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Efficacy of Electronic Foramen Locators in Controlling Root Canal Working Length during Rotary Instrumentation

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The present study evaluated the efficacy of electronic foramen locators (EFLs) to control root canal working length during rotary instrumentation and to assess possible reliability variations of different working lengths. Forty-eight human mandibular bicuspids were randomly divided in 2 groups according to the used device, Root ZX II (RZX) and Propex II (PRO). They were further subdivided in 2 subgroups according to the root canal preparation level (0.0 and -1.0). Preparation was performed with the Protaper rotary system using a crown-down technique. RZX was employed on its automatic auto-reverse mode (AAR) and PRO was used with the MPAS-10R contra-angle to monitor the preparation. The last used file (F3) was fixed, and the apical portion of the teeth was worn buccolingually, allowing to measure the extent between the file tip and the apical foramen (AF). The precision values of 0.0 mm and -1.0 mm were 100% and 0.0% for RZX, and 100% and 66.7% for PRO, respectively, with a range of ±0.5 mm. Statistical analysis showed no differences between the groups at 0.0 mm. However, at -1.0 mm, RZX showed the poorest results (0.96±0.11 mm), followed by PRO (0.43±0.23 mm). The difference between RZX and PRO was statistically significant. The EFLs were precise in maintaining the working length during rotary preparation when reaching the AF, but when their penetration was limited, both devices showed decreased precision; the RZX AAR failed in all instances.

Key Words: electronic foramen locators, root canal preparation, working length.

Introduction

Precisely determining root canal length is one of the key steps leading to successful outcomes and treatment safety (1-3). Studies have shown that electronic foramen locators (EFLs) are extremely effective, reaching success rates greater than 80% *ex vivo* (4-7) or *in vivo* (2,8-12).

Root ZX (J. Morita, Tokyo, Japan) works by determining root canal length by calculating the impedances at two frequencies, 0.4 and 8.0 kHz, measured simultaneously (2,5,9,13). Studies have shown that Root ZX presented reliable results, providing accurate values over 90% when used even under unfavorable conditions (5,12,14-17).

Recently, hand pieces with integrated EFLs have been employed to assist in the mechanical preparation of the root canal system. This arrangement has increased use because of its simplicity, improved workflow and reliability (1-3,7,18). One such device is Root ZX II (J. Morita, Tokyo, Japan), which associates 2 modules that allow the integration of an EFL with an electric motor for mechanical preparation (1-3,7,18). Another possibility is to integrate an EFL and a low-speed MPAS-10R contra-angle (NSK, Tokyo, Japan) into a single unit, further simplifying the equipment. It combines with an electric motor (X-Smart; Dentsply-Maillefer, Ballaigues, Switzerland), allowing the operator constant monitoring of the position inside the root canal system (2). This device could be coupled to any EFL. One of them, the Propex II (Dentsply-Maillefer), is based on the determination of the square root of the mean impedances at two frequencies, 0.5 and 8.0 kHz, measured separately and compared to the reference values of the device memory. According to the manufacturer, Propex II has the advantage of improved accuracy due to reduced electronic noise (15). Studies evaluating its accuracy in *ex vivo* and *in vivo* conditions with manual instruments showed precision values up to 90% (12,15,17).

The apical limit of root canal instrumentation should extend to 1.0 mm short of the radiographic apex, a position that would represent the *loci* of the apical constrictions (19,20). However, based on instrument rigidity, apical curvature and anatomy of the apical foramen (AF), some researchers suggest different instrumentation end-points. The main benefits to extend preparation up to the AF include reducing the risks of apical deviations and eliminating bacterial contamination possibly located in the last 1.0 mm of the root canal (16,21,22). However, the use of the hybrid devices limited to positions short of the AF may compromise the accuracy and reliability of the EFLs (7,9,17).

It is well established that the combination of EFLs with slow speed hand pieces improves workflow, however the accuracy of these strategies (e.g., Root ZX II and Propex

II/MPAS-10R) has been questioned (2,3). Accordingly, the aim of this study was to evaluate the precision of these hybrid devices and possible variations caused by different working lengths (0.0 mm and -1.0 mm short of the AF).

Material and Methods

Forty-eight human single-rooted mandibular bicuspids with complete root formation, extracted for orthodontic, prosthetic and/or periodontal reasons were selected for this study after approval by the Research Ethics Committee of the Federal University of Ceará (Protocol. #531.206/2014). The selected teeth were limited to premolars with Vertucci Type I roots and patent apical foramina measuring less than 200 µm. Teeth with extensive caries, significant curvatures, root resorption or fractures were excluded from the study.

Access opening was created using a water-cooled high-speed handpiece, diamond burs #1012 and #3081 (KG Sorensen Ind., Barueri, SP, Brazil) in a standard technique. Initial canal exploration was performed with manual #10 K-files (Dentsply-Maillefer) in order to verify the presence of a single root canal and foraminal patency. At this moment the original diameter of the AF was determined adjusting a K-file in its opening observed with a clinical microscope using 40x magnification (Alliance, Campinas, SP, Brazil). Canals in disagreement with the inclusion criteria were substituted. Then, the specimens were numbered and the root canal lengths were determined under magnification. The foramina were then instrumented to a #20 K-file.

Biomechanical preparation of cervical and middle thirds of the root canals was performed with the Protaper System S1 and SX instruments (Dentsply-Maillefer), using the crown-down technique. The instruments were rotated in an electric motor (X-Smart; Dentsply-Maillefer) according to manufacturer's recommendations (300 rpm and 2.0 N) 5.0 mm from the AF. Irrigation was made between each instrument insertion with 1.0 mL of 2.5% sodium hypochlorite (Biodinâmica, Ibiporã, PR, Brazil) with an appropriate irrigating syringe and needles (Navitip; Ultradent, South Jordan, UT, USA). After the preparation of the cervical and middle thirds of the root canal, the excess irrigating solution was suctioned from the pulp chamber keeping the root canal moist and maintaining foraminal patency.

After the preparation of the cervical and middle thirds of the root canal was completed, the teeth were randomly divided in 2 groups according to the used EFL device: Group 1 - Root ZX II; and Group 2 - Propex II/MPAS-10R. These groups were divided into 2 subgroups depending on the extent of the apical preparation (i.e. working length): 0.0 mm (n=12) and 1.0 mm short from the AF (n=12). The teeth were then attached to a support and their root apices were immersed in alginate (Jeltrate II; Dentsply, Petrópolis, RJ, Brazil) to help establish contact with the labial clip of the device. The experiment was performed in groups of 6 or fewer teeth in fresh alginate mixed no more than 30 min before measurements were performed.

A single researcher calibrated and blinded to the previously determined real length, conducted root canal instrumentation of the specimens. The sequence of instrumentation followed the Protaper manufacturer's recommendations with the crown-down technique, concluding with an F3 file. 1.0 mL of 2.5% sodium hypochlorite was used between each file insertion and the foraminal patency was checked. The Root ZX II employed calibration of the automatic auto-reverse (AAR) function based on both apical limits (0.0 mm and 1.0 mm). The Propex II/MPAS-10R device used the apical limit presented by the ELF, as determined by the operator. Following root canal preparation, the last instrument was disconnected from the contra-angle and fixed in place at the assigned working length with cyanoacrylate adhesive (Super Bonder; Loctite of Brazil, São Paulo, SP, Brazil).

The teeth were visualized under the clinical microscope at a 16x magnification and had their apical 4.0 mm carefully worn with a diamond tip (#3082; KG Sorensen) in buccolingual direction to allow for the visualization of the entire apical portion of the root canal. The last layer of dentin was removed with a scalpel blade (#15; Embramac, Campinas, SP, Brazil). The specimens were photographed with a digital camera attached to the microscope at 40x magnification (Fig. 1) and analyzed with Image Tools 3.0 software (UTHSCSA, San Antonio, TX, USA). The photomicrographs were blindly analyzed, with negative

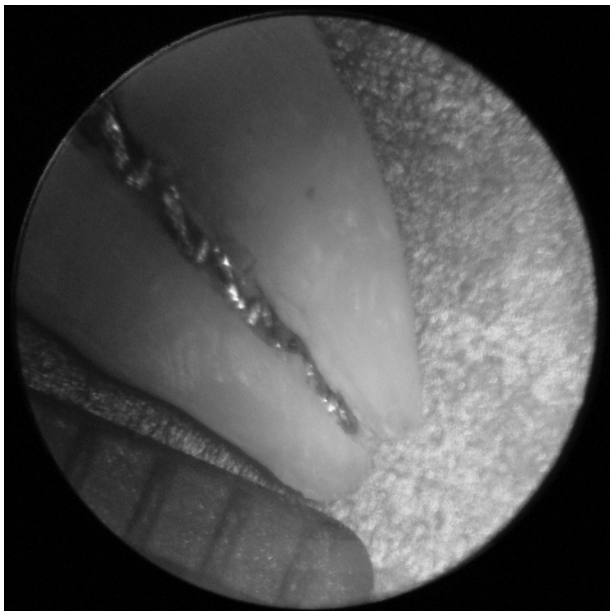

Figure 1. Image captured at 40× magnification presenting a specimen after the preparation of root apex for the error measurement.

and positive values assigned to measurements indicating short and beyond the AF, respectively. Statistical analysis was carried out to measure the differences between the absolute mean errors of devices, measured in millimeters. The Shapiro-Wilk test confirmed the parametric nature of the results; they were submitted to the ANOVA and Bonferroni test with significance set at 5%.

Results

Table 1 presents the average errors with standard deviation, as well as the values found for each group at 0.0 mm and -1.0 mm from the AF. Statistical analysis showed no significant difference between the devices when measurements at the AF were analyzed (0.0 mm) ($p>0.05$). However, when the penetration of the instruments was set at -1.0 mm, a significant difference was detected between the devices when compared to the other groups ($p<0.05$).

Tables 2 and 3 present the distribution and percentages of each device with respect to the preparations at 0.0 mm and -1.0 mm, respectively. Accuracy of the devices with a tolerance of ±0.5 mm at 0.0 mm was 100% for both the Root ZX II and Propex II. At -1.0 mm, using the same tolerance level, the accuracy of Root ZX II was 0.0% and of Propex II was 66.7%. Instrumentation beyond the apical limit occurred in 33.3% of the Root ZX II instrumented teeth and 0.0% with the Propex II instrumented teeth. Regardless of the device used, a statistically significant difference was found between the measurements at 0.0 mm and -1.0 mm ($p<0.05$).

Discussion

The present study aimed to verify *ex vivo* the ability of devices that combine EFLs for determining the root canal length with electric motors for mechanical instrumentation of the root canal system, allowing precise control of the apical extent during the root canal preparation. Although care should be taken before extrapolating the results of *ex vivo* studies to clinical reality, studies have shown that the methodology used in this study was able to faithfully reproduce what was found in clinical conditions (23).

The methodological procedures performed in the present study do not differ from previous researches (4,6,7,14,17). However, special attention was given to standardization of the specimens and the used preparation levels. Relative to the standardization, the main aspect was AF calibration. It was performed to achieve similar apical adjustment for the employed rotary files; this adjustment was appointed as an important tool for increasing the EFL precision rates (5,6,9). As for the apical preparation level (i.e., the working length [WL]), although the instrumentation is commonly established at 1.0 mm before the AF (4,7,21,22), recent studies presented a decrease of precision rates of ELFs at

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

Distance from apical foramen (mm)	Root ZX II		Propex II + MPAS	
	n	%	n	%
< -0.51*	0	0.0	0	0.0
-0.5 to -0.01*	3	50.0	5	83.3
0.00	1	16.7	1	16.7
0.01 to 0.5	2	33.3	0	0.0
> 0.51	0	0.0	0	0.0

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

Distance from apical foramen (mm)	Root ZX II		Propex II + MPAS	
	n	%	n	%
< -2.01*	0	0.0	0	0.0
-2.0 to -1.51*	0	0.0	0	0.0
-1.5 to -1.01*	0	0.0	1	16.7
-1.00	0	0.0	0	0.0
-0.99 to -0.50	0	0.0	3	50.0
-0.49 to 0.0	5	83.3	2	33.3
> 0.01	1	16.7	0	0.0

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

Device	0.0				-1.0			
	Mean*	SD	Margin		Mean*	SD	Margin	
			Minimum	Maximum			Minimum	Maximum
Root ZX II	0.11a	0.08	-0.26	0.19	0.96c	0.11	0.82	1.11
Propex II + MPAS	0.22a	0.12	-0.33	0.00	0.43b	0.23	-0.40	0.78

*Mean error calculated in terms of absolute values of the determinations. Different superscript letters indicate statistically significant differences according to the one-way ANOVA and Bonferroni tests ($p<0.05$).

this level (7,9,17). Considering this information, two WLs were employed at the present study: 1.0 mm before the AF, and at the AF, a reference point at which EFLs present their highest precision (7,9,17); in both cases were used the same Protaper F3 file.

Until the present study was conducted, no study evaluated the accuracy of Propex II in monitoring the working length during mechanical preparation at any level. The MPAS/10R combination allowed the use of this apparatus throughout the mechanized preparation of the canal system. The results obtained by this association were compared to those by Root ZX II.

In the present study, Root ZX II presented extremely accurate results when controlling the extent of root canal preparation, when set to reach the AF. In all specimens of this group, the device pointed apical extension of instrumentation within the employed margin of tolerance (±0.5 mm). These results disagree with some previous studies that used its AAR control, presenting values around 50% or lower (3,18). This disagreement may be related to the employed apical limit (the AF instead of 0.5 mm before the AF). Insertion until reaching the AF may have favored a better interpretation of the resistive factor when processing the data during the mechanical preparation, as demonstrated by Vasconcelos et al. (7). When evaluating the results obtained at 1.0 mm short of the AF (-1.0 mm), theoretically defining the area of the pulp stump and apical stop, Root ZX II erroneously determined the canal length in all specimens, presenting a significant difference when compared to other groups.

Propex II, when used with the MPAS-10R showed 100% accuracy when set to reach the AF, considering the margin of error. However, when the working length was limited to -1.0 mm, it presented a decrease in accuracy, offering mean errors statistically different from those provided by this device at the AF; in every case better than those provided by Root ZX II at the same limit. This could be related to differences between their operating methods. Such results are difficult to compare with the published literature since this equipment has not been previously employed with a monitoring function. Considering the monitoring function as previously described, Propex II presented results slightly lower than those found in its conventional application (2,15,17). This finding may be related to the existence of some delay between the EFL determination and the interruption of file penetration into the root canal.

It is important to emphasize the accuracy of the tested hybrid devices. Root ZX II, in AAR function and Propex II/ MPAS-10R combination, both enabled monitoring and provided excellent reliability as tools for working length control during mechanical root canal preparation, as long as calibrated to the AF (0.0 mm). However, the results show great difficulty in maintaining accuracy when restricted to 1.0 mm short from the AF. Such findings highlight the reliability of these devices to control and/or monitor the extent of the root canal preparation; yet, they lose accuracy in positions below the AF. Their determinations in these cases should be confirmed, improving accuracy that may improve success rates of endodontic treatments.

Thus, considering the conditions of this study, the tested devices/combinations were extremely accurate in maintaining the apical extent of mechanical instrumentation when used up to 0.0 mm from the AF. When limited to -1.0 mm from the AF, the devices presented reduced accuracy; with Root ZX II AAR system failing to indicate the correct limit in all cases.

Resumo

O presente estudo avaliou a eficiência de localizadores eletrônicos foraminais (LEFs) em controlar o limite apical de instrumentação durante o preparo com instrumentos rotatórios. Adicionalmente, determinou-se possíveis variações quando do emprego de diferentes comprimentos de trabalho. Quarenta e oito pré-molares inferiores humanos foram randomicamente divididos em 2 grupos de acordo com o aparelho empregado, Root ZX II (RZX) e Propex II (PRO). Em seguida foram subdivididos em 2 subgrupos em função do limite de preparo (0,0 e -1,0 mm). O preparo dos canais foi realizado com o sistema Protaper em sentido coroa-ápice. O RZX foi utilizando em sua função auto-reverso automático (ARA) e o PRO associado ao contra-angulo MPAS-10R, foi empregado como ferramenta de monitoramento durante o preparo. O último instrumento utilizado (F3) foi fixado em posição, após o que a porção apical dos dentes foi desgastada permitindo a determinação da distância entre a ponta dos instrumentos e o forame apical (FA). A precisão a 0,0 mm e -1,0 mm foi de 100% e 0,0% para o RZX, e de 100% e 66,7% para o PRO, respectivamente, considerando uma margem de ±0,05 mm. A análise estatística não encontrou diferenças entre os grupos a 0,0 mm, todavia, a -1,0 mm, o RZX ofereceu os piores resultados (0,96±0,11 mm), seguido do PRO (0,43±0,23 mm). Esta diferença foi estatisticamente significante. Os LEFs foram precisos na manutenção do comprimento de trabalho durante o preparo rotatório quando se atingiu o FA, todavia, quando esta penetração foi limitada, ambos os aparelhos perderam em precisão; o sistema ARA do RZX falhou em todos os casos.

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