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Accuracy of five electronic foramen locators with different operating systems: an *ex vivo* study

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ABSTRACT

Objective: The aim of this study was to evaluate, *ex vivo*, the precision of five electronic root canal length measurement devices (ERCLMDs) with different operating systems: the Root ZX, Mini Apex Locator, Propex II, iPex, and RomiApex A-15, and the possible influence of the positioning of the instrument tips short of the apical foramen. Material and Methods: Forty-two mandibular bicuspids had their real canal lengths (RL) previously determined. Electronic measurements were performed 1.0 mm short of the apical foramen (-1.0), followed by measurements at the apical foramen (0.0). The data resulting from the comparison of the ERCLMD measurements and the RL were evaluated by the Wilcoxon and Friedman tests at a significance level of 5%. Results: Considering the measurements performed at 0.0 and -1.0, the precision rates for the ERCLMDs were: 73.5% and 47.1% (Root ZX), 73.5% and 55.9% (Mini Apex Locator), 67.6% and 41.1% (Propex II), 61.7% and 44.1% (iPex), and 79.4% and 44.1% (RomiApex A-15), respectively, considering ±0.5 mm of tolerance. Regarding the mean discrepancies, no differences were observed at 0.0; however, in the measurements at -1.0, the iPex, a multi-frequency ERCLMD, had significantly more discrepant readings short of the apical foramen than the other devices, except for the Propex II, which had intermediate results. When the ERCLMDs measurements at -1.0 were compared with those at 0.0, the Propex II, iPex and RomiApex A-15 presented significantly higher discrepancies in their readings. Conclusions: Under the conditions of the present study, all the ERCLMDs provided acceptable measurements at the 0.0 position. However, at the -1.0 position, the ERCLMDs had a lower precision, with statistically significant differences for the Propex II, iPex, and RomiApex A-15.

Key words: Endodontics. Tooth apex, anatomy & histology. Odontometry methods. Dental equipment. Electric impedance.

INTRODUCTION

Precise root canal length determination using the apical constriction or the apical foramen (AF) as references is an extremely relevant factor for the success of endodontic treatments[10,11,21,23]. Electronic root canal length measurement devices (ERCLMDs) are considered efficient tools for this purpose[12,15,18,26,28], achieving precision percentages upwards of 80% *ex vivo*[2,4,6,9,17-20,23-26] and *in vivo*[8,23,27,29,30].

Presently, the most widely used ERCLMD is the Root ZX (J. Morita, Tokyo, Japan), which simultaneously measures the impedance values at two different frequencies (0.4 and 8.0 kHz), then calculates their quotient value[4,15,17,23,25,26]. This device has been extensively evaluated, displaying precision rates greater than 90%[8,12,13,17,27,29]. Another popular ERCLMD is the Mini Apex Locator (SybronEndo, Glendora, USA), a compact device operating as a

two frequency-based measurement system that emits an all-digital signal, which according to its manufacturers, leads to improved precision. Another ERCLMD, the iPex (NSK, Tochigi, Japan), based on a multi-frequency principle, was launched in 2008. However, little information is available regarding its technical specifications, aside from the fact that it utilizes two different signal frequencies. Both the Mini Apex Locator and the iPex have demonstrated satisfactory clinical results, despite the relative lack of information on their operating mechanisms, especially with regards to how these devices electronically interpret the impedance values obtained in the different frequencies during measurements within the canal[4,16,18,23,24,26].

Recently launched in the market, the RomiApex A-15 (Romidan Ltd., Kyriat Ono, Israel) and the Propex II (Dentsply/Maillefer, Ballaigues, Switzerland), measure 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[6,13,14]. The devices compare the results obtained with reference values stored in its memories and then present the file positions. Thus, differing from most ERCLMDs, the RomiApex A-15 and the Propex II operate by detecting the energy of the signal, rather than its amplitude[14]. Although these devices seem promising, at the present there are no studies in the available literature evaluating the precision of the RomiApex A-15, both *ex vivo* and *in vivo*. As for the Propex II, at the present, its precision has only been evaluated *ex vivo* at the foramen level, with satisfactory results[6,14]. Despite being based on similar operating systems, these devices have different electronic components with distinct layouts, and the possible variations due to these differences are still unknown. Regardless of their operating mechanisms, ERCLMDs have been extensively evaluated, demonstrating satisfactory precision when files are inserted up to the AF[4-7,9,12,13,15,19,26]. Nevertheless, some authors suggest the adoption of working length measurements short of the apical foramen in order to preserve the vitality of the foraminal tissues and possibly allow for the formation of a biological seal via the pulp tissue cells present in the cement canal[2,24,27]. However, recent studies show that the precision of some ERCLMDs is negatively affected in measurements short of the apical foramen, with significant variations in the mean distances to the working length in their measurements[24,26]. Nevertheless, the effects of this protocol of ERCLMD utilization are still unknown for some operating mechanisms employed by several of the devices currently in use, such as the Mini Apex Locator, the RomiApex A-15 and the Propex II.

With this in mind, the aim of the present study was to evaluate the performance of the Root ZX, the Mini Apex Locator, the Propex II, the iPex and the RomiApex A-15, all ERCLMDs with different operation systems, both at levels 1.0 mm short of the AF (-1.0 mm) and at the AF (0.0 mm).

MATERIAL AND METHODS

Forty-two single-rooted human mandibular bicuspids with completely formed roots and referred for extraction for orthodontic reasons were selected. This study was approved by the Ethics Committee of the Federal University of Ceará, Brazil under protocol number 099/11, prior to the sample collection. All the teeth were healthy, corresponded to Vertucci's type I root canal configurations and did not exhibit sharp curvatures.

The coronal access was performed using #1012 and #3081 high speed diamond burs (KG Sorensen, Barueri, Brazil) under constant irrigation. When absent, flat surfaces were created to serve as anatomical references for the rubber stops. The canals were initially explored with #10 K-files (Dentsply/Maillefer, Ballaigues, Switzerland) to confirm the absence of anatomic alterations and the foraminal patency. Two teeth did not meet these criteria and were excluded from the study. The remaining specimens were numbered and had their real lengths (RL) determined with #10 K-files introduced into the canal until their tips were visualized at the apical foramen opening under 16x magnification using an operating microscope (DF Vasconcellos, São Paulo, Brazil). The distance between the tip of the file and the stop was measured by a digital caliper with ±0.01 mm resolution (FNCL; Worker Gage, Esteio, Brazil). The diameter of the K-file adjusted at the real canal lengths for each canal was also recorded.

The coronal and middle thirds were prepared using K3 30/.06 files (SybronEndo, Anaheim, USA) 5.0 mm short of the RL, under irrigation with 2.5% sodium hypochlorite. Next, the excess solution was removed but the canals remained moist. The root apices were embedded in alginate (Jeltrate II; Dentsply, Petrópolis, Brazil) previously mixed and immediately placed in a plastic container, along with the ERCLMD lip clip. Only five teeth were embedded *per* container, to ensure that the alginate remained fresh. All devices were used at full power and the measurements were conducted in triplicate by an operator blind to the RL. The first ERCLMD to be used was randomly determined, alternating the sequence employed for the remaining ERCLMDs. All the measurements were performed with files well fitted to the canal diameter, at the length appointed by each device. Initially, the file was inserted until the device displayed that the tip was at the position of 1.0 mm on the device display, and then the instrument was removed from the

canal and measured. The measurements at the apical foramen level were conducted in the same manner, but the file was inserted until the "APEX" postion and/or 0.0 were displayed. Measurements were considered concluded only after 05 seconds of stability.

The mean values obtained were compared to the RL and RL -1.0 mm in order to calculate the mean error (discrepancy) of each device, in millimeters, at the two positions relative to the apical foramen. Negative and positive values were assigned for measurements under or over the previously determined RLs, respectively. Considering the non-parametric nature of the data presented by the Shapiro-Wilks goodness-of-fit test, the statistical analyses were carried out by the Wilcoxon test for the comparisons between both levels (0.0 mm and -1.0 mm) for each ERCLMD measurement and by the Friedman test for comparisons among the ERCLMDs at the same level, both with a significance level established at 5%.

RESULTS

The diameters of the root canals at the real canal length ranged between 150 µm and 350 µm, presenting 250 µm as the mean value.

Table 1 presents the mean error (absolute values of discrepancies), in millimeters, between the electronic measurements and the previously established RL and RL -1.0 mm. Comparison of the measurements at 0.0 mm and -1.0 mm, using the Propex II, the iPex, and the RomiApex A-15, presented statistically significant differences ($P<0.05$), which was not observed for the Root ZX and the Mini Apex Locator ($P>0.05$). Regardless of the ERCLMD utilized, statistically significant differences in the precision were also detected between the measurements taken at 0.0 mm and -1.0 mm ($P>0.05$).

Tables 2 and 3 lists the distribution of measurements obtained from all devices at the 0.0 mm and -1.0 mm levels, respectively. Considering the measurements performed at the 0.0 mm level, the occurrence of determinations beyond and at

Table 1- Distance (mm) from device measurements to 0.0 and -1.0

Device	0.0			-1.0		
	Mean*	SD	Mean Ranks	Mean*	SD	Mean Ranks
Root ZX	0.39^{a,A}	0.29	0.43	0.61^{a,A}	0.35	0.62
Mini Apex Locator	0.40^{a,A}	0.32	0.50	0.61^{a,A}	0.53	0.61
Propex II	0.39^{a,A}	0.30	0.50	0.80^{b,AB}	0.41	0.81
iPex	0.47^{a,A}	0.43	0.54	1.01^{b,B}	0.55	1.01
RomiApex A-15	0.38^{a,A}	0.27	0.39	0.68^{b,A}	0.38	0.66

* Mean error calculated in terms of absolute values of the determinations. SD= standard deviation

^{a,b}Different superscript lower case letters indicate statistically significant differences between different positions in the same device according to the Wilconxon test (P<.05)

^{A,B}Different superscript upper case letters indicate statistically significant differences between different devices at the same position according to the Friedman test (P<.05)

Table 2- File tip position relative to the apical foramen for measurements performed to 0.0

Distance from apical foramen (mm)	Root ZX		Mini Apex Locator		Propex II		iPex		RomiApex A-15	
	n	%	n	%	n	%	n	%	n	%
<-1.01*	4	11.8	4	11.8	3	8.8	5	14.7	3	8.8
-1.0 to -0.51*	3	8.8	5	14.7	8	23.5	7	20.6	3	8.8
-0.5 to -0.01*	14	41.2	17	50.0	15	44.1	13	38.2	14	41.2
0.00	2	5.9	1	2.9	3	8.8	3	8.8	3	8.8
0.01 to 0.5	9	26.4	7	20.6	5	14.7	5	14.7	10	29.4
0.51 to 1.0	2	5.9	0	0.0	0	0.0	1	2.9	1	2.9
>1.01	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0

*Negative value indicates file position short (or coronal) to the apical foramen

Table 3- File tip position during measurements performed short of the apical foramen (-1.0 mm)

Distance from apical foramen (mm)	Root ZX		Mini Apex Locator		Propex II		iPex		RomiApex A-15	
	n	%	n	%	n	%	n	%	n	%
<-2.01*	0	0.0	4	11.8	8	23.5	12	35.3	0	0
-2.0 to -1.51*	3	8.8	5	14.7	6	17.6	2	5.9	3	8.8
-1.5 to -1.01*	4	11.8	8	23.5	6	17.6	7	20.6	2	5.9
-1.00	1	2.9	2	5.9	2	5.9	0	0.0	0	0
-0.99 to -0.50	11	32.4	9	26.5	6	17.6	8	23.5	13	38.2
-0.49 to 0.0	11	32.4	5	14.7	5	14.7	4	11.8	11	32.4
>0.01	4	11.8	1	2.9	1	2.9	1	2.9	5	14.7

*Negative value indicates file position short (or coronal) to the -1.0 mm position

the apical foramen were determined at 32.9% and 5.9% (Root ZX), 20.6% and 2.9% (Mini Apex Locator), 14.7% and 8.8% (Propex II), 17.6% and 8.8% (iPex), and 32.3% and 8.8% (RomiApex A-15), respectively (Table 2).

DISCUSSION

Although the results from the *ex vivo* studies should not be simply extrapolated to a clinical setting, they still provide valuable information[8]. It would be difficult to use such a large number of devices with the same patient. Furthermore, *ex vivo* tests allow, as performed in the present study, the maintenance of all controlled conditions by using fresh alginate to simulate the periapical tissue conditions[1], by maintaining the canals moist with a NaOCl solution during the acquirement of the measurements[8,26,28-30], by verifying the patency of each canal[14,28], pre-flaring[3], and measuring the canals with well-fitted files[4,9,22,25].

The values obtained for the measurements at the apical foramen level corroborate with previous studies, showing precision rates of approximately 90% (Root ZX at 88.2%, Mini Apex Locator at 88.2%, Propex II at 91.2%, iPex at 85.3%, and RomiApex A-15 at 91.2%), assuming a tolerance margin of ±1.0 mm[19,23,26]. Some authors, however, consider this margin to be excessive, over-estimating the precision of the devices[4,19,26,30]. In fact, when the tolerance margin was set at ±0.5 mm, we observed marked reductions in the precision of all ERCLMDs (73.6% for the Root ZX, 73.5% for the Mini Apex Locator, 67.6% for the Propex II, 61.7% for the iPex, and 79.4% for the RomiApex A-15), also reported by Pascon, et al.[19] (2009) and Vasconcelos, et al.[26] (2010). Thus, considering the risks of over-estimation of the precision of the devices, it seems more accurate to consider the tolerance margin of ±0.5 mm.

The mean error values showed that regardless of the operating system utilized, all the tested devices had a higher precision at the apical foramen level (0.0 mm), corroborating with previous evaluations for the Root ZX (0.39±0.29 mm)[4,6,7,12,13,17,19,26], the Mini Apex Locator (0.40±0.32 mm)[4,7], the Propex II (0.39±0.30 mm)[6,12,13], and the iPex (0.47±0.43 mm)[16,23,26]. As highlighted for the RomiApex A-15, no previous studies with a similar design evaluating its precision were found. However, our findings show that this device had the lowest mean error values among all the tested ERCLMDs (0.38±0.27 mm) suggesting that systems based on the evaluation of the energy of the signal, instead of its amplitude, may result in extremely reliable measurements. Considering these values, special attention should be given to the fact that, in order to prevent the compensation between positive and negative readings, the mean error values have been calculated as its absolute values (*modulus*), representing the real error value produced by the devices.

For the measurements at the -1.0 mm level, all devices suffered a reduction in their mean error values. Previous studies presented similar values for the Root ZX at this position[2,24,26], which despite presenting a slight increase in its mean error value (from 0.39 mm to 0.61 mm), it can still be considered a precise device for measurements at the -1.0 mm level. Similarly, the results for the iPex corroborate with a previous evaluation, where a great variation in the mean error values were found in the measurements conducted -1.0 mm short of the AF[26]. In the present study, the mean discrepancy of the iPex rose from 0.47 mm to 1.01 mm, corresponding as the worst result among the tested devices ($P<0.05$). For some reason, still unclear due to the relative lack of information regarding the operation of the iPex, it seems that the precision of this multi-frequency

device is greatly affected when the instruments do not reach the AF. One possible hypothesis is that its operating system interprets the capacitance and the resistance separately at some instances, which would explain its loss of reliability when these factors are absent when determining the position of the instruments within the canals.

The other ERCLMDs, until now, had not been tested at positions short of the AF. The Mini Apex Locator, the Propex II, and the RomiApex A-15 also presented increases in their mean error values from 0.40 mm to 0.61 mm, from 0.39 mm to 0.80 mm, and from 0.38 mm to 0.68 mm, respectively. The results provided by the Mini Apex Locator, despite the limited technical information available, suggest that its mechanism may be quite similar to that of the Root ZX, since the devices displayed analogous behavior at different levels. This was also observed in previous studies, where these devices were submitted to different root canal preparations or in the presence of different irrigating solutions[4,7,9]. The Propex II and the RomiApex A-15 presented statistical significant differences between their measurements at both levels (0.0 mm and -1.0 mm) ($P<0.05$). This behavior suggests that although these ERCLMDs rely on energy signals and not on their amplitude, their accuracy is reduced during complicating factors, such as not reaching the AF. This may be explained by the loss of resistance data, similarly to what might have occurred to the iPex.

The results demonstrated the importance of conducting electronic canal length measurements at the apical foramen level, with the file tip positioned either at the apical constriction or at the major AF, structures that cannot be differentiated clinically[24,28]. Nevertheless, the Mini Apex Locator, together with the Root ZX (which operates by calculating the impedance at two different frequencies) had a smaller loss of precision when the tip was positioned 1.0 mm short of the AF. On the other hand, the iPex (a multi-frequency device), the Propex II and the RomiApex A-15 (devices that operate by detecting the energy of the signal) suffered a significant loss of precision.

CONCLUSION

Under the conditions of the present study, all the ERCLMDs provided acceptable measurements at the position of 0.0. However, at the -1.0 position, the ERCLMDs had a lower precision, with statistically significant differences for the Propex II, iPex, and RomiApex A-15.

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