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Ex vivo accuracy of three electronic apex locators: Root ZX, Elements Diagnostic Unit and Apex Locator and ProPex

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Abstract

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Aim To compare *ex vivo* the accuracy of three electronic apex locators (EALs): Root ZX, Elements Diagnostic Unit and Apex Locator and ProPex.

Methodology Electronic working length determination was carried out in 40 extracted teeth using an *ex vivo* model. After access preparation, a first operator determined the reference length (AL) for each tooth under a 30× stereomicroscope using the apical constriction as the apical landmark. All teeth were then measured with each EAL and the results obtained were compared with the corresponding AL. The AL was subtracted from the electronically determined distance. The measurements exceeding the AL were recorded as positive (long) and the measurements short of the AL were recorded as negative. Data were analyzed using the Friedman Test and Tukey multiple range test for nonparametric correlation amongst groups. Statistical significance was considered at $P < 0.05$.

Results Comparing the differences between measurements obtained with the three EALs and those obtained with the stereomicroscope, the percentage of measurements within ±0.5 mm of the AL was 97.37% (84.22% within 0.5 mm short of AL) for the Root ZX, 94.28% (88.57% within 0.5 mm short of AL) for the Elements and 100% (35.9% within 0.5 mm short of AL) for the ProPex.The mean difference between the AL and the lengths measured by the Root ZX, the Elements and the ProPex were, respectively, −0.157 ± 0.228, −0.103 ± 0.359 and 0.307 ± 0.271 mm.

Conclusions The results of the present study confirm that the EALs determined the canal length within ±0.5 mm from the apical constriction in the majority of cases. The majority of the ProPex readings were long.

Keywords: electronic apex locators, endodontics, working length.

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Introduction

Accurate working length determination is a prerequisite for successful root canal treatment, reducing the chance of insufficient cleaning of the canal or of damaging the periapical tissues from overinstrumentation (Sjögren *et al.* 1990, Ricucci & Langeland 1998, Chugal *et al.* 2003).

Apical anatomy determines the termination of root canal instrumentation and filling. The cemento-dentinal junction (CDJ), which is also described as the apical constriction (Gordon & Chandler 2004), is the anatomical and histological landmark where the periodontal ligament begins and the pulp ends (Grove 1931). Root canal preparation techniques aim to end the biomechanical instrumentation at the apical constriction (Kuttler 1955). Root fillings terminating at the apical constriction provide optimal healing conditions with minimal contact between the filling material and the apical tissue, thus reducing tissue destruction, persisting inflammatory responses and foreign body reactions (Seltzer *et al.* 1968, 1969, Ricucci & Langeland 1998). Furthermore, the majority of outcome studies conclude that optimal rates of healing occur when

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instrumentation, debridement, disinfection and filling are contained within the region of apical constriction (Basmadjian-Charles *et al.* 2002, Kojima *et al.* 2004).

The location of the apical constriction varies considerably from root to root (Dummer *et al.* 1984) and its relationship to the CDJ is also variable as the CDJ is highly irregular and can be up to 3 mm higher on one wall of the root compared with the opposite wall (Gutierrez & Aguayo 1995). Furthermore, the CDJ cannot be identified clinically (Ricucci & Langeland 1998).

Traditional methods for establishing working length include the use of radiography (Stein & Corcoran 1992), anatomical averages and knowledge of anatomy (Green 1960, Burch & Hulen 1972), tactile sensation (Seidberg *et al.* 1975, Chandler & Bloxham 1990) and moisture on a paper point (Ruddle 2002). All of these methods have limitations (Tamse *et al.* 1980, Olson *et al.* 1991, Stein & Corcoran 1992). Radiographs are subjected to distortion and magnification and are technique sensitive in both their exposure and interpretation (Stein & Corcoran 1992). Furthermore, a radiograph provides a two-dimensional image of a three-dimensional structure which lacks of a real representation (Pratten & McDonald 1996). Even amongst experienced clinicians the use of anatomical averages, knowledge of anatomy and tactile sensation has been shown unreliable and subjected to marked intra-subject differences (Seidberg *et al.* 1975, Chandler & Bloxham 1990). Therefore, these methods for root canal measurement do not allow precise localization of apical constriction and CDJ and do not guarantee that instrumentation beyond the apical foramen will be avoided (ElAyouti *et al.* 2001, 2002).

The development of electronic apex locators (EALs) has helped make the assessment of working length more accurate and predictable (Pratten & McDonald 1996, Fouad & Reid 2000, ElAyouti *et al.* 2002) and used with appropriate radiographs, it allows for much greater accuracy of working length determination (McDonald 1992, Stein & Corcoran 1992, Pratten & McDonald 1996, Hoer & Attin 2004).

The concept that root canal length could be estimated using an electrical current was developed by Suzuki (1942) who studied the flow of direct current through the teeth of dogs. In 1962, Sunada demonstrated that the electrical resistance between the periodontal ligament and oral mucosa had a constant value that could be measured. This phenomenon was originally thought to be an electrochemical/biological characteristic of the root dentine, periodontal ligament and oral mucosa (Sunada 1962). Modern theories suggested, however, that the phenomenon could be mainly electrophysical in nature (Ushiyama 1983, Huang 1987). Inoue (1972) developed a sonic readout system by using a transistor equalizer-amplifier feedback circuit and low frequency oscillation for root canal length measurement. Ushiyama (1983) described the gradient impedance method to determine working length in the presence of electrolytes.

The main shortcoming of early first and second generation EALs (erroneous readings with electrolytes) was overcome by Kobayashi *et al.* (1991) with the introduction of the ratio method and the subsequent development of the self-calibrating Root ZX (J. Morita Corp., Tokyo, Japan). The Root ZX is a third generation EAL where no calibration is required and a microprocessor calculates the impedance quotient (Kobayashi & Suda 1994). Third generation EALs use multiple frequencies to determine the distance from the end of the canal. These units still use impedance measurements to measure location within the canal, but have more powerful microprocessors and are able to process the mathematical quotient and algorithm calculations required to give accurate readings (Gordon & Chandler 2004). The change in electrical capacitance at the apical constriction is the basis for the operation of the Root ZX and its reported accuracy (Shabahang *et al.* 1996, Pagavino *et al.* 1998) even in presence of different electrolytes in the canal and under different clinical conditions (Mayeda *et al.* 1993, Kobayashi & Suda 1994, Dunlap *et al.* 1998, Jenkins *et al.* 2001, Meares & Steiman 2002).

Several *in vivo* and *ex vivo* studies have been conducted on various commercially available EALs to determine their accuracy and consistency (Fouad *et al.* 1990, Mayeda *et al.* 1993, Shabahang *et al.* 1996, Dunlap *et al.* 1998). These studies reported that the accuracy of the recent generation of EALs was approximately 90% (Fouad *et al.* 1993, Frank & Torabinejad 1993, Weiger *et al.* 1999, Welk *et al.* 2003).

The Elements Diagnostic Unit and Apex Locator (Sybron Endo, Sybron Dental, Anaheim, CA, USA) is claimed to be a fourth generation apex locator. The device does not process the impedance information as a mathematical algorithm, but instead takes the resistance and capacitance measurements separately and compares them with a database to determine the distance to the apex of the root canal (Gordon & Chandler 2004). It uses a composite waveform of two signals, 0.5 and 4 kHz, compared with the Root ZX at 0.4 and 8 kHz (Gordon & Chandler 2004). The signals go through a digital-to-analogue converter to be converted into an analogue signal, which then goes through amplification and then to the patient circuit model which is assumed to be a resistor and capacitor in parallel. The feedback signal waveforms are then fed into a noise reduction circuit (Gordon & Chandler 2004). The manufacturer claims that directly measuring resistance and capacitance eliminates the potential of error introduced by the possibility of reading the same impedance provided by the different combination of resistance and capacitance if they are not measured independently (Tselnik *et al.* 2005). The Elements Unit uses multiple frequencies to eliminate the influence of the canal conditions, which is similar to the Root ZX (Tselnik *et al.* 2005), thus permitting less sampling error per measurement and more consistent readings (Gordon & Chandler 2004). A recent investigation has demonstrated a great level of accuracy of this EAL in usage *in vivo* (Tselnik *et al.* 2005).

ProPex (Dentsply Maillefer, Ballaigues, Switzerland) is a multi-frequency based apex locator which is based on the same principles of the other modern devices which use multiple frequencies to determine root canal length. One important characteristic of ProPex is that the calculation is based on the energy of the signal where the other apex locators usually use the amplitude of signal. The manufacturer claims that energy measurement is more precise. The manufacturer does not specify any other technical characteristics and no studies are present in current literature on the *ex vivo* or *in vivo* accuracy of this EAL.

The objective of the present study is to test in an *ex vivo* model the accuracy of two new EALs, the Elements Diagnostic Unit and Apex Locator and the ProPex and to compare them with the Root ZX, that has been studied widely and considered of great accuracy.

Materials and methods

Forty single-rooted permanent teeth without caries or restorations were selected from a tooth bank. Roots with resorption, fractures, open apices or radiographically invisible canals were excluded from the study.

Before the test, the teeth were stored in formalin solution (10%) and placed into 5.25% sodium hypochlorite solution for 2 h to remove the periodontal ligament (Tinaz *et al.* 2002). All remaining organic residues were removed from external root surfaces with a scaler. After rinsing in tap water teeth were transferred again to formalin solution, with careful examination under stereomicroscope at 30× magnification [Stemi SV6, Carl Zeiss S.p.A., Arese (MI), Italy] to check for root fractures and to confirm that apex formation was complete. Two preliminary radiographs were taken in a buccolingual and mesiodistal direction for studying root canal anatomy, identify the radiographic apex and exclude teeth with accessory canals or those where the main canal was not visible.

The cusps were flattened with a tapered diamond bur using a high-speed handpiece under water irrigation to establish a level surface to serve as a stable and unequivocal reference for all measurements. Standard access to the root canal system was prepared with a high-speed handpiece, water coolant and a diamond bur and a tapered stainless steel size 012 Batt bur (Dentsply Maillefer, Ballaigues, Switzerland) was used to smooth the pulp chamber walls.

After the root canal orifices were identified the canals were cleansed of debris by irrigating with 5 mL of 5.25% sodium hypochlorite (NaOCl) after which canal patency was evaluated using a size 10 K-Flexofile (Dentsply Maillefer) to discard any teeth with canal obstructions. Pulp tissues were extirpated using barbed broaches without any attempt to enlarge the canal with the root canal instruments. Root canals were irrigated with 5 mL of NaOCl for 15 min in order to remove the organic contents of root canal space.

After access preparation, a first operator (LB) inserted a size 15 K-Flexofile into each canal until the tip of the file became visible through the foramen under 20× stereomicroscope. The file was then withdrawn until its tip lied tangential to the apical foramen. The silicone stop was adjusted to the nearest flat anatomical tooth landmark chosen as reference for root canal measurement. The distance from the base of the silicone stop to the file tip was measured under 4.5× magnification with a millimetre ruler to the nearest 0.25 mm. Then 0.5 mm was subtracted from the measurement. Each measurement was repeated three times and the mean value calculated and computed. This value was recorded for each tooth as the reference length and registered as the Actual Length (AL).

Teeth were then embedded in an alginate model specially developed to demonstrate electronic working length measurement (Tinaz *et al.* 2002) which was manufactured from plastic dental jaws, natural teeth and alginate impression material.

All measurements were made within 2 h of the model being prepared in order to ensure the alginate was kept sufficiently humid (Lucena-Martln *et al.* 2004).

The following EALs were used: the Root ZX, the Elements Diagnostic Unit and Apex Locator and the ProPex. Each apparatus was calibrated according to the manufacturer's instructions and the 'apex' as indicated by each device was chosen as the apical reference.

For electronic measurement, size 15 K-Flexofiles connected to the EAL was used in all cases. At first, canals were irrigated using 5.25% sodium hypochlorite placed with an endodontic syringe (Navy Tip, Ultradent, South Jordan, UT, USA), then the pulp chamber was gently dried with an air syringe; cotton pellets were used to dry the tooth surface and eliminate excess irrigating solution.

Using the Root ZX, the file was advanced within the root canal to just beyond the foramen, as indicated by the flashing APEX bar and the solid tone. The file was then withdrawn until a flashing bar between APEX and 1, a flashing tooth on the LCD display and the audible signal indicated that the minor constriction had been reached.

Using the Elements Diagnostic Unit and Apex Locator, the file was advanced into the canal to just beyond the foramen, as indicated by the '0.0' on the LCD display. The file was then withdrawn until the reading of the EAL showed a consistent '0.5' with corresponding symbol and audible signal indicating that the root canal constriction had been reached.

Using the ProPex, the file was advanced into the canal to just beyond the foramen, as indicated by the red light and the warning signal. The file was then withdrawn until the reading of the EAL showed a consistent '0.0' and a solid tone indicated that the apex had been reached.

The silicone stop was adjusted and the distance from the base of the silicone stop to the file tip was measured under 4.5× magnification with a millimetre ruler to the nearest 0.25 mm.

Measurements were considered as valid if the instrument remained stable for at least 5 s, otherwise the value was recorded as an unstable measurement due to inability of the EALs to reveal a constant reading. Unstable measurements were not able to evaluate the accuracy of measurements provided by the EALs.

All teeth were measured individually and independently by two operators (GP and NMG). The evaluators did not know the preliminary measurements of the AL. Measurements were repeated three times and the average was calculated and computed for each operator. A mean value of these measurements was recorded for each tooth and for each EAL and registered as the Root ZX Length (RL), Elements Diagnostic Unit and Apex Locator Length (EL) and ProPex Length (PL).

The recorded AL was compared with the values obtained with the EALs (RL, EL and PL). In each case, the AL was subtracted from the electronically determined distance, recording the result in tabular form. Positive values indicated measurements exceeding the AL (long), negative values indicated measurements short of the AL. For each EAL the mean value of the difference between the values obtained with the EAL and the AL were calculated.

Percentages were determined and statistical evaluation was completed using the Friedman Test and Tukey multiple range test for nonparametric correlation amongst groups. Statistical significance was considered when $P < 0.05$.

Results

Accuracy was calculated only on stable measurements. Unstable measurements were found with all the three EALs: two with the Root ZX, 5 with the Elements and one with the ProPex.

The cases and corresponding percentage values of electronic canal measurement are presented in Table 1. The mean and standard deviation (in mm) of the difference between the values obtained with each EAL and the AL are illustrated in Table 2.

There was a highly significant difference ($P < 0.001$) when the differences between measurements obtained

Table 1 Difference between Actual Length (AL) and readings of the three electronic apex locators (EALs)

Distance from actual length (mm)[a]	Root ZX $n = 38$	%	Elements diagnostic $n = 35$	%	ProPex $n = 39$	%
−1.0 to −0.51	1	2.6	1	2.9	0	
−0.5 to 0.0	32	84.2	31	88.6	14	35.9
0.01 to 0.5	5	13.2	2	5.7	25	64.1
0.51 to 1.0	0	0	1	2.9	0	0

[a]Negative value indicates measurements short of the AL.

Table 2 Mean difference between the values obtained with each electronic apex locator (EAL) and the actual length (mm)

	Mean[a]	SD
Root ZX ($n = 38$)	−0.157	0.228
Elements ($n = 35$)	−0.103	0.359
ProPex ($n = 39$)	0.307	0.271

[a]Minus sign indicates measurements short of the actual length.

with the three EALs and those obtained with the stereomicroscope (AL) were compared. There was no significant difference between the Root ZX and Elements Diagnostic EALs. A statistically significant difference was observed between the ProPex and Root ZX and the ProPex and Elements Diagnostic ($P < 0.05$).

Table 1 shows that most measurements were within ±0.5 mm of the AL. The percentage of measurements ±0.5 mm to the apical constriction was 97.37% for Root ZX, 94.28% for Elements and 100% for ProPex. Root ZX and Elements Diagnostic Unit registered, respectively, 84.22 and 88.57% of the measurements within 0.5 mm short of the AL. The ProPex registered 35.9% of the measurements within 0.5 mm short of the AL and 64.1% within 0.5 mm long of the AL.

The mean difference between the length measured by the Root ZX, the Elements Diagnostic Unit and Apex Locator and the ProPex and the AL were, respectively, −0.157 mm (SD 0.228), −0.103 mm (SD 0.359) and 0.307 mm (SD 0.271) (Table 2).

Discussion

The use of electronic devices to determine working length has gained increasing popularity in recent years (Kim & Lee 2004). Modern apex locators are able to determine an area between the minor and major apical foramina by measuring the impedance between the file tip and the canal with different frequencies and enables tooth length measurements in the presence of electrical conductive media in the root canals (Kobayashi 1995).

As the mean foramen to apical constriction distance is approximately 0.5–1.0 mm for all tooth types (Kuttler 1955, Green 1960, Dummer *et al.* 1984), it was chosen in this study to record the reference length by subtracting 0.5 mm from the measurement when the file appeared at the foramen under the optical stereo microscope.

Some authors have suggested that taking the instruments slightly long when using EALs and then retracting them may increase the accuracy of readings of EALs (Dunlap *et al.* 1998, Lee *et al.* 2002). Thus, to confirm the measurement, the file was advanced <0.5 mm long to verify that warning signals indicated the foramen was penetrated and then retracted to obtain the consistent 'apex' reading again.

The relative stiffness of the alginate mould prevented fluid movement inside the canal that is responsible of premature electronic readings registered with previous models (Fouad *et al.* 1990, Czerw *et al.* 1994). In this way, it could be possible to overcome the limitations of the *in vitro* models.

The results of the present study confirmed that EALs can accurately determine the canal length within ±0.5 mm from the apical constriction as shown previously (Fouad *et al.* 1990, Czerw *et al.* 1995, Vajrabhaya & Tepmongkol 1997, Kauffman *et al.* 2002). The measurements obtained revealed that the EALs were able to measure the canal length with a high level of precision compared with the AL. If the estimated working length = AL ± 0.5 mm is considered to be clinically acceptable, then the measurements made with the three EALs were acceptable in virtually all cases.

The EALs tested were constantly within ±0.5 mm to the AL and only in one case did the measurements exceed the apical foramen (>0.5 mm long) (Table 1). The use of these devices, therefore, reduces the risk of instrumentation beyond the apical foramen.

The Root ZX and the Elements Diagnostic Unit and Apex Locator registered respectively 84.22% and 88.57% of the measurements within 0.5 mm short of the AL. The ProPex was in 64.1% of the measurements slightly longer than the AL and in 35.9% of the measurements within 0.5 mm short of the AL. This could be due to the fact that the manufacturer suggests the file is placed apically until the numeric display reads '0.0', this representing the limit corresponding to the major apical foramen, instead of the ideal landmark of the apical constriction.

The Root ZX has become the benchmark to which other apex locators are compared. The results of this study are in general agreement with previous reports on the accuracy of the Root ZX (Czerw *et al.* 1995, Shabahang *et al.* 1996, Vajrabhaya & Tepmongkol 1997, Dunlap *et al.* 1998, Pagavino *et al.* 1998, Welk *et al.* 2003).

A literature search revealed no *ex vivo* studies evaluating the accuracy of the Elements Diagnostic Unit and Apex Locator and no studies on the accuracy of the ProPex EAL. An *in vivo* study (Tselnik *et al.* 2005) reported the Elements EAL to be accurate to within ±0.5 mm from the minor diameter 75% of the time and to within 1.0 mm 91.7% of the time.

In the present study, the accuracy of the Elements EAL was not significantly different from the accuracy of the Root ZX and was in agreement with other reported values (Shabahang *et al.* 1996, Dunlap *et al.* 1998, Pagavino *et al.* 1998, Martinez-Lozano *et al.* 2001, Goldberg *et al.* 2002). Whilst the ProPex EAL was accurate in 100% of cases when determining the location of the apical constriction ±0.5 mm, the mean distance from the file tip to the constriction had a positive value ('long' when compared with the established working length). This is in agreement with other previous studies which reported that normally EALs establish working length beyond the apical constriction (Dunlap *et al.* 1998, Pagavino *et al.* 1998, Welk *et al.* 2003, Tselnik *et al.* 2005).

Conclusions

The results of the present study confirm that EALs can accurately determine the root canal length within ±0.5 mm from the apical constriction.

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