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In vitro comparison of working length determination using three different electronic apex locators

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ABSTRACT

Background: The aim of this study was to compare the accuracy of the apex-locating functions of DentaPort ZX, Raypex 5 and Endo Master electronic apex locators (EALs) *in vitro*.
Materials and Methods: Thirty extracted human single-rooted teeth with mature apices were used for the study. The real working length (RWL) was established by subtracting 0.5 mm from the actual root canal length. All teeth were mounted in an alginate model that was especially developed to test the EALs and the teeth were then measured with each EAL. The results were compared with the corresponding RWL, which was subtracted from the electronically determined distance. Data were analyzed using a paired-samples *t*-test, a Chi-square test and a repeated measure analysis of variance evaluation at the 0.05 level of significance.
Results: Statistical analysis showed that no significant difference was found among all EALs ($P > 0.05$).
Conclusion: The accuracy of the EALs was evaluated and all of the devices showed an acceptable determination of electronic working length between the ranges of ±0.5 mm.

Key Words: DentaPort ZX, electronic apex locator, Endo Master, Raypex 5, working length

INTRODUCTION

Proper root canal treatment procedures exhibit the following features: the complete removal of infected pulp tissues, thorough canal cleaning, shaping, disinfection and three-dimensional filling.[1] During this process, it is critical to determine and maintain the working length (WL). The apical constriction (AC) is recommended as the ideal end-point for the instrumentation and filling of the root canal system. This anatomic landmark is the narrowest point of the root canal, where the smallest blood vessels are found and is therefore the site, where the smallest wound is created and has the best healing conditions.[2] Although the AC was showed to be located 0.5-1 mm from the major foramen on the root surface, the apical foramen does not coincide with the anatomical apex; it might be located laterally and at a distance of up to 3 mm from the anatomical apex.[3] This makes it difficult to localize the foramen and AC using conventional methods (tactile sensation or radiographs).[4]

The development and production of electronic apex locators (EALs) for locating the canal terminus have been major innovations in the field of endodontics. Custer[5] was the first to introduce an electrical method of locating the apical foramen. Suzuki[6] discovered that electrical resistance between the periodontal ligament and oral mucosa has a constant value of 6.5 kΩ; this led to the development by Sunada[7] of the first EAL. Since then, different generations of EALs have been developed to measure root canal length. First and second generations of EAL devices used a single direct or a single frequency alternating current as the measuring signal.[8] However, these devices provided inaccurate measurements as a result of presence of pulp tissue, blood, exudates or

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moisture in the root canal.[9] Modern EALs determine the WL by measuring impedance with two or more different frequencies. The canal does not need to be dried before modern EALs are used because they can work in the presence of electrolytes.[10] Therefore, practitioners have widely accepted modern EALs because they have high reliability, have high accuracy and reduce the number of radiographs for required WL determination.[11]

DentaPort ZX (Morita Co., Tokyo, Japan), Raypex 5 (VDW, Munich, Germany) and Endo Master (EMS, Nyon, Switzerland) are some of the modern EALs. DentaPort ZX, a third generation combined device, simultaneously calculates the ratio of 2 impedances in the same canal using 2 different frequencies (8 kHz and 0.4 kHz)[12] and works with the same principle as the original Root ZX does,[13] which has been tested in previous studies and has subsequently become a reference in electronic working length (EWL) investigations.[14-18] The Raypex 5, a fourth-generation device, also uses two different frequencies (8 and 0.4 kHz) and its measurements are based on the root mean square values of the signals.[10,12] In previous studies, the Raypex 5 was able to detect the correct WL (± 0.5 mm) in 75-87.2% of measurements.[13,14,19,20] The Endo Master is another combined device with a fourth-generation apex locator and simultaneously calculates the impedance of 3 different frequencies (100 Hz, 385 Hz and 8.3 kHz).

To the best of our knowledge, the Endo Master was evaluated only in two *in vitro* studies[21,22] for their ability to determine the WL. Thus, this *in vitro* study's purpose was to compare the DentaPort ZX, Raypex 5 and Endo Master by determining their ability to locate the AC.

MATERIALS AND METHODS

Selection and preparation of teeth

Thirty human teeth with single, straight root canals that were extracted for periodontal, orthodontic, or prosthetic reasons were selected for this study. All the extracted teeth were numbered and kept in 5.25% sodium hypochlorite (NaOCl) for 2 h and then stored in sterile 0.9% saline solution. The teeth were decoronated at the cementoenamel junction with a diamond disc to simplify access to the root canal and to obtain a reliable occlusal landmark. Gates-Glidden drills (Dentsply Maillefer, Ballaigues, Switzerland) #3 and #4 were used to flare the coronal one-thirds of each root canal. A 2.5% NaOCl solution was used for irrigation during the process and the patency of the apical foramen was maintained using size 10 K-File (Dentsply, Maillefer, Switzerland).

WL determination

The actual length (AL) of root canal was measured by inserting a size 10 K-file into the root canal under ×6 magnification in a stereomicroscope (SMZ 800, Nikon, Tokyo, Japan). When the file tip was just visible at the apical foramen, the silicone stop was placed at the reference point and the file was removed from the canal. The distance from the base of the silicone stop to the file tip was measured with a ruler to the nearest 0.25 mm. Each measurement was repeated 3 times and the mean value was calculated and computed. The real working length (RWL) was established by subtracting 0.5 mm from the AL. Then, an adequate amount of alginate was condensed within the plastic boxes and upon setting, the corresponding root was embedded within the alginate, leaving approximately 5 mm of the root surface exposed. The root was kept in that position until the alginate had completely set. All measurements were made at intervals of 2 h, with the alginate maintained in sufficiently humid conditions. During electronic measurement, the labial clip of the corresponding locator was inserted into the alginate.

EWL determination

DentaPort ZX (Morita Co., Tokyo, Japan), Raypex 5 (VDW, Munich, Germany) and Endomaster (EMS, Nyon, Switzerland) EALs were used in accordance with their manufacturers' instructions for detecting the AC. In order to obtain electronic measurements, size 15 K-files with silicone stoppers that were connected to the EALs were used to determine the WL in each of the 30 canals, using each of the three EALs. The canals were first irrigated with 2.5% NaOCl and then, cotton tips were used to dry the tooth surface and to eliminate the excess irrigating solution. For DentaPort 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 "0.5" had been reached. For Raypex 5, the file was advanced to just beyond the foramen (red light) and it was withdrawn until all flashing green bars had been reached. For Endo Master, the file was advanced to just beyond the foramen, as indicated by the error light and warning signal. Then, the file was withdrawn until the "0.5" red LED was lit. Measurements were determined to

be unstable when the reading of the EAL did not remain stable for at least 5 s.

When the EAL exhibited the specified reading, the silicone stop was adjusted to the coronal surface, the file was removed and the distance from the stop to the file tip was measured with a ruler to the nearest 0.25 mm. In order to indicate the EWL, a mean value of 3 measurements was recorded for each canal. To standardize procedures throughout the study, only one operator conducted the experiments in order to avoid variables during specimen preparation. A mean value of these measurements was recorded for each tooth and for each EAL and was registered as DentaPort ZX Length, Raypex 5 Length and Endo Master Length.

The recorded RWL was compared with the values obtained with the EALs. In each case, the RWL was subtracted from the EWL and the results were recorded in tabular form. Positive or negative values were recorded when the tip was detected beyond or short of the RWL, respectively.

Statistical analysis

Data were analyzed using a paired-samples *t*-test, a Chi-square test and a repeated measure analysis of variance evaluation at the 0.05 level of significance.

RESULTS

The mean and standard deviations (mm) of the differences among the values obtained with each EAL and the RWL are shown in Table 1. The mean distance measurements to the RWL were found to be 0.17 mm for the DentaPort ZX, 0.18 mm for the Raypex 5 and 0.23 mm for the Endo Master, respectively. Statistical analysis showed that no significant difference was found between all EALs tested ($P > 0.05$). The cases and the corresponding percentage values of the electronic canal measurements are shown in Table 2. Within ±0.5 mm, the accuracies were 96.7% ($n = 29$) for the DentaPort ZX, 90% ($n = 28$) for Raypex 5 and 86.7% ($n = 26$) for Endo Master, respectively. The accuracies in locating the AC were 26.7% ($n = 8$) for the DentaPort ZX and for the Raypex 5 as well as 23.3% ($n = 7$) for Endo Master.

Table 1: Mean difference between the values obtained with each EAL and the RWL (mm)

Groups	*n*	Mean	SD
DentaPort ZX	30	0.17*	0.30
Raypex 5	30	0.18*	0.32
Endomaster	30	0.23*	0.33

*Positive values indicate measurements beyond of the RWL, EAL: Electronic apex locator; RWL: Real working length, SD: Standard deviation

Table 2: Distribution of frequency of the distance between the file tip and the RWL

Distance from RWL (mm)*	DentaPort ZX % (*n*)	Raypex 5 % (*n*)	Endomaster % (*n*)
−1.0 to −0.51*	0.0 (0/30)	0 (0/30)	3.3 (1/30)
−0.5 to −0.01*	16.7 (5/30)	16.7 (5/30)	6.6 (2/30)
0.00	26.7 (8/30)	26.7 (8/30)	23.3 (7/30)
0.01 to 0.5	53.3 (16/30)	50 (15/30)	56.7 (17/30)
0.51 to 1.0	3.3 (1/30)	6.6 (2/30)	10 (3/30)

*Negative value indicates measurements short of the RWL, RWL: Real working length

DISCUSSION

This study evaluated the accuracy of three EALs in locating the AC. With regard to the *in vitro* assessment of EALs, studies have been investigating tooth-embedding media that may simulate the impedance values of human tissues.[23] The advantages of these media were their simplicity, their ease of use and the ability to have strict control over the experimental conditions tested. Furthermore, a greater number of canals could be tested over a shorter period of time than could have been achieved by clinical means. The disadvantages of laboratory models are their inability to simulate conditions *in vivo*.[24] Different media have been used to simulate the clinical situation, such as alginate, agar, saline and gelatin. An alginate model was used in the present study because alginate remains around the root, simulating the periodontal ligament's colloidal consistency and presents favorable electroconductive properties.

The use of irrigants and their benefits in endodontics has been clearly proven and irrigants are used for their antimicrobial, tissue dissolving and lubrication capabilities. It is of great importance that a clinician has confidence in the accuracy of an EAL, even in the presence of an irrigant.[11] NaOCl is the most used endodontic irrigant due to its widespread utility. Previous studies showed that NaOCl can be safely used to determine the canal length with the EALs.[11,25] Therefore, 2.5% NaOCl was used in the present study as the root canal irrigant and the electrical conductive medium.

The present study's measurements were attained in a target interval of ±0.5 mm to the AC because this clinical tolerance of ±0.5 mm is considered to be the strictest acceptable. Measurements within

this minimal tolerance are highly accurate.[15,26] The present study showed that the percentage of measurements within ±0.5 mm was 96.7% for the DentaPort ZX, 90% for the Raypex 5 and 86.7% for the Endo Master respectively. DentaPort ZX functions on the same principle as the Root ZX does, which is considered to be the gold standard against which newer EALs are evaluated.[27] Numerous studies have reported the accuracy of Root ZX and its series EALs in determining the WL. Previous studies showed that the percentages of measurements ±0.5 mm to the AC were 100%, 97.3% and 96.2% of cases, respectively, using the Root ZX.[26,28,29] D'Assunção *et al*.[30] showed that the Root ZX II's accuracy in establishing the RWL within the limits of ±0.5 mm was 97.4% of cases. Duh[31] and Ebrahim *et al*.[32] in their study also demonstrated that the percentage of measurements within ±0.5 mm to the AC was 97.6% and 93% of cases, respectively, using the DentaPort ZX. The results of this present study are in general agreement with previous reports on the accuracy of the Root ZX series.[2,23,25-29]

In a previous study, Wrbas *et al*.[16] found that the Raypex 5 predictably determined the WL to the AC with (± 0.5 mm) 80% accuracy compared with the Root ZX's (± 0.5 mm) 75% accuracy. No significant difference was found between the results of Root ZX and Raypex 5 in determining the AC. In another study, Vieyra and Acosta[29] evaluated the accuracy of the Root ZX, Elements-Diagnostic, Precision AL and Raypex 5 EALs when compared with radiographs for locating the AC. They showed that the percentage of measurement within ±0.5 mm was 100% for the Root ZX and Raypex 5. In the present study, the accuracy of the DentaPort ZX was not significantly different from the accuracy of the Raypex 5, in agreement with the previous reported studies.[16,29]

Limited studies evaluated the accuracy of the Endomaster. In a previous study, Stavrianos *et al*.[21] showed that results of the Endomaster, DentaPort ZX and Raypex 5 were 100% within ±0.5 mm limit in the control group. The present study showed that the percentage of measurement within ±0.5 mm was 86.7% for the Endomaster, 96.7% for the DentaPort ZX and 90% for the Raypex 5. These differences might be due to the fact that root canal preparation was done before the EWL measurement was obtained. Although only the coronal third was prepared with the Gates-Glidden drills in the present study, total root canal preparation was made in this previous study.[21] In another study, Barthelemy *et al*.[22] evaluated the WL determination of the different apex locators and found that the mean differences between the electronic and ALs were 0.52 mm for the X-Smart Dual, 0.24 mm for the Endomaster and 0.18 mm for the DentaPort ZX. The mean distance measurements to the RWL in the present study were found to be 0.17 mm for the DentaPort ZX and 0.23 mm for the Endomaster. Furthermore, no statistically significant difference was found between the Endomaster and other EALs. Our results for the DentaPort ZX and the Endomaster were consistent with Barthelemy *et al.* previous findings.[22]

As the measurements for each tooth were completed under the same conditions, the present study's most remarkable results to be discussed are related to the overextended readings. Although all EALs that were tested in this study determined the AC within an acceptable range, the file tips were extruded beyond the AC in 17 samples (56.6%) for DentaPort ZX and Raypex 5 and in 20 samples (66.7%) for Endomaster. This might be due to the fact that the EALs were used according to the manufacturers' instructions to determine the AC. Some previous studies reported evidence of overestimated WL using EALs, as manufacturers recommended [22,26] and our results are in agreement with those previous studies. This fact must be seriously considered because in clinical conditions, in contrast with *in vitro* studies, a greater variation in measurements is expected because the favorable circumstances for precise measurements are not available[33] and consequently, an overestimated WL could lead to a poor prognosis.[34] The present study's and the previous studies' results could raise the question of whether the WL should be established at the point where the EAL indicates the AC or at some distance coronal to that point. Thus, in order to avoid over preparation, some authors recommended a withdrawal of the instrument of between 0.5 and 1.0 mm from the electronic measurement.[13,16]

Some previous studies stated that the size of the foramen apicale affected electronic length determination. In a study by Huang[35] showed that when the size of the major foramen was less than 0.2 mm, measurements were not influenced, even in the presence of irrigants, but as it increased to above 0.2 mm, the measured distance from the apical foramen increased. Similarly, another previous study reported that as the size of the foramen apicale

increased, the distance between the file tip and the apical foramen increased.[36] The diameter of the apical foramen of the roots was not standardized in this study. Instead, we used the roots with mature apices in order to prevent a large apical foramen problem and we compared the results of the EALs measurements for the same roots.

CONCLUSION

The results of the present study confirm that these three EALs showed an acceptable determination of the root canal length within ±0.5 mm from the AC in the majority of cases. However, further studies are needed to compare the Endomaster under both *in vitro* and *in vivo* conditions with other combined devices and EALs.

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