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Ex Vivo Accuracy of Three Electronic Apex Locators Using Different Apical File Sizes

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This study evaluated the accuracy of three electronic apex locators (Root ZX, Novapex, and Justy II) in root canal length determinations using different apical file sizes, considering the apical constriction (AC) and the major foramen (MF) as anatomic references. The diameter of the apical foramina of 40 single-rooted teeth was determined by direct visual measurement and the master apical file was established. Electronic measurements were then performed using 3 instruments: the selected master apical file (adjusted file), one size smaller (intermediate file), and two sizes smaller (misfit file). The distances from the tip of files fixed in the canals to the MF and to the AC were measured digitally. Precision at AC and at MF for the misfit, intermediate and adjusted apical files was as follows: 80%/88%/83% and 78%/83%/95% (Root ZX); 80%/85%/80% and 68%/73%/73% (Novapex); and 78%/80%/78% and 65%/78%/70% (Justy II). Considering the mean discrepancies, statistically significant differences were found only for the adjusted file at MF, with Root ZX presenting the best results at MF. The chi-square test showed significant differences between the acceptable measurements at AC and at MF for the Justy II and Novapex (± 0.5 mm) regardless of file adjustment. Under the conditions of the present study, all devices provided acceptable electronic measurements regardless of file adjustment, except for Root ZX which had its performance improved significantly when the precisely fit apical file was used. Justy II and Novapex provided electronic measurements nearest to the AC.

Key Words: Endodontics, tooth apex, anatomy and histology, working length determination, methods, dental equipment, electric impedance.

INTRODUCTION

Since the early 20th century, several methods have been suggested for working length determination in root canals, namely monitoring patient's response when the file penetrates the apical foramen, application of the Thales' theorem, radiographic assessment and, more recently, the use of electronic apex locators (EALs) (1).

Radiographic methods are most commonly used, despite their disadvantages. Multiple radiographs are frequently required to adequately measure the canal length, and determine the shape and number of roots, canals and their possible anatomical variations. Furthermore, this technique presents several difficulties in execution and image interpretation (2-4).

EALs have been reported to present advantages over radiographic techniques (5,6). Ravanshad et al. (4) mention reduced exposure to radiation during endodontic therapy when EALs are used. Another benefit of electronic measuring devices is their ability to accurately determine the position of the foramen, particularly when the foramen does not coincide with the root apex, a frequent occurrence in all groups of teeth (7,8).

Due to these benefits and to the positive results from previous studies, showing accuracy rates of up to 90% (3,9-13), EALs have become popular among endodontists and general dentists (3,9,14) being currently used in several clinical conditions (5,6,11,13). Since their introduction, EALs evolved remarkably. In the present, the most widely used EAL is Root ZX (J. Morita, Tokyo, Japan), which simultaneously measures the impedance values at two frequencies (0.4 and 8.0 kHz) and then

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calculates their quotient (1,3,9-11). This device has shown accuracy rates between 90 and 100% even when used in unfavorable conditions, and for this reason is recognized as the gold standard of EAL (3,14).

Two other EALs have drawn attention due to their ease of use, low cost and safety: Justy II (Hager & Werken, Duisburg, Germany) and Novapex (Forum Engineering Technologies Ltd., Rishon Lezion, Israel). The first one, similarly to Root ZX, employs the quotient-ratio method based on two frequencies, but different frequencies (0.5 and 2.0 kHz) and one at a time (2). Novapex uses voltage difference and operates based on the principle that impedance measurement not only differs between two electrodes, but also differs greatly at an apical constriction region (12,13,15).

Regardless of the mechanism of operation, employed by EALs, their use with adjusted files has been recommended, but the relationship between apical file size and precision of the EALs is still poorly understood. The objectives of this study were to evaluate *ex vivo* the accuracy rates of 3 electronic devices - Root ZX, Novapex and Justy II - and to assess their performance when using different apical file sizes. Additionally, this study analyzed whether the devices were calibrated to measure canal length to the apical constriction (AC) or to the major foramen (MF).

MATERIAL AND METHODS

Forty single-rooted human teeth were selected for this study after ethics committee approval. The teeth had been extracted due to orthodontic or periodontal reasons and all donors had previously signed an informed consent form. All selected teeth had patent apical foramina and intact roots classified as Vertucci type I (16). Teeth with multiple canals, resorption, fracture, and/or incomplete apex formation were discarded.

The external root surfaces were cleaned to remove tissue remnants and the teeth were stored in saline. Coronal access was performed in a standardized manner and the canals were explored by inserting a #10 K-file (Dentsply-Maillefer, Ballaigues, Switzerland) up to the MF to establish an approximated root canal length with the aid of a clinical microscope at ×20 magnification (DF Vasconcellos, São Paulo, SP, Brazil). Cervical interferences were removed using the Profile Orifice Shapers (Dentsply-Maillefer) in order to prevent bias in the definition of the real lengths and file adjustments.

Sequentially, a file was introduced into the canal until its tip was visible at the MF, once again under magnification. At this length, the stop was placed at the occlusal reference point, the file was removed and its length was measured with an endodontic millimeter ruler (Dentsply-Maillefer) determining the real root canal length. The apical file that adjusted to this real length (master apical file) determined the anatomic diameter of the canal. The size of this file was recorded and used to select the three files to be used during the study.

In the following step, the teeth were fixed to a support and root canal instrumentation was performed in a crown-down manner using Profile Orifice Shapers (Dentsply-Maillefer) and Profile rotary system (Dentsply-Maillefer) up to sizes 30/06, 2.0 mm short of the previously established root canal length. Irrigation was carried out with 3.0 mL of 2.5% sodium hypochlorite at each change of file, using an endodontic syringe with specific needles (Navi Tip; Ultradent, South Jordan, UT, USA).

The electronic measurements were performed as previously described by Vasconcelos et al. (3). The apical third of each tooth was immersed in a plastic box containing fresh alginate (Jeltrate II; Dentsply Ind. & Com. Ltda, Petrópolis, RJ, Brazil). The lip clip electrode was also inserted into the alginate. Since this experiment involved the use of fresh impression material, the time frame for measurement of the canals was 30 min *per* group of 10 teeth. The devices were operated according to manufacturers' instructions: after connecting the lip clip, the electrode was attached to the file inserted in the canal. The file was then advanced into the canal until the EAL screen displayed the reach of the apex (0.0) by presenting the word "APEX" (Root ZX), the "0.0" led activation (Novapex), or the needle approach to the "APEX" landmark (Justy II).

The canals were kept moist with irrigant throughout the procedures. All measurements were made in triplicate with the 3 devices (Root ZX, Novapex, and Justy II) and with the three apical file sizes, always varying the sequence of use. Initially, the electronic measurements were carried out with a file two sizes smaller than the master apical file determined previously (misfit file), then with a file one size smaller (intermediate fit), and finally with the master apical file (adjusted file), which was fixed to the pulp chamber of each tooth with a cyanoacrylate-based adhesive (Three Bond do Brazil Ind. & Com. Ltda, São Paulo, SP, Brazil) after the last measurement was performed.

After that, two grooves were made on the buccal

and lingual aspects of each root using a double-faced diamond disc, taking care to avoid reaching the canal. An additional transverse groove 5.0 mm distant from the root apex was made to allow cleavage of the apical third without disrupting the file fixation. The apical thirds were then split into halves with a chisel and digitally photographed under ×10 magnification in order to analyze the location of the file tip in relation to the AC and to the MF, using the Carnoy 2.0 software (Laboratory of Plant Systematics, Katholieke University, Leuven, Belgium). The distances between the file tips and each anatomical structure were correlated with all the other measurements obtained for each specimen. Statistical analysis was carried out by Kruskal-Wallis and Mann-Whitney tests at 5% significance. The percentage of acceptable measurements recorded with each EAL at 0.5 mm and 0.75 mm tolerance margins were also analyzed using the chi-square test. The significance level was set at 5%.

RESULTS

Table 1 presents the mean discrepancies, in absolute values, between the electronic measurements to the AC and MF, in millimeters, contrasting the results obtained for each file (adjusted, intermediate fit and misfit). Table 1 also shows the mean ranks of these measurements. Considering the MF, comparisons between the readings using the misfit and intermediate files did not demonstrate statistically significant differences ($p>0.05$). However, when the adjusted apical file was used, Root ZX (0.31 mm) differed significantly from the other two EALs ($p<0.05$). Novapex (0.54 mm) and Justy II (0.56 mm) did not differ significantly from each other ($p>0.05$).

Also considering the MF, when each EAL was analyzed alone, it was observed that using an adjusted, intermediate, or misfit file did not influence the accuracy of Novapex and Justy II. The results were statistically similar for these two EALs, regardless of the file used ($p>0.05$). However, for Root ZX, readings using the adjusted apical file (0.31 mm) statistically similar results were found to the intermediate file (0.40 mm) ($p>0.05$) and significantly better results ($p<0.05$) were obtained compared with the misfit file (0.50 mm). On the other hand, measurements with the misfit file did not significantly differ from the readings obtained with the intermediate file ($p>0.05$).

The mean distances, in millimeters, from the tips of each file (adjusted, intermediate and misfit files) to the AC did not show statistically significant differences ($p>0.05$). Comparison between the three EALs also revealed no significant differences, regardless of the file used ($p>0.05$).

Table 2 presents the percentages of acceptable measurements to the MF and the AC within ±0.50 mm and ±0.75 mm margins of error. The results indicate that Root ZX reached higher levels of accuracy in all measurements, regardless of the file used, considering MF as the reference point. When the margin of error was raised to ±0.75 mm, a significant increase in accuracy was observed for all EALs, for both AC and MF.

Comparisons by the chi-square test revealed significant differences between the occurrences of acceptable measurements to the AC and MF considering ±0.50 mm

Table 1. Distance (mm) from electronic measurements considering the file adjustment.

EAL	File adjustment	Apical constriction			Major foramen		
		Mean	SD	Mean rank	Mean	SD	Mean rank
Justy II	Adjusted	0.40^{a,A}	0.29	6.46	0.56^{a,B}	0.42	8.02
	Intermediate	0.41^{a,A}	0.33	6.90	0.55^{a,A}	0.48	7.61
	Misfit	0.46^{a,A}	0.35	7.91	0.64^{a,A}	0.51	8.79
Novapex	Adjusted	0.43^{a,A}	0.27	7.43	0.54^{a,B}	0.39	7.45
	Intermediate	0.39^{a,A}	0.30	6.77	0.51^{a,A}	0.40	7.20
	Misfit	0.42^{a,A}	0.34	7.31	0.57^{a,A}	0.43	7.96
Root ZX	Adjusted	0.41^{a,A}	0.25	6.90	0.31^{a,A}	0.25	4.81
	Intermediate	0.43^{a,A}	0.35	7.20	0.40^{a,b,A}	0.33	5.94
	Misfit	0.49^{a,A}	0.36	8.10	0.50^{b,A}	0.39	7.21

EAL: electronic apex locator. ^{a,b}Different superscript lowercase letters indicate statistically significant differences between different file adjustments in the same EAL (Mann Whitney test, $p<0.05$). ^{A,B}Different superscript uppercase letters indicate statistically significant differences between EALs, considering each file adjustment (Mann Whitney test, $p<0.05$).

margin for Justy II and Novapex ($p<0.05$). Considering ±0.75 mm of margin the test did not reveal significant differences ($p>0.05$). The analysis did not present significant differences for the Root ZX for both tolerance margins ($p>0.05$).

The occurrence of measurements beyond the MF, that is, lengths that would reach the soft tissues, were detected at rates of 15.3% (Justy II), 29.7% (Novapex), 8.1% (Root ZX) considering only the adjusted files.

DISCUSSION

Studies in the literature do not offer standardization regarding the anatomical reference to be adopted when establishing root canal length, the measurement techniques, or even the usage instructions for each device. The accepted margin of error also varies between different studies, generating discrepancies in the results reported (3,10,14).

In the present work, two different margins of error were adopted: ±0.50 mm and ±0.75 mm. The first value is based on previous reports (3,10). Some authors, however, have suggested that this margin should be raised, since EAL readings generally fall within a distance ranging from 0.50 mm to 0.75 mm from the anatomic target selected. Other authors, such as Gutman and Leonard (17) maintain that the root canal does not always end in the AC, but rather at the MF. For this reason, some researchers consider ±1.0 mm an acceptable margin of error, as previously reported (3). Another important difference in the methodology of the present study was the measurement of the distances to two distinct anatomic references: AC and MF.

Goldberg et al. (18) evaluated four EALs and reported accuracy of 80% and 95% with Propex (Dentsply-Maillefer); 70% and 95% with Novapex; 60% and 90% with Root ZX; and 60% and 85% with Elements Diagnostic Unit and Apex Locator (SybronEndo, Glendora, CA, USA) when errors of 0.5 mm and 1.0 mm were accepted, respectively. Their results are similar to those observed in the present study when the 0.75 mm margin of error was adopted.

Root ZX, considered the gold standard in accuracy of EALs, is commonly used as a reference for comparisons (1). Studies by Plotino et al. (19) demonstrated excellent accuracy for Root ZX (94.2%, within a 0.5 mm margin of error). Dunlap et al. (20), on the other hand, reported accuracy of 82.3% for Root ZX, within the same margin of error. In another study, Welk et al. (21) reported that Root ZX was able to determine the AC in 90.7% of the specimens. The results of the present work disagree with those of these previous studies (20,21), as Root ZX showed higher accuracy than the other devices tested only when a precisely fit apical file was used (accuracy 95% within a 0.75 mm margin of error), although no significant differences were observed between the anatomical references adopted.

D'Assunção et al. (15) evaluating the accuracy rate of Novapex at the AC, observed 82% of accuracy within 0.50 mm of tolerance. A similar value was found in the present work (81.6%), when analyzing the measurements within a 0.75 mm margin of error.

Briseño-Marroquín et al. (22) also investigated the precision of four different EALs with three different file sizes. Exact measurements were obtained 36.99%, 39.04%, and 44.93% of the time with the Elements Diagnostic Unit and Apex Locator; 38.62%, 32.41%, and 43.41% with Justy II; 42.76%, 39.31%, and 39.06% with Raypex 5 (VDW, Munich, Germany); and 38.62%, 43.45%, and 40.63% with Propex II, respectively, using

Table 2. Percentage of cases with acceptable measurements for the different electronic apex locators (EALs) considering the file adjustment.

EAL	File adjustment	Apical constriction		Major foramen	
		±0.50	±0.75	±0.50	±0.75
Justy II	Adjusted	68*	78	48*	70
	Intermediate	68*	80	48*	78
	Misfit	65*	78	38*	65
Novapex	Adjusted	68*	80	53*	73
	Intermediate	70*	85	53*	73
	Misfit	68*	80	48*	68
Root ZX	Adjusted	73	83	83	95
	Intermediate	75	88	73	83
	Misfit	63	80	55	78

*Symbol indicate statistically significant differences between occurrence of acceptable measurements to different anatomic references with the same device at the same tolerance margin, according to the chi-square test ($p<0.05$).

sizes 8, 10 and 15 files, without significant differences. Those authors, however, did not previously select an apical file to precisely fit the foramen, as done in the present work. Instead, they used three file sizes that most likely did not fit the apical foramina of the specimens in their study (22).

The fit of the apical file is an important step to establish adequate file positioning, minimizing the risk of instrument displacement, and one additional factor that may potentially interfere with this is the canal preflaring (23-25). Camargo et al. (10) compared the influence of preflaring on the accuracy of Root ZX, Elements Diagnostic Unit and Apex Locator, Mini Apex Locator (SybronEndo), and Apex DSP (Septodont, Saint-Maur des Fossés, Cedex, France). The precise and acceptable (P/A) readings in non-flared canals were 50%/97.5%, 47.5%/95%, 50%/97.5% and 45%/67.5%, respectively. For preflared canals, the readings were 75%/97.5%, 55%/95%, 75%/97.5%, and 60%/87.5%, respectively. No differences were found between the EAL readings except for Apex DSP, which presented lower accuracy.

This interference occurs when the apical file is not properly fit to the canal was previously discussed by Vasconcelos et al. (3). It is important to consider the fragmentation of the physical parameters of resistance and capacitance, which might affect the precision of the measurements when gaps are present between the files and the root canal walls. The present results provide some important information for the comprehension of the relation between these physics parameters, the electronic mechanism of EALs and the adjustment of the files. The significant increase of accuracy provided by the Root ZX reinforce the importance of the capacitive factor in the interpretation of file position for this impedance quotient-ratio device which perform its measurements with both frequencies simultaneously. This characteristic differentiates it from the other EALs and could be the crucial point for its better results. For the other tested devices, this reduction of interferences to the capacitance determination did not provide any difference.

Differences in the precision of devices when using the MF or the AC as references might be explained by the calibration of each device, making some EALs more accurate when measuring canal length to one or the other anatomical reference. Possibly, differences in the operating frequency and or measuring of impedances of each device may explain the variations in accuracy when canal lengths were measured to the AC or the MF. In the present study, the results indicate that the Justy II and Novapex devices were calibrated to accurately locate the AC in consequence of having significant differences observed when the chi-square test compares its readings for both anatomical structures. Differently, Root ZX seems to concentrate its measurements at a position between the AC and the MF.

Under the conditions of the present work, the three EALs demonstrated an adequate accuracy, once again attesting the validity of these devices. Root ZX provided the most accurate results mainly when used with a precisely fit apical file; Justy II and Novapex were not influenced by this factor. Considering the calibration point, Justy II and Novapex seem to use the AC whereas, for Root ZX, it was not possible to determine.

RESUMO

Este estudo avaliou a precisão de três localizadores eletrônicos foraminais (Root ZX, Novapex e Justy II) nas determinações de odontometria utilizando limas com diferentes padrões de ajuste, considerando-se a constrição apical (CA) e do forame principal (FA) como referências anatômicas. O diâmetro dos forames apicais de 40 dentes unirradiculados foi previamente determinado por visualização direta e a lima compatível com o forame apical foi estabelecida. Medições eletrônicas foram realizadas utilizando 3 instrumentos diferentes: lima compatível com o forame apical (lima ajustada), lima um tamanho menor (lima intermediária), e lima dois tamanhos menores (lima desajustada). As distâncias da ponta dos instrumentos ao FA e a CA foram determinadas em software específico. A precisão na CA e no FA para os instrumentos desajustado, intermediário e ajustado foram: 80% / 88% / 83% e 78% / 83% / 95% (Root ZX); 80% / 85% / 80% e 68% / 73% / 73% (Novapex), e 78% / 80% / 78% e 65% / 78% / 70% (Justy II). Considerando os erros médios oferecidos pelos aparelhos, foi encontrada diferença estatística apenas nas determinações realizadas com os instrumentos adaptados tendo como referência o FA onde o Root ZX ofereceu os melhores resultados. O teste qui-quadrado apresentou diferenças significantes entre as determinações consideradas aceitáveis para a CA e o FA tanto para o Justy II quanto para o Novapex (±0,5 mm), independente do ajuste do instrumento. Nas condições do presente estudo todos os dispositivos ofereceram medições aceitáveis independentemente do ajuste dos instrumentos; exceção feita apenas ao Root ZX, que teve seu desempenho melhorado quando uma lima ajustada foi utilizada. Os aparelhos Justy II e Novapex ofereceram determinações mais próximas à CA.

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