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ORIGINAL RESEARCH

In vitro evaluation of the accuracy of five different electronic apex locators for determining the working length of endodontically retreated teeth

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Abstract

The aim of this study was to evaluate the accuracy of five electronic apex locators (EALs) in determining the working length (WL) of teeth after removal of the root canal obturation materials. A total of 32 extracted straight, single-rooted teeth were used. The actual canal length (AL) was determined and the WL was established by subtracting 0.5 mm from the AL. The root canals were instrumented and divided into two groups. One group ($n = 6$) served as control, while the other group ($n = 26$) was the experimental group. In the experimental group, the root canals were obturated using vertically compacted gutta-percha with AH 26 sealer. In both groups, the access cavities were restored with a provisional restoration and stored for 15 days at 37°C and 100% humidity. The root canal obturation material was removed, and the teeth were then mounted in an experimental apparatus. Five EALs were used: Dentaport ZX™®, ProPex, Foramatron D10, Apex NRG and Apit 7. For the electronic measurement of canal length, a size 25 K-file was used. During measurement, the canal was irrigated with 2.5% sodium hypochlorite. The difference (D) between the AL and the electronically determined length (EDL), AL–EDL, was calculated and recorded for each measurement. Data were analysed by two-way ANOVA and Fisher's PLSD test. In both groups, statistically significant differences were found among the EALs ($P < 0.01$). In conclusion, the Dentaport ZX™®, ProPex and Foramatron D10 were more accurate than the other two EALs in determining the WL in teeth after removal of the root canal obturation materials. However, the Apex NRG and Apit 7 were also reliable for determination of the WL in the majority of the cases.

Introduction

Non-surgical endodontic retreatment is an attempt to re-establish healthy periapical tissues after inefficient treatment or reinfection of an obturated root canal system because of coronal or apical leakage. It requires regaining access to the entire root canal system by removing the original root canal filling, further cleaning and re-obturation (1). Necrotic tissue or bacteria may be responsible for periapical inflammation or pain. The complete removal of the old root canal filling material is important to enhance the effect of irrigating solutions and intracanal medicaments.

The apical constriction is the landmark at which endodontic instrumentation should preferably end (2). Traditionally, radiographs are used for determination of the root canal length, but it is difficult to achieve accuracy because the apical constriction cannot be identified, and variables in technique, angulations and exposure distort this image and lead to error (3). Thus, in addition to radiographic measurements, electronic root canal working length (WL) determination has become increasingly important. The electronic method eliminates many of the problems associated with radiographic measurements. Its most important advantage over radiography is that it can measure the length of the root canal to the apical foramen, not to the radiographic apex (4).

The development of electronic apex locators (EALs) began in 1942, when it was reported that the electrical resistance between the periodontal ligament and the oral mucosa *in vivo* was a constant value of ~6.5 kΩ (5). Later, Sunada introduced the principle of the 'biological characteristic theory' into clinical practice, stating that EALs could read the apex by measuring the differences of electrical resistance values between the periodontal ligament and the oral mucosa (6).

Problems inherent in using direct current led to the development of EALs that used alternating current (7). These second-generation EALs, which use a single frequency of alternating current to detect changes in the impedance of the canal, underwent considerable development. Studies show their accuracy to be between 83% and 93.4% (8–13). The major disadvantage of second-generation EALs is that the canal needs to be relatively free of electrically conductive materials for an accurate reading. The presence of tissue and conductive irrigants in the canal can change the electrical characteristics and lead to measurement error.

The third generation of multiple frequency EALs attempted to overcome or minimise this problem; these devices are also based on alternating current, but they operate on the principle that the impedance difference between electrodes depends on the signal frequencies used. In 1994, Kobayashi and Suda developed an apex locater (Root ZX, J. Morita Co., Tokyo, Japan), which simultaneously calculates the ratio of two electrical impedances in the same canal using two different current frequencies to determine the canal length precisely even in the presence of electrolytes or vital pulp tissue (14). The accuracy of the Root ZX within 0.5 mm of the apical constriction has been reported to range from 82% (15) to 100% of the measurements (16). The Root ZX has also been combined with a handpiece to measure canal length when rotary files are used (17). This is marketed as the Tri Auto ZX™® (J. Morita Co., Tokyo, Japan) with an integrated handpiece, and more recently as the Dentaport ZX™® (J. Morita Co., Kyoto, Japan).

Many studies have demonstrated the accuracy of EALs in determining the WL (3,18–22). Pommer *et al.* compared *in vivo* the influence of the root canal status on the determination of the root canal length by an EAL in vital and necrotic canals and canals with root canal obturation retrieval (23). They stated that the AFA Apex Finder is a reliable tool for determining the root canal length in vital and necrotic teeth, with an accuracy of 86% within ±0.5 mm range of the radiographic apex. Goldberg *et al.* evaluated *in vitro* the accuracy of three EALs in determining the WL of teeth during retreatment (24). They found that the ProPex, NovApex and Root ZX were accurate within 0.5 mm 80%, 85% and 95% of the time, and within 1 mm 95%, 95% and 100% of the time, respectively. Alves *et al.* evaluated *in vitro* the capacity of the Tri Auto ZX™® to locate the apical foramen following the removal of root filling material during root canal retreatment (25). They found that the Tri Auto ZX™® was accurate to ±0.5 mm in more than 80% of teeth when used following removal of root canal obturation materials. In addition, some studies reported that the presence of debris and dentine chips, frequently produced after instrumentation, can affect the precision of EALs and thus affect the WL readout (26,27).

The objective of this *in vitro* study was to evaluate the accuracy of five different EALs in determining the WL in teeth after removal of root canal obturation materials.

Materials and methods

A total of 32 extracted intact, straight, single-rooted human teeth with completely formed roots that had been stored in distilled water containing 10% formalin were used. Soft tissue and calculus were removed from the root surfaces with an ultrasonic scaler (EMS Piezon® Master 400, CH-1260 Nyon, Switzerland). Digital radiographic images in both the buccolingual and mesiodistal directions were taken to evaluate the root canal anatomy. Standard access preparation was carried out using a high-speed diamond fissure bur (Mani, Tochigi, Japan) under water coolant. The incisal or occlusal edges were ground lightly to create a flat surface to simplify length measurements. The actual canal length (AL) was determined by introducing a size 10 or 15 K-file (Zipperer, Munich, Germany) into the canal until the tip of the file became visible at the major apical foramen under a digital microscope (VH-S30; Keyence, Osaka, Japan) at a ×20 magnification. A rubber stop was then carefully adjusted to the reference level and the distance between the rubber stop and the file tip was measured with a digital calliper (Sankin, Mitutoyo Co., Kanagawa, Japan), and recorded to the nearest 0.01 mm. The WL was established by subtracting 0.5 mm from the AL.

Size 1–3 Gates-Glidden drills (Mani, Tochigi, Japan) were used to prepare the coronal and middle thirds of the root canals. K3 nickel titanium instruments (SybronEndo, Glendora, CA, USA) of size 40/0.06 taper, size 35/0.06 taper, size 30/0.06 taper and size 25/0.06 taper were used in a crown-down manner in combination with a torque-controlled handpiece (Dentaport ZX™®; J. Morita Co., Kyoto, Japan) at 300 r.p.m. according to the manufacturer's instructions. The apical preparation was finished with a size 30/0.06 taper file. Each instrument was coated with a lubricant containing EDTA (RC Prep; Premier Dental Products Co., Plymouth Meeting, PA, USA) before use.

Each canal was irrigated using 2 mL of 2.5% NaOCl through a 27-gauge needle (Nipro, Osaka, Japan) during the cleaning and shaping. Furthermore, 1 mL of 15% EDTA (Showa Yakuhin Kako Co., Tokyo, Japan) was used for 5 min to remove the smear layer followed by 2 mL of 2.5% NaOCl for 3 min. Patency was constantly checked using a size 10 K-file.

The teeth were then randomly divided into two groups. One group ($n = 6$) served as control, while the other group ($n = 26$) was the experimental group. In the control group, the canals were dried with sterile paper points, and a small cotton pellet was placed at the canal orifice. Then, the access cavity was restored with a provisional material (Caviton™, GC, Tokyo, Japan). The six teeth were stored for 15 days at 37°C and 100% humidity. For the experimental group, the canals were obturated using vertically compacted gutta-percha with AH 26 sealer (Dentsply DeTrey, Konstanz, Germany). After drying the canals with sterile paper points, a size FM non-standardised gutta-percha master cone (Analytic Endodontics, Glendora, CA, USA) was trimmed and fitted apically, coated with sealer and placed into the canal to WL. Using a System B heat device (Analytic Endodontics, Orange, CA, USA) adjusted to 200°C, the gutta-percha master cone was cut at the canal orifice with a Buchanan Plugger. The master cone was vertically thermoplasticised by a continuous wave of condensation technique (28). A backfill with Obtura II gutta-percha (Obtura, Spartan) and condensation with an S-Kondenser (Obtura, Spartan) were performed, a small cotton pellet was placed at the canal orifice, and the access cavity was filled with Caviton™. The teeth were radiographed in the bucco-lingual and mesio-distal directions to confirm the adequacy of the root filling. They were then stored for 15 days at 37°C and 100% humidity to ensure setting of the sealer.

In the experimental group, the roots had 5–6 mm of obturation material removed from the coronal and middle thirds of the canal using Gates Glidden drills #2 and #3. Then, a drop of gutta-percha solvent (Eucaly Soft, Toyo Chemical Lab., Inc. Tokyo, Japan) was introduced and the softened apical gutta-percha penetrated with a size 20 or 25 K-file. Two or three additional drops of solvent were applied to reach the WL. Copious irrigation with 2.5% NaOCl and 15% EDTA was performed after each instrument.

In both groups, the lid of a polystyrene specimen bottle (20 mL, Iuchi, Osaka, Japan) was used to mount the tooth. An adequate amount of 1% agar (Wako Pure Chemical Industries, Ltd. Osaka, Japan) was put in the bottle, and upon setting, the corresponding tooth was embedded in the agar, leaving the crown exposed for stabilisation, using auto-polymerising resin. The tooth was kept in that position until the agar had set completely as described in previous reports (20–22).

Five EALs were used: Dentaport ZX™®, ProPex (Dentsply-Maillefer), Foramatron D10 (Parkell Electronic Division, Farmingdale, NY, USA), Apex NRG (Kibbutz Afikim, Israel) and Apit 7 (Osada, Tokyo, Japan). Each device was adjusted according to the manufacturers' instructions before use. For the electronically determined length (EDL), a size 25 K-file was used. During canal length measurement, the canal was flushed with 2.5% NaOCl. A file was gently inserted into the root canal until the 'APEX' signal was emitted by the corresponding EAL; except for ProPex the signal indicated 0.0. A rubber stop was then carefully adjusted to the reference level, and the file was withdrawn to measure the distance between the rubber stop and the file tip with a digital calliper. All lengths were measured three times and the average recorded. The distance (D) between the AL and EDL was calculated, and AL ±0.5 mm and AL ±1.0 mm (29,30) were used to evaluate the accuracy of the five EALs.

Statistical analysis

Data were analysed using the two-way ANOVA and Fisher's PLSD test. A statistically significant difference was determined at the 95% confidence level. The analyses were carried out with Stateview 5.0 software (Abacus Concepts, USA).

Results

The results are presented in Tables 1 and 2. The mean and standard deviation (in mm) of the difference between the values obtained with each EAL and the AL are shown in Table 3.

Table 1 Distance between AL and EDL (AL–EDL) in the control group

	Dentaport ZX™®	ProPex	Foramatron D10	Apex NRG	Apit 7
AL–EDL (mm)†	*n* (%)	*n* (%)	*n* (%)	*n* (%)	*n* (%)
–1.0 to –0.51				6 (100%)	6 (100%)
–0.5 to 0.0	6 (100%)	6 (100%)	6 (100%)		

†Negative values indicate measurements short of the AL. AL, actual canal length; EDL, electronically determined length.

Table 2 Distance between AL and EDL (AL–EDL) in the experimental group

	Dentaport ZX™®	ProPex	Foramatron D10	Apex NRG	Apit 7
AL–EDL (mm)†	*n* (%)	*n* (%)	*n* (%)	*n* (%)	*n* (%)
–1.5 to –1.1		2 (8%)	4 (15%)	8 (31%)	11 (42%)
–1.0 to –0.51	2 (8%)	3 (12%)	3 (12%)	3 (12%)	7 (27%)
–0.5 to 0.0	22 (85%)	20 (77%)	18 (69%)	15 (58%)	7 (27%)
0.01 to 0.5	2 (8%)	1 (4%)	1 (4%)		1 (4%)

†Negative values indicate measurements short of the AL. AL, actual canal length; EDL, electronically determined length.

Table 3 Mean difference between EDL and AL (in mm) with standard deviation for both groups

	Control group	Experimental group
	Mean† ± SD	Mean† ± SD
Dentaport ZX™®	–0.1 ± 0.0	–0.3 ± 0.2
ProPex	–0.2 ± 0.0	–0.3 ± 0.3
Foramatron D10	–0.3 ± 0.0	–0.5 ± 0.4
Apex NRG	–0.6 ± 0.0	–0.7 ± 0.4
Apit 7	–0.8 ± 0.0	–0.9 ± 0.5

†Negative values indicate measurements short of the AL. AL, actual canal length; EDL, electronically determined length; SD, standard deviation.

In the control group, the EDLs by Dentaport ZX™®, ProPex and Foramatron D10 were within AL ±0.5 mm 100% of the time, while for the other two EALs (Apex NEG and Apit 7), the EDLs were within AL ±1.0 mm 100% of the time. In the experimental group, the EDLs determined by the five EALs (Dentaport ZX™®, ProPex, Foramatron D10, Apex NRG and Apit 7) were within AL ±0.5 mm 92%, 81%, 73%, 58% and 31% of the time, and within AL ±1.0 mm 100%, 92%, 85%, 69% and 58% of the time, respectively.

In both groups, statistically significant differences were found between the EALs ($P < 0.01$). In the experimental group, no statistically significant differences were found between Dentaport ZX™® and ProPex, between ProPex and Foramatron D10, between Foramatron D10 and Apex NRG, or between Apex NRG and Apit 7.

Discussion

The aim of the present study was to evaluate the precision of five different EALs in determining the WL of teeth after removing root canal obturation materials. It has been suggested that EALs operate on electrical principles rather than being dependent on the biological properties of the tissues involved (31). Therefore, *in vitro* models in which extracted teeth are immersed in media with similar electrical resistance to the periodontium can provide valuable information (18,20–22,31,32). In this study, a 1% concentration of agar was selected as a medium to simulate the normal periodontium. This model has been shown to be an effective tool for evaluating EALs and familiarising the operator with electronic length measurements (18,20–22).

Removal of filling materials is an important phase in root canal retreatment because it requires chemomechanical re-instrumentation and re-disinfection of the root canal system (33). To date, it has been proven that complete removal of obturation materials can ensure success of root canal retreatment and that remaining materials may cause the retreatment to fail. Therefore, removing as much obturation material as possible from an inadequately prepared and/or obturated root canal system would appear to be essential in order to uncover the remaining necrotic tissues or bacteria that may be responsible for persistent periapical inflammation. Bergenholtz *et al.* found complete apical bone regeneration in 36% of treated root canals with overfillings compared with 62% of the cases without overfillings (33). They reported that the frequency of apical regeneration in retreated cases significantly decreased when overfilling existed.

EALs are frequently used during root canal therapy to determine the root canal length (3,18,19) or during retreatment (24,25). It is almost impossible to remove all traces of gutta-percha/sealer from canal walls (34–36). The accuracy of EAL in determining the WL after removing the root canal obturation materials has not been fully clarified. In this study, two groups (control and experimental) were used and five different EALs were evaluated to determine the WL in teeth after removing root canal obturation materials.

Many studies used an error range of ±0.5 mm to assess the accuracy of the EALs (15,32). Measurements attained within this tolerance are considered highly accurate. Other studies relied on a more lax clinical range of ±1.0 mm to the foramen (37). One reason cited for accepting a ±1.0 mm margin of error is the wide range seen in the shape of the apical zone (19). Root canals do not always end with an apical constriction, a well-delineated minor or major apical diameter, or an apical foramen within the base of the cemental cone (38). With a lack of such demarcations, an error tolerance of ±1.0 mm is deemed clinically acceptable (19).

The control group in this study exhibited significantly better scores than the experimental group. The measurements determined by the three EALs (Dentaport ZX™®, ProPex and Foramatron D10) were within AL ±0.5 mm 100% of the time, while with the other two EALs (Apex NEG and Apit 7) the measurements were within AL ±1.0 mm 100% of the time.

In the experimental group, the measurements determined by the five EALs (Dentaport ZX™®, ProPex, Foramatron D10, Apex NRG and Apit 7) were within AL ±1.0 mm 100%, 92%, 85%, 69% and 58% of the time, respectively. The results obtained in both groups with the three EALs (Dentaport ZX™®, ProPex and Foramatron D10) were accurate and thought to be acceptable when determining the WL before and after removal of the root canal obturation materials, and also showed better readings than the other two EALs (Apex NRG and Apit 7). Based on a study by Shabahang *et al.* (19), where the authors considered an error tolerance of ±1.0 mm to be clinically acceptable, the results obtained with the two EALs (Apex NRG and Apit 7) were also acceptable because the largest average difference value with Apit 7 was –0.90 mm. The results of present study are in agreement with those of Alves *et al.* (25) and Goldberg *et al.* (24), who found that the EALs are useful for determining the WL of root canals in retreatment cases.

The present study and some previous studies indicate that, even in fully controlled *in vitro* study conditions, there is some inconsistency in EAL measurements (20–22,32). It should be emphasised that the results obtained in this *in vitro* study cannot be directly extrapolated to the clinical situation, but can provide an objective assessment of a number of variables that are not practical to test clinically.

Conclusions

Under the conditions of this study, the Dentaport ZX™®, ProPex and Foramatron D10 were more accurate than the other two EALs in determining the WL in teeth after removing the root canal obturation materials. However, the Apex NRG and Apit 7 were also reliable for determination of the WL in the majority of the cases.

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