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Accuracy of an electronic apex locator in primary teeth with root resorption

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Abstract

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Aim To evaluate whether root resorption of primary molar teeth affects the accuracy of the Root ZX apex locator and to compare the Root ZX at different meter readings with direct canal measurement.

Methodology Sixty extracted primary molar teeth with root resorption affecting one sixth to one third of root length were used. The teeth were embedded in an alginate model. A K-type file was used in association with a Root ZX apex locator to measure canal length. Measurements were recorded using the Root ZX meter reading 'Apex' and '0.5 bar'. Actual tooth length was measured with a K-file to the major foramen. All measurements were read under a stereomicroscope at 15× magnification. The deviation of the Root ZX measurement from the actual canal length was determined.

Results Mean differences between Root ZX length meter reading 'Apex' and actual length were 0.01 ± 0.23 mm whereas mean differences between Root ZX length meter reading '0.5 bar' and actual length were −0.33 ± 0.30 mm. The Root ZX was 96.7% accurate to within ± 0.5 mm of the apical foramen when compared with the actual canal length of primary molars with root resorption.

Conclusions Using a criterion of ± 0.5 mm, the accuracy of the Root ZX was high and not affected by root resorption. When compared with direct canal measurement, the error in locating the apical foramen was smaller with measurement at meter reading 'Apex' than meter reading '0.5 bar'.

Keywords: electronic apex locator, primary teeth, root canal determination, root resorption, Root ZX.

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Introduction

Maintaining the integrity of the primary dentition until physiologic exfoliation is a major goal when treating young patients. To maximize the success of endodontic treatment in primary teeth, the evaluation of root morphology is a factor of concern. The root canal anatomy of primary molars is difficult to predict because of the balance of resorption and hard tissue deposition. Physiologic resorption starts soon after the complete formation of the root, even while hard tissue deposition continues to modify the root canal system (Goerig & Camp 1983). Moreover, pulp and/or periodontal inflammation may lead to pathological root resorption and further complicate root and canal anatomy (Rimondini & Baroni 1995). Shape, dimension, and position of the root apex are continuously altered. Thus, the exact location of the apical foramen remains difficult to determine (Goerig & Camp 1983, Kielbassa *et al.* 2003). Radiographic determination of root canal length may give misleading results particularly in cases where resorption is present. In addition, it is often difficult to take a diagnostic radiograph in children because of poor cooperation and limited access

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(Mente *et al.* 2002, Kielbassa *et al.* 2003). The errors induced by the measurement technique may result in an increased risk of over instrumentation and/or overfilling, which can damage the germ of a permanent tooth (Holan & Fuks 1993, Coll & Sadrian 1996, Mente *et al.* 2002).

For over 40 years, electronic apex locators have been used for locating the canal terminus. The operation mode of electronic apex locators has been developed over the years using the principle of resistance, impedance and frequency (McDonald 1992). Electronic methods for root length determination have gained popularity in permanent teeth and studies have reported the accuracy of electronic apex locators as being greater than 80% (McDonald 1992, Pratten & McDonald 1996, Shabahang *et al.* 1996, Vajrabhaya & Tepmongkol 1997, Pagavino *et al.* 1998). The accuracy of electronic apex locators is influenced by two factors: (i) moisture content in root canals; and (ii) diameter of the apical foramen (Huang 1987). In 1994, the Root ZX (J. Morita Corp. Tokyo, Japan) was introduced to overcome the problem of moist canals (Kobayashi & Suda 1994). The concept of the Root ZX is based on the ratio method. The quotient of impedances of two different frequencies was calculated to reveal the position of the file inside the canal. The measurements appear to be less accurate when the apical foramen is immature or otherwise large (Berman & Fleischman 1984, Huang 1987, Hülsmann & Pieper 1989, Saito & Yamashita 1990, Fouad *et al.* 1993, Kaufman & Katz 1993). Many studies report the critical diameter of the foramen as 0.20 mm (Huang 1987), 0.30 mm (Fouad *et al.* 1993), or up to 0.62 mm (Saito & Yamashita 1990). This means that teeth with a wide foramen such as in primary teeth with resorption, traumatized teeth and teeth with pathological resorption might influence electrical measurement of root canal length (Mente *et al.* 2002).

Due to progressive resorption, there is general agreement in the literature that primary teeth should be salvaged only if the resorbed root remains more than two thirds of its full length. Extensive resorption of more than one third of the root should be considered as a contraindication for root canal treatment (Mathewson & Primosch 1995, Camp *et al.* 2002). Pulpectomy in primary teeth is inevitably complicated by root resorption. Although many studies have pointed out that electronic apex locators do not give accurate results in permanent teeth with open apices (Berman & Fleischman 1984, Huang 1987, Hülsmann & Pieper 1989, Saito & Yamashita 1990, Fouad *et al.* 1993, Kaufman & Katz 1993), few studies have reported the use of an electronic apex locator in primary teeth with apical root resorption (Katz *et al.* 1996, Mente *et al.* 2002, Kielbassa *et al.* 2003), generally with no clear definition of what stage of root resorption had occurred. In addition, only two papers reported both the meter readings 'Apex' and '0.5 bar' of the Root ZX devices in permanent teeth (Ounsi & Naaman 1999, Weiger *et al.* 1999) but none has investigated the different meter readings of the Root ZX device at the apical foramen of primary teeth with root resorption.

The purposes of this laboratory study were to evaluate whether root resorption of primary teeth affected the accuracy of the Root ZX apex locator and to compare the Root ZX at different meter readings with direct measurement.

Materials and methods

Primary molar teeth were preserved in 10% formaldehyde solution immediately after extraction. The study was approved by the Ethics in Human Research Committee of Chulalongkorn University, Bangkok, Thailand. All teeth were extracted for reasons unrelated to the study, generally because of extensive caries (in Thailand, parents often choose extraction rather than pulp therapy for primary molars). Teeth were immersed in 5.25% sodium hypochlorite for 15 min to remove organic residues from root surfaces. Stains and calculus were removed with scalers and curettes. The teeth were inspected for root fractures and evidence of incomplete root formation, and any doubtful teeth were discarded. Teeth were coded and one canal from each specimen was randomly assigned for the experiment. Root length was determined by measuring the distance between the crest of curvature at the cementoenamel junction and the apex of the root with a divider to an accuracy of 0.5 mm (Bow divider 030-395-00; Dentaurum, Germany). The root length was measured and calculated in accordance with G.V. Black's table of the primary teeth root length (Ash 1993). To ensure that all teeth had root resorption, teeth with root resorption between one sixth of root length to one third of root length were selected. All together sixty primary molar teeth with root resorption were used.

A standard endodontic access cavity was prepared using a tungsten carbide bur. The occlusal surface was ground with a wheel to create a flat surface perpendicular to the long axis of the experimental canal. The tooth was mounted as described previously (Kaufman & Katz 1993). The root of the tooth was embedded in

freshly mixed alginate (Geltrate Plus, Dentsply, Milford, DE, USA) in a plastic cylindrical box (2.5 cm in diameter and 4 cm in height). The pulp was extirpated with a barbed broach and the canal was then irrigated with 0.9% normal saline solution. Excess normal saline solution was absorbed using a cotton pellet. A clear plastic plate (1 × 15 × 15 mm) with a hole at the centre was fixed with glue (Alpha Techno Company, Osaka, Japan) to the flat occlusal table to be used as the coronal reference and to guide file insertion. The canal length was measured using the Root ZX (J. Morita Corp.) strictly according to the manufacturer's instructions. An appropriate size of K-type file, range between sizes 15–40 (Mani, Inc., Tochigi, Japan), which fitted the canal was slowly inserted into the root canal via the hole at the centre of the plastic plate until the signal on the display flashed 'Apex'. The rubber stop was then placed flush with the flat plastic plate. Flowable light-cured composite resin (Tetric ®; Flow, Ivoclar Vivadent, Inc., Schaan, Leichtenstein) was injected to cover the shaft of the file over the rubber stop and allowed to set. After complete polymerization, the file was removed and the file-length was recorded using a measuring device under a stereomicroscope (SZH10; Olympus Optical Co., Tokyo, Japan) at 15× magnification to an accuracy of 0.01 mm. A new file was used for each measurement. Measurements for each canal were taken three times and the average value was recorded as the Root ZX measurement meter reading 'Apex'. Measurements when the meter reading '0.5 bar' was accomplished using the same technique until the signal on display flashed '0.5 bar'. Three measurements for each canal were taken and the average value was recorded as Root ZX measurement meter reading '0.5 bar'.

After electronic length determination, the tooth was removed from the alginate mould and the experimental root was marked with erythrosine dye at 5–6 mm from apex to scope the area to be examined under magnification. The actual tooth length was measured by inserting a K-file of similar size into the root canal until the tip was seen from a tangential angle at the apical exit to extend 1 mm beyond the apical foramen under a stereomicroscope at 10× magnification. The file was then removed slowly until the file tip was just visible at the most coronal part of the apical foramen under 30× magnification. A rubber stop was then placed to the coronal reference and fixed with flowable light-cured composite resin. The file was removed after complete polymerization and the file-length was recorded using the measuring device under a stereomicroscope at 15× magnification. This procedure was repeated three times with a new file used each time. The three measurements were obtained and the average value was calculated. All together, nine files were used for each canal.

Each file-length measurement for both techniques was repeated after a time interval of at least 24 h to verify intra-examiner reliability.

Data analysis

The difference between the mean of Root ZX measurement and the mean actual canal length was calculated. Positive values mean that the file extended through the apical foramen while negative values mean that the file tip was positioned within the apical foramen and zero values mean that the file tip was flush with the apical foramen. Such values are considered as a measurement of the accuracy of Root ZX. The proportion of the measurements within a tolerance of ± 0.5 mm was calculated. A paired *t*-test was used to show the difference between 'Apex' error and '0.5 bar' error. A McNemar Chi-squared test was used to compare between the number of 'Apex' readings at or beyond the apex (39/60) and the corresponding number with '0.5 bar (6/60).

Intra-operator reliability was estimated using Pearson correlation test to compare the two values of file-length measurement obtained by one operator. Each file-length measurement was done twice with a time interval of at least 24 h in between.

Results

The numbers of primary root canals and their root length used in the study are summarized in Table 1. Accuracy of the Root ZX measurements compared with the actual canal length is shown in Table 2. The distribution of differences between the Root ZX measurement meter reading 'Apex' and the actual length are shown in Fig. 1 and those between the Root

Table 1 Distribution of sixth primary canals

Primary molar roots	Number (canals)	Root length (mm)
Maxillary first molars	15	7.40 ± 0.39
Maxillary second molars	14	8.46 ± 0.93
Mandibular first molars	12	7.79 ± 0.33
Mandibular second molars	19	8.53 ± 0.68
Total	60	8.08 ± 0.79

Table 2 Accuracy of Root ZX measurement meter reading 'Apex' and '0.5 bar'. An accurate reading is defined as one within ± 0.5 mm of the measured length to the apical foramen

The Root ZX meter reading	Primary molar roots	Number (canals)	Mean differences between the Root ZX measurement and actual length (mm)	Accuracy	95% Confidence interval
'Apex'	Maxillary				
	Primary first molars	15	−0.07 ± 0.37	86.67%	−0.27 to 0.14
	Primary second molars	14	0.01 ± 0.10	100.00%	−0.05 to 0.07
	Mandibular				
	Primary first molars	12	−0.03 ± 0.21	100.00%	−0.16 to 0.10
	Primary second molars	19	0.08 ± 0.15	100.00%	0.09 to 0.16
	Total	60	0.01 ± 0.23	96.70%	−0.05 to 0.07
'0.5 bar'	Maxillary				
	Primary first molars	15	−0.40 ± 0.36	60.00%	−0.59 to −0.20
	Primary second molars	14	−0.32 ± 0.25	78.57%	−0.47 to −0.17
	Mandibular				
	Primary first molars	12	−0.31 ± 0.30	75.00%	−0.50 to −0.13
	Primary second molars	19	−0.31 ± 0.30	78.95%	−0.45 to −0.16
	Total	60	−0.33 ± 0.30	73.33%	−0.41 to −0.26

ZX measurement meter reading '0.5 bar' and the actual length are shown in Fig. 2. With the meter reading 'Apex', 96.7% (58/60) of readings were within 0.5 mm of the actual foramen, compared with 73.3% (44/60) when the meter was set at '0.5 bar' (Table 2). When compared with direct canal measurements, the Root ZX measurement at meter reading 'Apex' had a smaller error (0.01 mm) than the meter reading '0.5 bar' (−0.33 mm) as shown in Table 2 (paired $t = -12.96$, $P < 0.001$). Using the 'Apex' setting, a tendency for a slight overestimate of the actual length was observed, with 39/60 readings at or beyond the foramen (though always within 0.5 mm), while only 2/60 readings were >0.5 mm short of the actual apex (Fig. 1). On the other hand, with the '0.5 bar' setting, most readings (54/60) were short of actual length, and 16/60 were >0.5 mm short (Fig. 2). Readings at or beyond the apex with 'Apex' measurement were significantly higher than those with '0.5 bar' setting (McNemar Chi-squared = 31.03, $P < 0.001$).

Intra-operator reliability using the Pearson correlation coefficient (r) was high (0.9).

Discussion

Huang (1987) concluded that the operation of an electronic apex locator was based on the principles of electricity rather than biological properties of the tissue involved. Therefore, in a laboratory study, the extracted teeth in the model should be immersed in a medium that has a similar electrical resistance to

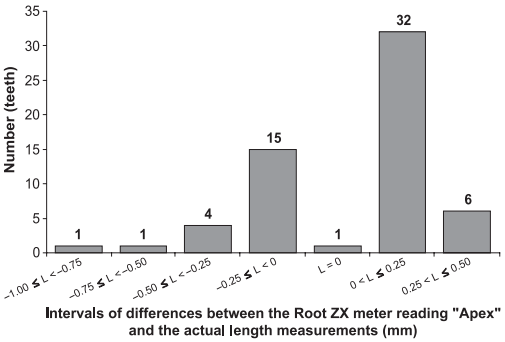

Figure 1 Differences between the Root ZX measurement meter reading 'Apex' and actual length (L). The data are presented in frequency ranges (0.25 mm increments), with bar height indicating the number of readings within each range.

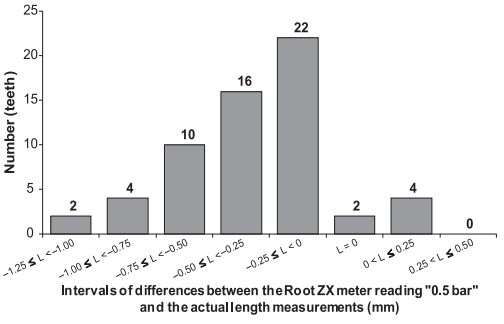

Figure 2 Differences between the Root ZX measurement meter reading '0.5 bar' and actual length (L). The data are presented in frequency ranges (0.25 mm increments), with bar height indicating the number of readings within each range.

that of the periodontium. The alginate model used in this study was found to be accurate, easy to use and the operator remained 'blinded' while locating the file tip in the canal. The technique has been shown to be reliable in previous studies (Kaufman & Katz 1993, Keila *et al.* 1994, Fuss *et al.* 1996, Nguyen *et al.* 1996, Kaufman *et al.* 1997). In this study a clear plastic plate was fixed to the flat occlusal table to provide a stable surface for measuring actual canal length. This technique helped to avoid measuring errors resulting from different interpretations of the reference point.

To evaluate the accuracy of an electronic apex locator, distance measurements are usually measured from the tip of the file to three different reference points; apical foramen, apical constriction or radiographic apex (Certosimo *et al.* 1999). The apical constriction is widely accepted as the landmark for ending endodontic instrumentation. However, the interpretation should be done carefully in order to obtain the correct result, especially when instrumenting narrow root canals because the apical constriction might be unintentionally displaced or destroyed (Stein & Corcoran 1991, Weiger *et al.* 1999). In addition, radiographs may give dimensional distortion and may not reveal the opening of the apical foramen (Shabahang *et al.* 1996, Vajrabhaya & Tepmongkol 1997). The apical foramen on the root surface, which is a natural feature and easy to locate in extracted teeth, is a reliable apical landmark (Ounsi & Haddad 1998, Ounsi & Naaman 1999), therefore it has been used as the reference in this study.

The criterion for detecting the stage of root resorption in primary teeth is not clear. It has been estimated subjectively in previous studies (Katz *et al.* 1996, Mente *et al.* 2002, Kielbassa *et al.* 2003). The generally accepted criterion for pulpectomy in primary teeth is that root resorption should not exceed one third of root length (Mathewson & Primosch 1995, Camp *et al.* 2002). Therefore, only teeth that had root resorption and root length more than two thirds of the average root length were used (Table 1).

Previous studies indicated that electronic apex locator measurements in roots with a wide apical foramen were considerably shorter than the actual canal length (Berman & Fleischman 1984, Hülsmann & Pieper 1989, Saito & Yamashita 1990, Fouad *et al.* 1993, Kaufman & Katz 1993). This was because the apical foramen was wide with flared canal configuration due to immature root formation (Hülsmann & Pieper 1989). Primary molars with root resorption did not show the same tendency in this study. Although the apical foramen was resorbed and enlarged, the conical shape of the canal was still maintained. The Root ZX can identify the narrowest canal diameter regardless of anatomical or mechanical constriction (Nguyen *et al.* 1996). The electronic apex locator is thus capable of functioning accurately in primary teeth with root resorption because the root canal typically has a decreasing taper towards the defect. Primary teeth with a root length between 7 and 10 mm were associated with round, regular apices, or multiple apices with intact apical deltas and apical diameters <0.3 mm (Rimondini & Baroni 1995). When root length became shorter than 7 mm the apices tended to have increased vertical and horizontal resorption and consequently an increase in diameter. The root length in this study was approximately 8 mm, with an apical diameter smaller than reported in previous studies (Saito & Yamashita 1990, Fouad *et al.* 1993). Thus, the present results are in agreement with previous studies, which reported on the accuracy of electronic apex locators in primary and in permanent teeth with root resorption (Katz *et al.* 1996, Goldberg *et al.* 2002, Mente *et al.* 2002, Kielbassa *et al.* 2003). Although questions still exist as to whether the accuracy of electronic apex locators in primary teeth with resorption can be affected by different types of electronic apex locators, no significant differences were found between the Root ZX (Morita) and the Endex (Osada, Tokyo, Japan) (Bodur *et al.* 2008).

In permanent teeth, it has been shown that the use of Root ZX meter reading 'Apex' gave more accurate measurements than the meter reading '0.5 bar' within 0.5 mm of the apical foramen (Ounsi & Naaman 1999) while Weiger *et al.* (1999) reported that reading '0.5 bar' gave more accurate measurements than meter reading 'Apex' within 0.5 mm of the apical constriction. The present study focused on comparing the Root ZX meter reading 'Apex' and '0.5 bar' in primary teeth with root resorption. The results showed that the use of the 'Apex' reading gave more accurate measurements than the meter reading '0.5 bar' within 0.5 mm of the apical foramen, in agreement with others (Ounsi & Naaman 1999) and the manufacturer's instructions. Deviation of 0.5 mm in relation to the foramen has been considered clinically acceptable (Fouad *et al.* 1990, Ricard *et al.* 1991, Shabahang *et al.* 1996, Vajrabhaya & Tepmongkol 1997). Thus, measurements attained within this tolerance are considered highly accurate (Fouad *et al.* 1990, Ricard *et al.* 1991). In this study the 'Apex' setting tended to overestimate length slightly (though within acceptable limits) as a result of an overextension of the file tip

beyond the most coronal part of the foramen. Clinically it seems reasonable to recommend a withdrawal of the instrument approximately 1.0–1.5 mm from Root ZX measurement at meter reading 'Apex' to avoid over instrumentation. At this level, the root canal will be filled to a point as close to the apical foramen as possible and still be within sound tooth structure (Mayeda *et al.* 1993). Further evaluation of the accuracy of this electronic method in clinical conditions is indicated and should be conducted in future *in vivo* studies.

The result of this study supports the use of electronic apex locator to determine root length in primary teeth that require pulpectomy. The use of the electronic apex locator is quick, comfortable, accurate, safe, painless, and does not involve unnecessary radiation. Radiographs, however, are still necessary to provide information regarding canal anatomy and root morphology.

Conclusions

When compared to direct canal measurement, the Root ZX tended to overestimate root length when the 'Apex' setting was used in primary molars with root resorption. The error in locating the apical foramen was smaller with the Root ZX measurement at the 'Apex' setting than with the '0.5 bar' setting. The accuracy of the Root ZX was high (within 0.5 mm of the apical foramen) and not affected by root resorption less than one third of root length in primary molar teeth.

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