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Electrical Stimulation of Pulp Nerves — Comparison of Monopolar and Bipolar Electrode Coupling

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Summary

In the present study monopolar and bipolar electrode couplings were compared in electrical stimulation of intradental nerves. In experiments on cats the threshold current values of A- and C-fibres and the jaw-opening reflex were measured with both techniques using different durations of current pulses (0.2–50 msec). In human studies the perception and pain thresholds were determined in the same manner. In experiments on anaesthetized cats 170 intradental nerve units were recorded. Of these 118 were A-fibres (conduction velocity (CV) > 2 m/sec) and 52 C-fibres (CV $\leqslant 2$ m/sec). The threshold current values (pulse duration 10 msec) of A-fibres were almost 2-fold (12.2 μA, S.D. = 7.9) and of C-fibres over 2-fold (91.3 μA, S.D. = 52.3) with bipolar stimulation compared to monopolar (6.9 μA, S.D. = 7.3 and 42.5 μA, S.D. = 21.5 respectively). The mean threshold of the jaw-opening reflex obtained with bipolar electrode coupling was about twice the value obtained with monopolar (8.2 μA, S.D. = 3.7 and 3.4 μA, S.D. = 0.7 respectively). In human experiments the mean perception threshold was 11.7 μA (S.D. = 6.7) with bipolar and 7.2 μA (S.D. = 3.2) with monopolar stimulation. The mean pain threshold was also higher with bipolar than with monopolar stimulation, 16.0 μA (S.D. = 8.8) and 10.3 μA (S.D. = 4.5) respectively. The subjective sensations were different with these two electrode couplings; the pain (at pain threshold level) induced by bipolar stimulation was experienced as sharp or cutting and with monopolar stimulation as dull or more indefinite.

It is concluded that there is a marked difference in the electrical threshold values of pulpal nerves and perception threshold of individual human teeth between monopolar and bipolar tooth stimulation. The thresholds of the A-fibres measured from the cat canine tooth closely correspond to the perception thresholds of the

human tooth, but the threshold values of the pulpal C-fibres were significantly higher.

Introduction

Electrical tooth stimulation is used in pulp vitality tests, when studying the innervation of teeth, and in experimental pain research. Almost all pulp testers used in clinical dentistry are monopolar, i.e., one electrode (cathode) is placed on the tooth and the indifferent electrode on some other part of the body. In experimental work on animals and human subjects, however, bipolar electrical tooth stimulation is more commonly used. In bipolar coupling both the cathode and the anode are placed on the tooth surface.

In some studies bipolar stimulation is considered to be more specific than monopolar stimulation in activating only the pulpal nerve fibres [4,5], but it has also been shown that there is no risk of monopolar stimulation activating extrapulpal nerve fibres if the current is below 150–200 μA and the tooth surface is carefully dried [7,9,19,21]. The thresholds reported for human incisors, for example, vary between 2 and 7 μA [8,10,12,13,18,22], and thus the safety margin for monopolar tooth stimulation would appear to be sufficient.

Both monopolar and bipolar stimulation have been used in some experiments, but no significant differences in threshold values have been found between these two electrode configurations [3,5,9]. The experimental set-up and the stimulus parameters vary in different studies, making it difficult or impossible to compare results.

In earlier studies by our group only monopolar electrode coupling was used, because with bipolar stimulation the thresholds were consistently higher. In the present study monopolar stimulation was compared with bipolar stimulation in single unit recordings and threshold measurements of the jaw-opening reflex in experimental animals, and in measurement of perception and pain thresholds in human subjects.

Material and Methods

Nine adult cats (6 female and 3 male) with fully developed permanent teeth were used in the experiments. They were anaesthetized with pentobarbitone sodium (35 mg/kg i.p.). The threshold value of the jaw-opening reflex was measured in response to electrical stimulation of each canine tooth with monopolar cathodal and bipolar current pulses of 0.2–50 msec. The current intensity that triggered the first noticeable movement in the digastric muscle was considered to be the threshold.

For single unit recordings the lower canine tooth was covered with Concise® restorative material. Two holes were then made in opposite sides of this insulator with a high-speed water-cooled drill until the enamel was exposed. Electrodes made of steel cannulae (18-gauge) were fixed into the holes and the tubes were filled with

electrode paste to ensure tight contact with the tooth surface. The inferior alveolar nerve was exposed for nerve recordings. The methods for the dissection and recording of pulp nerve units are described in detail in previous reports [19,20].

In human studies the perception thresholds (the minimum current intensity evoking a sensation) and the pain thresholds (the minimum current intensity evoking a pain sensation) were determined in 6 volunteers, (5 female and 1 male), aged between 22 and 30 years. The test tooth was an intact upper incisor. The electrodes were of the same type as in the animal experiments and were attached with Cyano Veneer ® (Ellman) to the labial and palatinal surfaces of the test tooth. The subjects sat in a reclining dental chair with a supporting headrest. They kept their mouths slightly open so that their lips made no contact with the electrodes. The current intensity was increased manually and the subjects were instructed to open their eyes when they perceived the current (perception threshold), then close them and open them again when they experienced it as painful (pain threshold). The duration of the current pulses in each trial was changed randomly. Three ascending trials were used to determine each threshold value.

A constant current tooth stimulator was used. The duration of current pulses could be varied between 0.2 and 50 msec, and the stimulus intensity between 0 and 500 μA. For studies of conduction velocities 1 msec pulses were used. The electrical resistance between the electrodes was checked 5–10 times during the session to make sure that there was constant contact with the tooth. The resistances of the test teeth in the animal experiments were between 490 and 650 kΩ with monopolar stimulation and between 1 100 and 1 300 kΩ with bipolar stimulation. In human studies the resistances varied from 1.2 to 1.8 MΩ with monopolar stimulation and from 2.6 to 3.2 MΩ with bipolar stimulation. Different electrical resistances (0.47, 1.0, 1.5, 2.2 and 4.7 MΩ) were used in series with the electrodes to ascertain that the current output of the stimulator was constant. The tests were carried out in both animal and human studies. The threshold currents were equal in all measurements in spite of the variable external resistance. The non-paired t test was used in the animal experiments and the paired t test in the human studies.

Results

Threshold currents of intradental nerve fibres in the cat

The threshold current values of 170 intradental nerve units were measured with current pulses of different durations (0.2–50 msec). Of these 118 (69%) were classified as A-fibres (conduction velocity (CV) > 2.0 m/sec) and 52 (31%) as C-fibres (CV $\leqslant$ 2.0 m/sec). With monopolar stimulation the mean threshold value with current pulses of 10 msec was 6.9 μA (S.D. = 7.4) for A-fibres and 42.5 μA (S.D. = 21.5) for C-fibres; the corresponding values with bipolar coupling were 12.2 μA (S.D. = 7.9) and 91.3 μA (S.D. = 52.3). The mean thresholds of A-fibres measured with bipolar tooth stimulation were almost twice as high as those obtained with monopolar stimulation ($P < 0.0005$) and more than twice as high for C-fibres ($P < 0.0005$), at all pulse durations (Fig. 1, Table I). Fourteen per cent of the

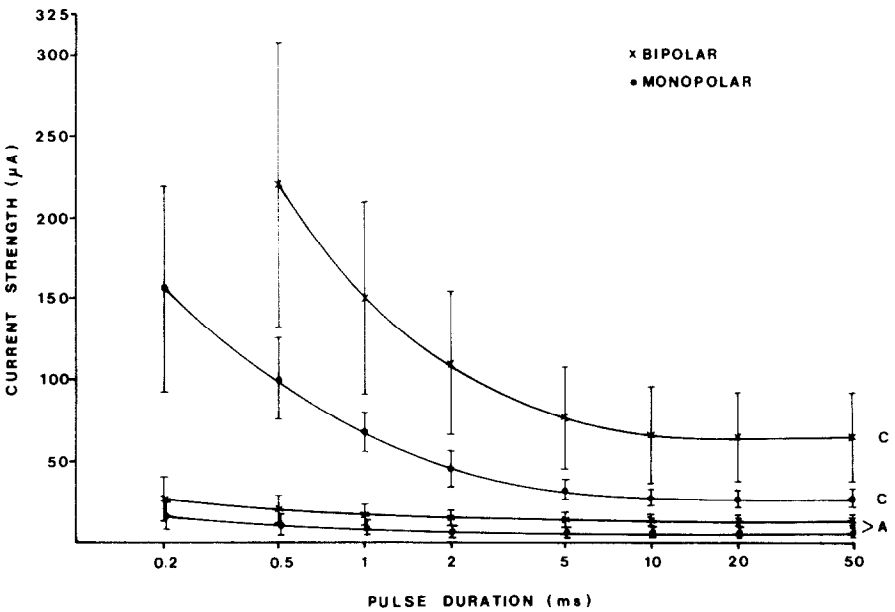

Fig. 1. Strength-duration curves of intradental A- and C-fibres with monopolar and bipolar tooth stimulation in the cat. The mean thresholds (± S.D.) are presented for each electrical pulse duration. With the shortest pulse duration (0.2 msec) most (56%) of the C-fibres failed to respond with bipolar stimulation.

A-fibres recorded and 29% of the C-fibres could not be activated with bipolar stimulation (max. current intensity 500 μA).

Thresholds of jaw-opening reflex in the cat

With current pulses of 10 msec duration the mean threshold values of the

TABLE I

MEAN THRESHOLD CURRENT VALUES OF A- AND C-FIBRES WITH MONOPOLAR AND BIPOLAR TOOTH STIMULATION (pulse duration 10 msec)

	Monopolar		Bipolar
A-fibres			
Number of fibres	118		101
Mean threshold current (μA)	6.9		12.2
S.D.	7.3		7.9
t test		$P < 0.0005$	
C-fibres			
Number of fibres	52		37
Mean threshold current (μA)	42.5		91.3
S.D.	21.5		52.3
t test		$P < 0.0005$	

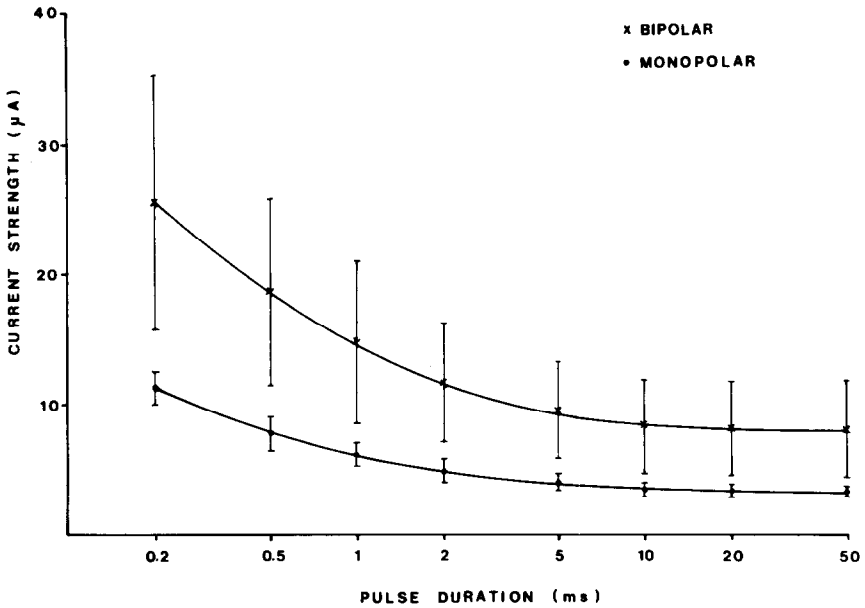

Fig. 2. Mean threshold current (±S.D.) of the jaw-opening reflex in the cat with different pulse durations using monopolar and bipolar electrical stimulation of the canine tooth.

jaw-opening reflex obtained with bipolar tooth stimulation (8.2 μA, S.D. = 3.7) were over twice as high as those obtained with monopolar stimulation (3.4 μA, S.D. = 0.7), $P < 0.0005$ (Fig. 2, Table II). The differences between the jaw-opening thresholds of maxillary and mandibular canine teeth were not statistically significant.

Sensation thresholds in human subjects

In human subjects the perception threshold values were higher with bipolar than with monopolar tooth stimulation ($P < 0.025$; Table III). The pain thresholds were also higher with bipolar than with monopolar stimulation but the difference was not statistically significant ($P > 0.1$; Table III). The perception and pain thresholds were

TABLE II

MEAN THRESHOLD CURRENT VALUES OF THE JAW-OPENING REFLEX IN RESPONSE TO MONOPOLAR AND BIPOLAR ELECTRICAL STIMULATION OF THE CANINE TOOTH IN CATS (pulse duration 10 msec)

	Monopolar		Bipolar
Number of teeth (both upper and lower canines)	14		14
Mean threshold current (μA)	3.4		8.2
S.D.	0.7		3.7
t test		$P < 0.0005$	

TABLE III

MEAN THRESHOLD CURRENT VALUES OF PERCEPTION AND PAIN THRESHOLDS IN HUMAN SUBJECTS (n = 6) USING MONOPOLAR AND BIPOLAR TOOTH STIMULATION (pulse duration 10 msec)

	Monopolar		Bipolar
Perception threshold (prepain) (μA)	7.2		11.7
S.D.	3.2		6.7
t test		$P < 0.025$	
Pain threshold (μA)	10.3		16.0
S.D.	4.5		8.8
t test		$P > 0.1$	

higher with all subjects when bipolar stimulation was used. Three of the subjects spontaneously described the nature of the sensation at pain threshold as different between these two electrode couplings. The subjects were then asked to describe the sensation in their own words, which were 'sharp' or 'cutting' with bipolar and 'dull' or 'more indefinite' with monopolar stimulation. Figs. 3 and 4 show the perception and pain thresholds obtained with monopolar and bipolar tooth stimulation using different pulse durations.

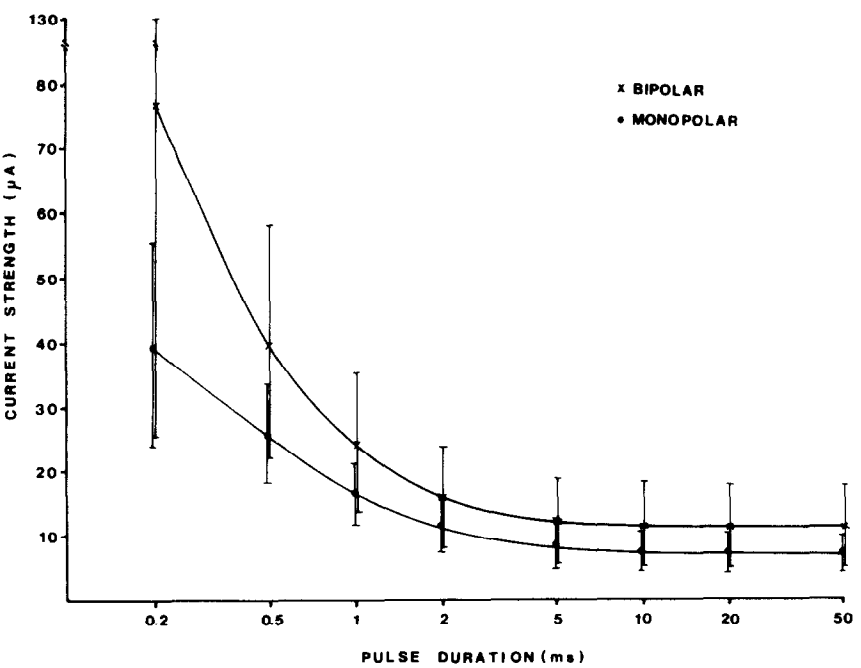

Fig. 3. Mean current values (± S.D.) of the perception threshold to electrical current pulses of different durations with monopolar and bipolar stimulation in human subjects.

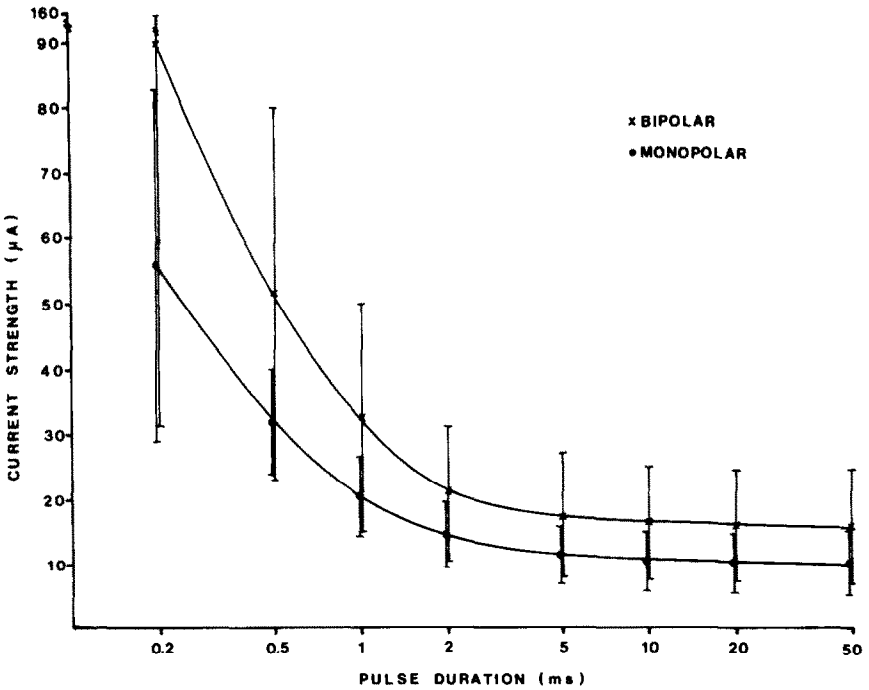

Fig. 4. Mean current values (±S.D.) of the pain thresholds to electrical current pulses of different durations with monopolar and bipolar stimulation in human subjects.

Discussion

Monopolar and bipolar electrode couplings were compared in the electrical stimulation of intradental nerves. These two methods differ mainly with respect to the resistance between the electrodes and the direction of the current flow. The electrical resistance of a human tooth varies considerably: in the enamel the value is mega-ohms and in the dentine kilo-ohms [14]. This makes special technical demands of the tooth stimulator. In bipolar coupling the electrical resistance of the tooth is twice as high as in monopolar coupling, and so the voltage needed is also twice as high. Since the resistance values can vary considerably, it is necessary to use a constant current stimulator.

The results of this study indicate that the thresholds measured with monopolar and bipolar stimulation are markedly different. Using bipolar stimulation in single unit recordings, the thresholds for A-fibres were almost twice as high and for C-fibres more than twice as high as with monopolar stimulation. Likewise, using bipolar coupling the thresholds for the jaw-opening reflex, which is mediated by the A-fibres of the pulp [21], were twice as high as the values obtained with monopolar coupling. Another notable finding was that some of the pulp nerve fibres could not be activated with bipolar stimulation (14% of the A-fibres and 29% of the C-fibres) within the current limits used (up to 500 μA).

Rushton's studies [23] show that the direction in which the current is applied to the nerve greatly influences the activation of the nerve fibres. The current is most effective when it flows in the longitudinal direction along the axons; the threshold values increase as the direction of the current path moves towards the perpendicular position. Since electrical current flows in the direction of least resistance, it travels in the tooth along the dentine tubules to the pulp cavum where it spreads as the resistance of the tissue decreases [15,17]. With monopolar stimulation the current in the pulp flows in the direction of the pulp fibres [17]. Considering the direction and density of the current path, in monopolar stimulation the most probable areas for the activation of pulp nerves are the border zone between the pulp and dentine under the stimulation electrode and the apical root pulp, where the current density is relatively high [15,17].

In bipolar coupling the stimulation current flows almost perpendicularly through the crown pulp [11] and thus the angle between the current flow and the nerve fibres is greater than in monopolar stimulation. In bipolar stimulation the direction of the current flow is not optimal for the activation of pulp nerves, and this is probably the reason for the higher threshold current values obtained with this electrode coupling. In bipolar stimulation the density of the current flow is at its highest in the crown pulp and thus the nerve fibres of the root pulp may remain inactivated.

In earlier studies on experimental animals the slowly conducting C-fibres have constituted only a relatively small proportion of the pulp nerves recorded [4,6,25], whereas in studies of our team C-fibres constitute a considerable proportion, approx. 40% [20,21,24]. The few C-fibre recordings reported might be due to the extremely short current pulses (0.05–1.0 msec) used in the earlier studies. As the duration of the pulse decreases, the thresholds of the nerve fibres increase; the thresholds of the C-fibres increase most rapidly (Fig. 1). Another contributing factor might be bipolar tooth stimulation, which has been widely used as a stimulation method in animal experiments. Since in this electrode coupling the current flows only through the crown pulp a great number of nerve fibres situated in deeper parts of the pulp may remain inactivated.

The perception and pain thresholds obtained in human experiments were of the same order as those obtained in the earlier studies [8,10,12,13,18,22]. However, the thresholds determined by bipolar stimulation were systematically higher than those determined by monopolar stimulation. Furthermore, the nature of the sensation at pain perception threshold was different: bipolar stimulation caused a sharp, cutting sensation, whereas monopolar stimulation was experienced as dull and indefinite. The explanation could be that in monopolar and bipolar coupling a sufficient density in the current flow is reached in different parts of the pulp and thus different pulp nerve fibre groups become active. Also, the temporal distribution of action potentials might be different in monopolar and bipolar couplings.

Comparison of the results of animal and human experiments shows that the thresholds of the A-fibres measured in the cat canine tooth closely correspond to the perception thresholds in the human tooth. Compared with these values the thresholds of the jaw-opening reflex in the cat were quite low, although there is no significant difference between the innervation of feline teeth and human teeth [2,16]. One

explanation for these low threshold values might be the smaller cross-section of the feline pulp cavity and consequent higher density of the current. The threshold values of the C-fibres determined with monopolar stimulation were 6 times as high and with bipolar stimulation almost 8 times as high as the thresholds of A-fibres. In spite of the anatomical differences it seems likely that the perception and pain thresholds measured in human teeth are due almost entirely to the activation of A-fibres. At the perception threshold activation of only a few low threshold axons is needed, but at the pain threshold summation of the activity of several fibre units is necessary. The use of stimulus intensities which exceed the pain threshold may also activate some of the pulpal C-fibres and this could have an effect on the perceived sensation.

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