-vital teeth when used on a range of anterior and posterior teeth, some with caries or large restorations. Kitamura, Takahashi and Horiuchi (1983) tested an instrument that did not have a constant-current output stage (Dummer *et al.*, 1986): they reported 100% accuracy in distinguishing between vital and root-filled teeth and only 4 false negatives out of 95 carious or filled vital intact teeth tested. Cooley, Stilley and Lubow (1984) had only slightly less success with the same instrument but neither study confirmed tooth vitality histologically.

Constant-current monopolar stimuli of 10 ms up to 150 μ A have not previously given rise to false positive results (Björn, 1946; Matthews *et al.*, 1974b), but we now found that stimulation of one sound upper central incisor with a completely necrotic pulp evoked

a response. The explanation for this discrepancy is not known as earlier work has suggested that stimuli of more than 200 p.A are needed to excite periodontal nerves (Björn, 1946; Matthews *et al.*, 1976). This incisor also appeared to respond to all of the bipolar stimuli at less than 200 μ A as well as to the thermal stimulus and it is possible that this patient responded inappropriately. However, in the same patient, stimulus intensities of greater than 300 p.A were needed before a response was obtained from another non-vital tooth with any of the electrical stimuli.

Overall, the sensory thresholds obtained using monopolar and bipolar stimuli of 10 ms were generally similar (cf. Hannam *et al.*, 1974; Matthews *et al.*, 1974a; Virtanen, 1985), although higher than values usually reported for healthy teeth (Mumford, 1965; Matthews *et al.*, 1974a). The higher thresholds and the large number of false negative results may have arisen through a significant proportion of the applied current by-passing the pulp because of caries or restorations. There was, however, no evidence to suggest that sound vital teeth had lower thresholds than those with caries or restorations. The histo-

Table 1. The number of teeth in each group that responded to each of the stimuli

	Vital teeth (38)	Non-vital in crown and root (7)	Non-vital crown, vital root (5)
Monopolar, 0.1 ms <150/ μ A	16	1	1
Monopolar, 1.0 ms <150/ μ A	19	1	1
Monopolar, 10 ms <150/ μ A	23	1	3
Bipolar, 0.1ms <200/ μ A	17	1	0
Bipolar, 1.0 ms <200/ μ A	23	1	2
Bipolar, 10 ms <200/ μ A	27	1	1
Ethyl chloride	31	2	1

logical determination of vitality did not specifically ascertain the presence of nerves, which must be present in order to obtain a vital response to these tests. It is, however, extremely unlikely that vital tissue would not be innervated unless some form of nerve injury had occurred.

As monopolar stimulation produces a higher current density in the root pulp than bipolar stimulation, these two tests might have allowed separate assessment of the vitality of the coronal and radicular parts of the pulp, as suggested by Matthews *et al.* (1974a). The results from the 5 teeth with non-vital coronal pulps and vital root pulps did not, however, support this proposal. This is inconsistent with observations made during the reinnervation of transplanted canines, where more teeth responded to bipolar than monopolar stimuli (Robinson, 1987). As we found that some teeth with necrosis of the coronal pulp responded to bipolar stimuli of less than 200 A, there must either have been remnants of vital tissue in the tooth crown or sufficient spread of current during bipolar stimulation to excite nerves within the radicular pulp. The inability to detect teeth with non-vital coronal pulps, as well as the lack of correlation between the sensory thresholds and the presence of pulp stones or diffuse mineralization, confirm that electrical pulp testing cannot reveal the pathological state of the pulp, as others have also concluded (Mumford, 1967; Johnson *et al.*, 1970; Matthews *et al.*, 1974a, b).

Thermal stimulation gave two false positive results, one from the upper central incisor already mentioned and the second from a carious lower first molar. This cold stimulation produced the least false negative results, fewer than found by Robinson (1987), and overall this test gave a correct prediction of vitality for 80% of the teeth. Taking into account simplicity of use and low cost, and providing that great care is taken to keep the stimulus as far as possible from the gingival margin and adjacent teeth, vitality testing with ethyl chloride would appear to be better than with electrical stimulation. As the presence of vital nerves in the dentine or pulp directly beneath the cold stimulus is presumably necessary in order to obtain a response, so electrical stimulation may be preferable for determining the pulp vitality of reimplanted or transplanted teeth (Ohman, 1965; Robinson, 1987). Fuss *et al.* (1986) compared electrical pulp testing with a range of cold stimuli (dichlorodifluoromethane, CO₂ snow, ethyl chloride and ice) applied to apparently healthy premolars. Although tooth vitality was not confirmed histologically, they also found that thermal stimuli gave better results than electrical and that dichlorodifluoromethane or CO₂ snow were the best methods of applying the cold stimulus. The application of CO₂ snow produces minimal damage to the enamel surface (Peters, Mader and Donnelly, 1986).

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