Electrode Placing Sites affect Pulp Vitality Test of Human Incisors and Premolars

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Objective: *To investigate electric pulp test thresholds at different sites on healthy incisors and premolars and determine appropriate test sites.*

Methods: *Overall, 47 volunteers aged 20 to 30 years were recruited, and 163 incisors and 140 premolars were tested at several sites with an Electric Pulp Tester. One-way analysis of variance and a Tukey test were used to analyse the threshold values among different tooth types and sites.*

Results: *The lowest threshold value for incisors was identified on the incisal edge. The difference of threshold on the incisal edge and other sites was statistically significant in mandibular incisors. For maxillary premolars and the mandibular second premolar, the lowest response was obtained with the tester tip on the lingual slope of the buccal cusp. For the mandibular first premolar, the response at the lingual slope of the buccal cusp, as the second lowest, was slightly higher than that at the buccal cusp.*

Conclusion: *The incisal edge for incisors and the lingual slope of the buccal cusp for premolars was favoured as the optimal sites for electric pulp test.*

Key words: *appropriate site, electric pulp test, incisor, premolar, pulp vitality*

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Electric pulp test (EPT) has long been one of the standard clinical pulp diagnostic tests. It is designed to invoke a pulp response through an electric current, evaluating pulp sensitivity, or more precisely, sensitivity of 'A' fibres. EPT helps the clinician to prejudge the pulp condition before determining a treatment plan. The clinician may deduce the necrotic status of the pulp with confidence from a negative result[1]. On the other hand, a positive result may only indicate the presence of some functional nerve fibres in the pulp rather than implying the histological status of the pulp.

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Certain studies have concluded that EPT has high specificity and substantially varied sensitivity[2-4]. It is widely accepted that EPT is unreliable for immature teeth, recently traumatised teeth, or those undergoing orthodontic therapy[5,6]. In addition, EPT was found more reliable for healthy teeth than those with diseased pulp tissues[3].

Along with the shortcomings of EPT, little information about the threshold value also precludes from better application and clinical interpretation. Factors affecting the EPT threshold include the thickness of enamel and dentine, the direction of dentinal tubules along the current pathway, the concentration of sensory 'A' fibres, and the size of the pulp chamber[1,7]. These factors, the exact effects of which are still unclear and difficult to identify, vary among different test sites and teeth. Consequently, the contact position of the electrode and the tooth surface may affect the threshold value of tested teeth.

Conceivably, the optimal test site becomes a clinical issue. Based on clinical experience, certain scholars have suggested that the electrode should be placed on the gingival third of the buccal surface of the crown[8]. Several studies have focused on the appropriate sites on teeth, which responded at the lowest threshold and have reported varying results. The reported optimum sites include the middle third region of the labial surface for anterior and premolar teeth[9], the incisal edge for anterior teeth[1], the tip of the mesiobuccal cusp for first molars[10] and the tip of the buccal cusp for lower premolars[7]. The middle third of the crown on the labia/buccal surface is still recommended as the test site for EPT, according to Chinese literature[11,12].

Moreover, participants involved in the aforementioned studies came from the United States[1], New Zealand[10], Africa[13] and Greece[7]. To the best of our knowledge, available data regarding recommended test sites are scarce in the Chinese population. The primary aim of this study was to determine the sensibility of incisors and premolars tested at different electrode placement sites, and to provide reference for the optimum test site in each case.

Materials and methods

In total, 47 healthy volunteers (15 men and 32 women) aged 20 to 30 (24.04 ± 1.35) years were recruited at the Department of Cariology and Endodontology, Peking University School and Hospital of Stomatology, Beijing, China. All participants provided written informed consent after thorough understanding of the study procedures. Ethical approval (No. PKUSSIRB_201522037) for the study was issued from the Biomedical Ethics Committee of the Peking University School and Hospital of Stomatology, and conducted in full accordance with the World Medical Association Declaration of Helsinki. Participants were periodontitis free and had no recent history of orthodontic treatment. Several incisors and premolars from each participant were selected, and the arch side (left or right) was randomly picked. All sample teeth met the following criteria: no recent history of trauma, no caries or restorations and no severe occlusal wear.

Selected teeth were isolated and dried using cotton rolls and cotton gauze without air blasts. An electric Pulp Tester (Vitality Scanner 2006, SybronEndo, Anaheim, CA) was operated in accordance with the manufacturer's instructions. The measuring scale was numbered from 0 to 80. To ensure greater probability of accurate outcomes, the rate of increase was set to a relatively low calibration of 21. The electrode tip was coated with toothpaste (Colgate, New York, USA) as the conducting medium and placed at different sites on the teeth by a gloved tester. Two examiners (A and B) carried out all of the tests. Inter-rater and intra-rater reliability was evaluated firstly. All participants were instructed to place their thumb and forefinger on the metal handle of the electrode and release it immediately after initial perception of the stimulus, which may present as a warm, tingling, stinging or painful sensation.

Five sites were tested on the anterior teeth: cervical, middle and incisal third of the labial surface, incisal edge and palatal fossa. Eight sites were tested on maxillary premolars: cervical, middle and occlusal third of the buccal surface, centre of the buccal cusp, palatal/lingual slope of the buccal cusp, buccal slope of the palatal/lingual cusp, centre of the palatal/lingual cusp and the palatal/lingual surface. Similarly, seven sites tested on mandibular premolars were almost the same as those on corresponding maxillary premolars, except for the buccal slope of the lingual cusp, which was too small to place the electrode tip. Each site was tested four times. The test sequence of the sites on different participants was randomly selected. To avoid the phenomenon of nerve accommodation, consistency of the test sequence and a recovery period of at least 1 min were guaranteed for each participant.

Data were analysed using SPSS software (SPSS 20; SPSS, Chicago, IL, USA). One-way analysis of variance (ANOVA) and a Tukey test were performed to compare the means of variables from each tested site on the same type of teeth, with the critical level of significance being 0.05. Similarly, the mean values of the incisors and the premolars were compared using ANOVA and Tukey test, respectively. During this process, the threshold values of the additional site (buccal slope of the palatal cusp) on maxillary premolars were excluded. In addition, a t-test made gender comparisons between the threshold values of each tooth type.

Results

A total of 303 teeth were evaluated. The average value of all 7468 EPT readings was 28.81 ± 11.75. For the female and male groups, the average reading values were 28.61 ± 12.29 and 29.21 ± 10.63, respectively. The two examiners' intra-rater consistency was 0.836(A)/0.858(B), and the inter-rater consistency coefficient was 0.860.

The mean threshold values at each electrode placement site on the incisors and premolars are presented in Tables 1 and 2. The lowest value was observed with the tester tip on the incisal edge of the incisors and the palatal/lingual slope of the buccal cusp of the upper first/second and lower second premolars, respectively. For the mandibular first premolars, the response at the lingual slope of the buccal cusp, as the second lowest, was slightly higher than that observed at the buccal

Table 1 Mean EPT values for incisors.

Tooth type/site	U1 (n = 45)	U2 (n = 45)	L1 (n = 43)	L2 (n = 30)
Labial cervical third	24.77 ± 7.68[b]	27.54 ± 8.03[b]	25.51 ± 8.09[b]	25.50 ± 7.54[b]
Labial middle third	22.27 ± 7.55	24.96 ± 6.82	21.44 ± 6.31[a,b]	22.98 ± 6.23[b]
Labial incisal third	21.04 ± 6.57	23.49 ± 6.62	18.80 ± 6.11[a,b]	20.43 ± 6.22[a,b]
Incisal edge	18.29 ± 6.81[a]	20.87 ± 8.40[a]	9.02 ± 6.88[a]	11.62 ± 7.77[a]
Palatal/lingual fossa	18.65 ± 6.03[a]	22.78 ± 7.02[a]	19.46 ± 6.31[a,b]	19.13 ± 5.37[a,b]

U1 = upper central incisor; U2 = upper lateral incisor; L1 = lower central incisor; L2 = lower lateral incisor
Subgroups with lowercase letter superscripts 'a' indicate statistically significant differences compared with cervical third values ($P < 0.05$) in the same column;
Subgroups with lowercase letter superscripts 'b' indicate statistical significance compared with values of incisal edge values ($P < 0.05$) in the same column.

Table 2 Mean EPT values for premolars.

Site/tooth type	U4 (n = 40)	U5 (n = 34)	L4 (n = 32)	L5 (n = 34)
Buccal cervical third	34.78 ± 8.57	38.80 ± 8.42	35.59 ± 8.98	35.38 ± 8.10[a]
Buccal middle third	33.82 ± 8.25[a]	36.66 ± 9.15	33.20 ± 7.03[a]	34.71 ± 9.53[a]
Buccal occlusal third	31.94 ± 7.57[a]	35.54 ± 9.68	31.69 ± 8.65[a]	34.80 ± 10.65[a]
Buccal cusp	31.29 ± 9.06[a]	35.48 ± 9.87	30.46 ± 8.68[a]	33.57 ± 10.89[a]
Lingual slope of buccal cusp	29.78 ± 8.36[a]	32.91 ± 10.96[a]	30.88 ± 8.74[a]	32.71 ± 11.50[a]
Buccal slope of lingual cusp	31.96 ± 7.71[a]	35.71 ± 12.36	33.90 ± 9.84[a]	37.32 ± 11.54
Palatal/lingual cusp	35.29 ± 8.71	38.05 ± 10.75		
Palatal/lingual surface	39.31 ± 8.62	42.70 ± 10.17	41.34 ± 10.56	44.70 ± 12.18

U4 = upper first premolar; U5 = upper second premolar; L4 = lower first premolar; L5 = lower second premolar
Subgroups with lowercase letter superscripts 'a' indicate statistically significant differences compared with palatal/lingual surface values in the same column ($P < 0.05$)

cusp. The threshold values increased as the tester tip shifted apically from the incisal edge to the cervical region of the labial/buccal surface for both incisors and premolars. Moreover, the threshold values on the palatal/lingual surface of the premolars were significantly greater ($P < 0.05$).

Comparisons of mean threshold values with regard to gender and tooth type is shown in Figure 1. Female participants responded at a significantly lower level when incisors were tested ($P < 0.05$). For premolars, no significant difference was observed in the responses of the male and female participants.

Regarding all incisors, the mean response levels increased in the following order: mandibular central incisors, mandibular lateral incisors, maxillary central incisors and maxillary lateral incisors. In addition, significant differences were observed only between mandibular lateral incisors and their maxillary counterparts

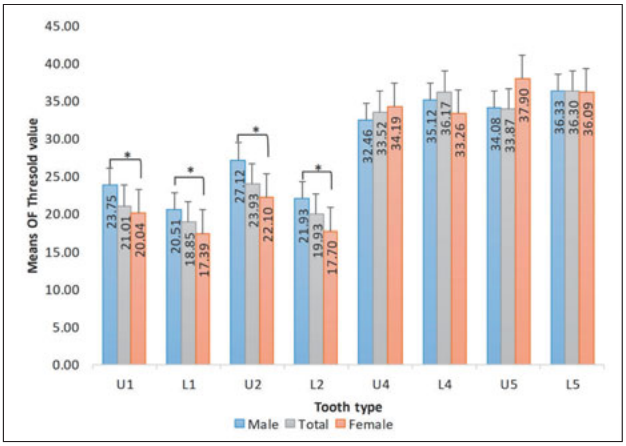

Fig 1 Mean values for each tooth type in males, females and all participants (with SD bar). U1: upper central incisor; U2: upper lateral incisor; L1: lower central incisor; L2: lower lateral incisor; U4: upper first premolar; U5: upper second premolar; L4: lower first premolar; L5: lower second premolar indicates statistically significant differences ($P < 0.05$) in mean responses of the same tooth type between male and female participants. The error bar shows standard deviation in each one, respectively.

($P = 0.015$). No difference of tooth type or jaws was observed for premolars.

Discussion

Optimum placement of the electric pulp tester tip with regard to the tooth is a clinical concern as teeth respond at different thresholds. An inappropriate test site may reduce the specificity and sensitivity of the EPT.

The design used in this experiment was similar to those used in previous studies with the same purpose[1,10]. Several studies have reported controversial findings regarding the optimum conducting media. Contrary to certain earlier studies[14-16], a recent study concluded that different media could influence EPT thresholds[17]. Similarly, a laboratory study suggested the use of a water-based interface medium for better conduction of current and less likelihood of a false-negative response[18]. Nevertheless, Colgate toothpaste was used in the study, and regardless of the influence of the toothpaste, all tested teeth were equally affected. As mentioned previously, the rate of increase of the EPT was set to a relatively low '2' to make it possible for volunteers to get a more accurate perception of the stimulus.

A possible explanation for the varied response threshold at each site on a tooth may be traced back to the principles of EPT and tooth structure. The electric pulp tester delivers a current that is sufficient to overcome the resistance of enamel and dentine and can stimulate the sensory 'A' fibres. During this process, unmyelinated 'C' fibres do not respond because they have a higher stimulation threshold[19]. With regard to placement of the electrode, several factors may be considered. The neural concentrations, thickness of the enamel and dentine, the direction of dentinal tubules along the current path, and probably the size of the pulp chamber, have all been proposed as factors influencing the EPT[1,7].

Jacobson concluded that the middle third of the buccal surface of the crown is the optimal electrode placement site based on an *in vitro* study, which was later criticised for neglecting the influence of neural concentrations[9]. According to Bender, a test area near neural elements with high intensity will logically have a relatively low threshold[1]. 'A' fibres principally located in the region of the pulp–dentine junction and ramified into the plexus of Raschow, from which the axons extend to the odontoblastic region and the inner dentine[20]. Most nerve endings are located in the pulp and dentine near the pulp horns and decrease in a gradient manner towards the cervical zone[21]. In our study, the response threshold increased as the tester tip was moved apically from the cusp tip to the cervical region of the tooth. Lin reported similar findings and found that this may confirm the influence of neural concentrations[10].

Moreover, the thickness of enamel and dentine may affect the response threshold. Enamel and dentine both have electrical resistance. Compared with dentine, enamel has a much higher electrical resistance, which is affected by the presence of cracks, caries and crown restorations. It may be deduced that the less thick the enamel and dentine, the lower the threshold; this may explain our result of the relatively lower threshold values of mandibular incisors, which possess thinner enamel than teeth of other types. In addition, for teeth with worn incisal edges, decreased enamel thickness may well contribute to the plummeting threshold values[1]. An investigation of enamel thickness in mandibular incisors demonstrated that the enamel thickness of the middle third of the lingual surface was thinner than that of the labial surface[22]. In the present study, mandibular incisors responded at a lower threshold when tested on the lingual fossa compared with the middle third of the labial surface. The relatively thinner lingual enamel may be one of the contributory factors for this result.

Furthermore, the length of the practical current path along dentinal tubules was also accountable. The shorter the current path, the lower the electrical resistance[1]. It was concluded that from the cementoenamel junction, the labial enamel thickness gradually increased and maintained a constant thickness in the incisal third for mandibular incisors[1,22]. Moreover, the same pattern of enamel thickness distribution on the labial surface was noted on the maxillary central incisors[23]. However, in our study, consistent with the results of previous studies[1,13], the threshold of incisors tested on the cervical third was the largest. This may partly be attributed to the lower concentration of nerve fibres in the cervical region and partly the direction of the dentinal tubules, which are curved in the cervical region and straight from the incisal edge to the pulp horn. Overall, the explanation may be comprehensive, but the exact influence of each factor was difficult to identify.

Regarding recommended test sites, sensitivity may be the determining factor when it comes to choosing the site, and other factors such as clinical accessibility and patients' perception of pain may also matter. Our results indicated the incisal edge as the optimal test site for incisors. For teeth with worn edges, the incisal third of the labial surface of incisors may be selected instead to avoid causing any possible discomfort[1]. Based on our results, despite its second lowest threshold for maxillary incisors and mandibular lateral incisors, the lingual fossa is not considered optimal owing to the inconvenience caused during tester tip placement. On premolars, we investigated additional sites than those investigated in previous studies[7]. According to results of the present study, the lowest response among premolars was observed either at the centre of the buccal cusp, consistent with results reported by Filippatos et al[7], or the lingual slope of the buccal cusp, which was not tested in the previous study[7]. Based on our experience, the buccal cusp of premolars of young participants could be quite sharp, which makes the contact area of the tester tip on the tooth surface relatively small and the contact less stable. Therefore, for more definite and controllable electrical conduction, the lingual slope of the buccal cusp is favoured. At the same time, the palatal/lingual side of the premolars response the least sensitively. On rare occasions when premolars are inevitably tested on the palatal/lingual side, possibly due to restoration on the buccal and occlusal aspects, the obtained large threshold value may not justify the impaired pulp vitality.

Certain previous studies have failed to correlate different thresholds with a gender[10,24-26]. In contrast, certain studies have demonstrated gender-related differences in this threshold[13,17]. In the present study, in the Chinese population, the mean threshold value for all incisors was significantly lower in female participants. A possible explanation may be that on an average, men possess larger crowns than women. This dimorphism is likely to be attributed to differences in dentinal thickness rather than enamel thickness[27-29]. Thicker dentine may increase the threshold in male participants. However, the mean threshold value for premolars did not display any sexual dimorphism in our study.

As mentioned previously, several factors affect the tooth sensitivity of EPT. For example, a recent study demonstrated that threshold values increased with age[7]. In our study, the age range (20 to 30 years) of participants was strictly narrow in order to preclude the age factor from affecting the test results. Also, in this setting, the tested teeth were all healthy. The thickness and electrical resistance of enamel and dentine may vary with certain situations, for instance abrasion and formation of tertiary dentine. Teeth with reversible or irreversible pulpitis or those that have severe cracks may look differently.

Conclusion

Within the limitations of this study, the recommended test sites were the incisal edge for incisors and the lingual slope of the buccal cusp for premolars in the Chinese population. The conclusion of our study should not be expanded without certain restraints.

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Conflicts of interest

The authors reported no conflicts of interest related to this study.

Author contribution

Dr Shi Yu TIAN made substantial contributions to conception and design, performed analysis on all samples, implemented data acquisition and wrote the manuscript draft. Dr Tang LIN performed analysis on all samples, implemented data acquisition, analysed, interpreted data, wrote the manuscript draft and revised the manuscript. Dr Chun Yan ZHENG supervised the work, helped in data interpretation and gave final approval to the manuscript.

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