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Ex vivo Analysis of Three Electronic Apex Locators Accuracy with Different Settings

Antonio Batista[1], Gilson Blitzkow Sydney[1], Marili Doro Andrade Deonizio[1], Thais Cristina Pereira[2], Carolina Carvalho de Oliveira Santos[1] and Bruno Cavalini Cavenago[1*]

[1]Department of Restorative Dentistry, Federal University of Parana, Curitiba, Brazil.
[2]Department of Dentistry, Endodontics and Dental Materials, Bauru School of Dentistry, University of São Paulo, Bauru, Brazil.

Authors' contributions

This work was carried out in collaboration between all authors. Authors AB and GBS designed the study, wrote the protocol and provided the materials and devices for this study. Author MDAD managed the literature searches and performed the statistical analyses. Authors TCP and CCOS managed the experimental process. Author BCC performed the data interpretation and wrote the manuscript. All authors read and approved the final manuscript.

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ABSTRACT

Aims: The correct determination of a root canal length is a fundamental step for an adequate chemical-mechanical preparation and consequently, for a successful endodontic treatment. Electronic apex locators (EAL) were developed to provide fast and reliable working lengths. The aim of the present study was to analyze the accuracy of the Root ZX II, RomiApex A-15, and SmarPex EAL's to determine the location of apical constriction, with and without the instructions recommended by the manufacturers.
Methodology: Fifteen mandibular premolars were randomly selected and root canals were

**Corresponding author: E-mail: brunocavenago@ufpr.br;*

accessed. The real canal length was determined by introducing a #15 K-file until the tip was visualized in the apical foramen, using 40x magnification of an operative microscope. In the sequence, the teeth were inserted in plastic flasks containing floral foam soaked in 0.9% saline solution. The root canals were filled with 1% sodium hypochlorite and the electronic measures were obtained with the selected devices until the "0.0" or the last green bar mark, as showed in devices display, and as per the manufacturers settings recommendation. The data were submitted to statistical analysis with the Friedman and Wilcoxon tests with a 0.05% significance level ($p < 0.05$).

Results: All devices were similar ($p > 0.05$) and showed precise and acceptable measurements at both times. Without manufacturers setting recommendation, the Root ZX II was the EAL that presented the greater percentage of coincidences with the real teeth length measures (73.33%), followed by the RomiApex A-15 (66.66%) and the SmarPex (40%). After performing the recommended settings the Root ZX II and the SmarPex presented 86.66% of coincidence with the real length, however, only the SmarPex device enhanced the mean precision with the real length ($p < 0.05$).

Conclusion: Considering a clinically acceptable average error of ±0.5 mm, all devices were effective in determining the measurement until the apical constriction. Although, there were no statistical significant difference with and without manufacturers instruction, for Root ZX II, the performance was better when manufacturer instructions were followed.

Keywords: Endodontics; root canal; electronic apex locator; working length.

1. INTRODUCTION

The success of endodontic treatment is determined by a satisfactory biomechanical preparation, irrigation, microbial control and complete filling of the root canal system [1,2]. Thus, the correct root canal length determination is crucial for an adequate instrumentation, promote a complete debridement and disinfection without traumatizing the periapical tissue [3]. Moreover, inaccurate working length determination may lead to over-instrumentation and overfilling [4]. A minor constriction occurs at the apical foramen due to the cementodentinal junction. This area represents the transition of the pulp and periodontal ligament tissues, and it is recommended that the root canal preparation and filling should be confined to this constriction [1].

Radiography is the most common and widely used technique for root canal length determination [2], but due to the several limitations of this method, the electronic apex locators (EAL) were developed to enhance this step in endodontic treatments. These devices were introduced by Sunada in [5], which used concepts recommended by Suzuki in 1942, who reported that the electrical resistance between the periodontal ligament and oral mucosa was a constant value of 6.5 kΩ [6]. The root canal tissues (dentine and cementum) are insulators for electrical currents, but at the apical foramen, there is a connection with the periodontal ligament that is itself a conductor of electric current. Hence, the apex locators are able to determine the resistance between the endodontic file and root canal walls until it decreases at the apical foramen [7]. Four device generations have been developed since their inception. To improve the efficiency, in 1994, the third generation of EAL emerged, using an alternating current with more than one frequency, reducing the error rate [7,8], and from this generation, the EAL has become widely used.

There are many available devices, among them, the Root ZX II (J.Morita, Tokyo, Japan) is a widely used EAL, which simultaneously measures the impedance values at two different frequencies (0.4 and 8.0 kHz) and then calculates their quotient value [9-11]. This device has been extensively evaluated showing rates of precision greater than 90% [12-14]. The EAL RomiApex A-15 (Romidan, Kyriat Ono, Israel) measures the working length by calculating the mean square root values of the impedance at two different frequencies (0.5 and 8.0 kHz), measured separately [15]. The devices compare the results obtained with reference values stored in its memories related to the file positions. However, differing from most EALs, the RomiApex A-15 operates by detecting the energy of the signal, rather than its amplitude [15]. In clinical reprodubility studies the RomiApex A-15 showed acceptable measurements at the 0.0 mark, moreover the majority of readings within the ±1.0 mm range [15,16]. Another EAL, the SmarPex (Meta Biomed, Cheongju, Korea) also simultaneously measures the impedance of dual

frequencies, this device is considered reliable in the presence of various root canal irrigants and varying sizes of the apical foramen [17] and can effectively detect root canal perforations [18].

According to the Root ZX II manufacturer's instructions, the "0.5" mark of the device indicates that the tip of the used file is at the apical constriction. Some authors also reported this recommendation to determine the working length [13,19]. The SmarPex manufacturer provides the same recommendation to determine the apical constriction, however, other manufacturer's instructions like the RomiApex A-15 does not report a recommendation, regardless of this kind of measure adjustment. The RomiApex A-15, and specially, the SmarPex have few studies reported in the literature [15-18], thus it would be relevant to evaluate them in comparison to the Root ZX II, considered a gold standard EAL.

The aim of the present study was to analyze the accuracy of the Root ZX II, RomiApex A-15 and SmarPex EAL's to determine the location of apical constriction by using the device´s zero position and consider the manufacturer´s recommendation.

2. METHODOLOGY

2.1 Collection and Sample Preparation

Fifteen mandibular premolars were randomly selected from the Human Teeth Bank of the Federal University of Parana and the study was approved by the Ethics Committee of the same institution. Periapical radiographs were taken with the Spectro 70 X (Dabi-Atlante, Ribeirão Preto, Brazil) equipment to observe the absence of root canal mineralization, incomplete root apex or endodontic treatment. The teeth that did not meet these criteria were excluded and replaced. After the removal of caries, the access cavities were performed with #1012 (KG Sorensen, Brazil) diamond burs used in high speed and completed with a #3205 (KG Sorensen) diamond bur.

The root canals were filled with 1% sodium hypochlorite (NaOCl) (Pharmacy Salvena, Curitiba, Brazil) and the glide path was made with a #10 K-file (Dentsply/Maillefer, Ballaigues, Switzerland). Gates-Glidden burs (Dentsply) #1, #2 and #3 were used for the preflaring.

Apex patency was determined with the #10 K-file. In all teeth, a perpendicular plateau was made with the aid of a #3205 diamond bur in the buccal cusp to establish a steady reference point. The specimens were individually placed in glass flasks containing 0.1% thymol solution (Pharmacy Salvena, Curitiba, Brazil) and stored in ambient temperature for teeth rehydration, where one remained for more than 72 hours. With the aid of an operative microscope (D.F.Vasconcellos, Valença, Rio de Janeiro, Brazil) at 40x magnification, the real root canal length was determined by introducing a #15 K-file until the tip could be visualized at the apical foramen.

2.2 Electronic Measurements of Root Canals

The teeth were inserted in plastic flasks containing floral foam soaked in 0.9% saline solution. The root canals were filled with 1% NaOCl and then the electronic measurements were determined for each tooth with the Root ZX II (J.Morita), SmarPex (Meta Biomed) and Romiapex A-15 (Romidan) devices. For this procedure, the labial clip was placed in the foam near the plastic flask, and the other connector in the intermediary of the endodontic file between the rubber stop and the handle. To avoid interferences in the connector position with the stop position, endodontic files with 31mm lengths were used.

The measurements were started using a #15 K-file and if this file was not fitted to the canal diameter, #20 or #25 K-files were used. Next, the endodontic file was introduced into the root canal until the device display showed 2 mm short of the 0.0 mark followed by the file gently advanced until the device showed the zero position. The SmarPex and RomiApex A-15 were used in each tooth in order to determine the canal length from a reference point to the supposed "0.0" showed in device display, thus defining the zero position. For the Root ZX II the zero position adopted was the last green bar mark, as indicated on the device. So, the rubber stopper was adjusted to the coronal reference and the instrument was removed from the root canal and measured with an endodontic ruler (Dentsply) after the zero position determination. This data was recorded as the electronic length. Measurements were repeated 3 times and the averages were calculated and recorded.

New measurements were performed with the Root ZX II and SmarPex devices in order to follow their manufacturer´s instructions, which recommend that the "0.5" mark of the device display indicates that the tip of the file reached

the apical constriction. In the RomiApex manufacturer's instructions, there is no recommendation regarding this kind of measure adjustment, so the zero position is considered as such. So were not made new measurements with corrections to this device. Measurements were repeated 3 times and the averages were calculated and computed. The precision of each EAL was determined by the real length minus the electronic length. From this calculation, positive and negative values indicated measures longer and shorter than the apical foramen, respectively.

Accuracy of the apex locators was classified as precise, acceptable and unacceptable. Precise, if the real length and electronic length measurements coincided. Acceptable, if it showed a range of ±0.5 mm in comparison to the real length. Unacceptable, if the electronic measurements were higher or lower than ±0.5 mm of real length.

2.3 Statistical Analysis

The real teeth length and the measures obtained with the devices were computed, and the data were submitted to statistical analysis with the Friedman test for comparisons between the devices at the same measurement time and the Wilcoxon test for the comparisons for each device between two measurement times. Both tests were carried out with a significance level of 0.05% ($p < 0.05$). Statistical analyses were performed with the use of the Prism 5.0 software (GraphPad Software Inc, La Jolla, CA, USA).

3. RESULTS

All evaluated devices used with stainless steel hand files were able to precisely and acceptably locate the apical constriction of the teeth. No unacceptable electronic readings were found for all groups. Tables 1 and 2 shows the percentage of measurements obtained from all devices at precise, acceptable and unacceptable readings, before and after the corrections recommended by the Root ZX II and SmarPex manufacturer's instructions, respectively.

The Root ZX II was the EAL that presented the greater percentage of coincidences with the zero position (73.33%), followed by the RomiApex A-15 (66.66%) and SmarPex (40%), however, no statistically significant differences in the precision ($p > 0.05$) were detected between devices in the first measurement time. Mean differences between the real root canal length and electronic measurements are shown in Table 3.

When the "0.5" was considered as zero position, according to the manufacturers instructions, the percentage of coincidence with the real length was 86.66% for the Root ZX II and the SmarPex. These results were similar ($p > 0.05$) in comparison to that found with the RomiApex A-15 device. Additionally, only this equipment presented measurements beyond the zero position (20%). Only the SmarPex device showed a statistically significant ($p < 0.05$) difference after the adjustment recommended by the manufacturer, and it enhanced the mean precision with the zero position (Table 3).

Table 1. Percentage of samples incidence of precise, acceptable, and unacceptable measurements found at the display "zero position" for the devices evaluated

Device	Precise		Acceptable				Unacceptable		Total (n)
			+ 0.5 mm		- 0.5 mm				
	%	n	%	n	%	n	%	n	
Root ZX II	73.33	11	13.33	2	13.33	2	0	0	15
SmarPex	40	6	46.66	7	13.33	2	0	0	15
RomiApex A-15	66.66	10	20	3	13.33	2	0	0	15

Table 2. Percentage of samples incidence of precise, acceptable, and unacceptable measurements after correction (at 0.5 mark) according to the Root ZX II and SmarPex manufacturer's instructions performed

Device	Precise		Acceptable				Unacceptable		Total (n)
			+ 0.5 mm		- 0.5 mm				
	%	n	%	n	%	n	%	n	
Root ZX II	86.66	13	0	0	13.33	2	0	0	15
SmarPex	86.66	13	0	0	13.33	2	0	0	15
RomiApex A-15	-	-	-	-	-	-	-	-	-

Table 3. Mean differences between the real root canal length and electronic measurements before (measurement 1) and after (measurement 2), following the manufacturers' recommendations

Device	Measurement 1		Measurement 2	
	Mean	SD	Mean	SD
Root ZX II	0^{aA}	0.27	-0.07^{aA}	0.17
SmarPex	0.17^{aA}	0.36	-0.07^{aB}	0.17
RomiApex A-15	0.03^{aA}	0.29	0.03^{aA}	0.29

- Positive values indicate means longer than the real root canal lengths. Negative values indicate means shorter than the real root canal lengths.

- Different superscript lower case letters in each column indicate statistically significant differences between devices at different measurement times ($p < 0.05$).

- Different superscript upper case letters in each row indicate statistically significant differences for each individual device for different measurement times ($p < 0.05$).

4. DISCUSSION

The present study used an *ex vivo* model to evaluate the accuracy of the EAL Root ZX II, SmarPex and RomiApex-15 to determine the real length of the root canal. The proposed study design provides valuable information for the clinical practice [12] because the methodology used was able to reproduce the oral cavity conditions, whereas when establishing the correct operation of all devices used, it was possible to verify the precision of different apex locators. Furthermore, in *ex vivo* studies, it is easier to keep the controlled conditions since the canals were maintained moist with NaOCl solution during the acquirement of the measurements [11,12,20], the patency was verified [15,20], and the canal measurements were made with well-fitted files [10,21].

Floral foam soaked in saline solution was used as a way to allow the electrical current conduction [4] and showed satisfactory results in the present study. Thus, this experimental model was made as similar as possible to the situation in endodontic therapy.

Before the measurements with the EAL's, the files were inserted in the canals until the tip was visualized at the foramen level. With the use of an operative microscope, it was verified where the tip was seen, and this position was considered the foramen (zero position). Even with the magnification of the operative microscope, it was not possible to observe if the file tip was exactly at the constriction or inside the cementary canal. It has been a controversy if the EAL are able to determine the smaller constriction or the biggest foramen.

According to the manufacturers, the 0.5 mm position of the Root ZX II indicates that the file tip is in the apex constriction. Hassasien et al. in [19] found that the cementum-dentine junction and the apex constriction are not at the same place, the apex constriction is coronally to the cementum-dentine junction, concluding that when we use the measure indicated in the Root ZX II equipment, we are closer to the cementum-dentine junction than the apical constriction. Lee et al. [13] considers the fact that the equipment makes the higher impedance gradient reading at the point where the periodontal ligament is found.

A rational way to determine the working length is to find the file length to reach the foraminal constriction and then subtract 1 mm [16]. Many studies have used an average error of ±0.5 mm to verify the device´s accuracy [9,16-18,22,23], because measures reached with this tolerance are highly accurate [21]. Other studies are based in a 1.0 mm average [24,25]. One of the acceptable reasons for the ±1.0 mm average error is due to the canal ramifications in the apical area [26]. However, it is important to consider that the root canal does not always end with a well-defined apical constriction, as in cases of apical resorption, for example [27,28].

In the comparative evaluation of the real measures of the teeth regardless of the three apex locators, we observed that the Root ZX II presented a 73.33% of coincidences with the zero point; in 13.33%, the measure was at +0.5 mm and in 13.33%, at -0.5 mm. These results show that independently of what measure was obtained, the file was inside the canal in 86.66% of the cases. In the study of Lucena-Martin et al., in 95% of the cases, the file was inside the root canal [22], while in the Cianconi et al. study, this situation was found in 65.3% of the cases [29]. However, with all apex locators, the measures were at a ±0.5 mm average in 100% of the cases, which is considered extremely accurate

[18,30]. This result was similar to the results found by other authors [25,27] that found a percentage of 97.5% and 97.4%, respectively with the Root ZX II. For the SmarPex and RomiApex A-15, the percentage of coincidences were smaller than the Root ZX II percentage, been 40% and 66.66% respectively, however, without a significantly statistical difference. The accuracy percentage of RomiApex A-15 device was slightly below that found in other studies [15,16].

When the correction after the zero position determination was made retiring the 0.5mm file according to the manufacturers instruction, the percentage of coincidence with the zero point increased to 86.66% for the Root ZX II and the SmarPex, with a statistical significance for the last one, probably was because the retreat of 0.5mm set to zero position the 46.66% of 0.5mm longer than the real root canal lengths found in the first measurement with SmarPex device. Nazari Moghaddam et al. [18] used the SmarPex according to manufacturers instructions and found 80% of accuracy to detected simulated apical root perforation.

In the RomiApex A-15 manufacturer's instructions, there is no recommendation regarding this kind of measure adjustment. When the three device´s percentage after the adjustment was compared, there was no significant difference. The studied devices could be considered reliable, since the measures found were at a ±0.5 mm average in 100% of the cases. Furthermore, following the rule of retiring 1.0 mm from the total teeth length to establish the working length of the root canal preparation and obturation [13], all the electronic apex locators were shown to be suitable.

5. CONCLUSIONS

Under the study conditions, the Root ZX II, SmarPex and RomiApex A-15 were effective to locate the apical constriction of the teeth, considering a clinically acceptable average error of ±0.5 mm. Although, there were no statistical significant difference with and without manufacturers instruction, for Root ZX II, the performance was better when manufacturer instructions were followed.

CONSENT

It is not applicable.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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