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In Vivo Accuracy of Two Electronic Foramen Locators Based on Different Operation Systems

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The aim of this study was to compare *in vivo* the accuracy of two electronic foramen locators (EFLs) based on different operation systems - Root ZX and Propex II. Ten healthy adult patients needing premolar extractions due to orthodontic reasons participated in the study, providing a sample of 17 noncarious, non-restored, vital teeth (n= 24 canals). After coronal access preparation and cervical preflaring and prior to tooth extraction, the root canal length was measured alternating the two EFLs. All measurements were performed with K-files well fitted to the canal diameter at the level that each EFL indicated the apical foramen in their display (APEX or 0.0). The last K-file were fixed in place with cyanoacrylate, the tooth was extracted, and the apical 4 mm of each root were resected to measure the distance between the file tip and the apical foramen. The mean errors based on the absolute values of discrepancies were 0.30 ± 0.29 mm (Root ZX) and 0.32 ± 0.27 mm (Propex II). Analysis by the Wilcoxon test for paired samples showed no statistically significant differences between the electronic canal measurements performed with the EFLs (p=0.587). The apical foramen was accurately located in 75% (Root ZX) and 66.7% (Propex II) of the cases, considering a ±0.5 mm error margin, with no statistically significant difference by the chi-square test. Despite having different measurement mechanisms, both EFLs were capable of locating the apical foramen with high accuracy *in vivo*. Under the tested clinical conditions, Root ZX and Propex II displayed similar results.

Key Words: electronic apex locator, root canal length determination, apical foramen, Root ZX, Propex II.

Introduction

Success of endodontic treatment may be confirmed clinically, radiographically, or histologically. Nevertheless, histological success is the true objective of endodontic therapy (1), despite not being regularly confirmed in clinical settings. Several *in vivo* studies demonstrated that histological conditions are more favorable when the filling remains short of or limited to the apical constriction (2). However, precise determination of this anatomical landmark is extremely difficult (3-5).

Several devices for measuring the root canal length have been developed and tested (4). Despite initially frustrating attempts, electronic foramen locators (EFLs) have evolved and today are regarded as important tools in clinical endodontic practice and currently used in several clinical conditions (5-7). Since their introduction, the precision of these devices was the aim of several *ex vivo* and *in vivo* investigations, demonstrating accuracy rates between 60% and 100% (3,5,7-17). Despite these high percentages, new mathematical methods for electronic canal length determination have been studied, aiming to further enhance the accuracy of the readings and minimize the potential interference of clinical factors, such as the presence of different fluids within the canal, anatomical variations, absence of foraminal patency, use in immature teeth with open apices, among others (4,6,12).

Root ZX (J. Morita, Tokyo, Japan), one of the most extensively evaluated EFLs (7,11,18,19), was developed in 1991 and introduced to use in 1994 (4). Its measurements are performed by calculating the impedance quotient of two distinct frequencies (0.4 and 8.0 kHz) (4,7,10,17-19) employed simultaneously at each point within the root canals during measurement (4,17). This device has shown precision rates greater than 90% and up to 100%, even when used in unfavorable conditions, and for this reason it is recognized as the gold standard for foramen locators (5,7,12,14,18-20).

Propex II (Dentsply-Maillefer, Ballaigues, Switzerland), an EFL recently launched to the market, operates by capturing the signals of two alternating currents (0.5 and 8.0 kHz) and for this calculation, the mean square root of impedances at these two frequencies are measured separately. The data obtained by these calculations are compared to reference values stored in its memory, providing readings of the file positions during its penetration in the root canals (13,15,21). Unlike most EFLs, the Propex II operating system measures not only the amplitude of the signal, but also its energy, being reportedly less affected

by potential interferences in the root canal (13,15,21). Previous *ex vivo* studies, assessing its precision at the apical foramen level, demonstrated its potential as a root canal length measurement device (13,15,21).

Considering the aforementioned factors, the lack of *in vivo* studies evaluating the precision of EFLs that work based on analysis of signal energy, the promising accurate results of these devices, and their widespread use among endodontists, the aim of the present study was to evaluate *in vivo* the accuracy of Propex II in comparison with Root ZX under clinical conditions for determining apical foramen location in the same sample of teeth.

Material and Methods

Ten healthy patients aged 18 to 30 years (mean age = 24 years) needing premolar extractions due to orthodontic reasons were invited to participate in the study. All participants signed an informed consent form after approval of the research protocol by the Ethics Committee of the Federal University of Ceará, Brazil (protocol #100/11).

The inclusion criteria were: absence of systemic diseases, recommended extraction of at least one premolar as part of the orthodontic treatment planning, and vital pulp. Teeth with extensive carious lesions, metallic class II restorations or restorations with signs of leakage, presence of dental resorption, or incompletely formed apices were not included.

Seventeen permanent teeth, totaling 28 canals were used in the analyses. All clinical procedures and measurements were carried out by a single experienced operator, following the protocol described by Welk et al. (8) After the periapical radiographs were taken, the teeth were anesthetized with 2% mepivacaine (Scandicaine 2%; Septodont, Saint-Mar-des-Fosses, France) and isolated with a rubber dam. Access cavities were prepared using #1012 and #3081 high-speed diamond burs (KG Sorensen, Barueri, SP, Brazil), under constant irrigation. Flat surfaces were created to provide stable reference points for the measurements. Canals were preflared with SX and S1 ProTaper rotary files (Dentsply-Maillefer) attached to an electric handpiece (Endomate DT; NSK, Tochigi, Japan) to 5.0 mm short of the total length based on the initial radiograph. Canals were irrigated during the chemomechanical preparation with 2.5% sodium hypochlorite (Biodinâmica, Ibiporã, PR, Brazil), and at its conclusion, excess solution was aspirated, whilst keeping the canals moist.

Electronic measurements were conducted using hand K-files (Dentsply-Maillefer) fitted to the anatomical diameter of each canal. The largest file was inserted until the tip reached the apex in the devices. Since the measurements were performed with both EFLs in all teeth, the first one to be used was randomly selected and their use was alternated. Both devices were operated according to the manufacturers' instructions: after positioning the lip clip, the electrode was attached to the file and inserted in the canal. The file was then advanced into the canal until the EFL screen displayed the word "APEX" (in Root ZX) or "APEX" simultaneously with "0.0" (in Propex II). Measurements were considered as accurate if the instrument remained stable for at least 5 s. The rubber stop was then positioned on the occlusal reference, and a new measurement was made, with special care to avoid shifting the file. The distance between the tip of the file and the stop was measured with a digital caliper a with ± 0.01 mm resolution (FNCL; Worker, Esteio, RS, Brazil). Measurements were recorded and the procedure was repeated with the other EFL, using the same file. Next, the file was re-inserted in the canal, up to the measurement indicated by the last device and fixed in this position with a cyanoacrylate-based adhesive (Super Bonder; Loctite do

Table 1. Distance from the file tip in relation to the major foramen (mm)

EFL	Mean§	SD§	5% confidence interval§		Measurements		
			Minimum	Maximum	Minimum	Maximum	Range
Root ZX (n=24)	0.30[a]	0.29	0.17	0.42	-0.80*	0.79	1.59
Propex II (n=24)	0.32[a]	0.27	0.21	0.44	-0.84*	0.75	1.59

§Calculation based on the absolute values of electronic root canal length measurements. Same letters indicate no statistically significant differences between devices according to the Wilcoxon test for paired samples ($p<0.05$). *Minus sign indicates file position coronal to major foramen.

Table 2. Number of root canals in function of the file tip position in relation to the major foramen

EFL	Root ZX (n=24)		Propex II (n=24)	
	n	%	n	%
-1.0 to -0.51*	3	12.5	7	29.2
-0.5 to -0.01*	10	41.7	11	45.8
0.00	2	8.3	1	4.2
0.01 to 0.5	6	25.0	4	16.7
0.51 to 1.0	3	12.5	1	4.2

Data are shown as number (percentage). $\chi^2=65.062$, $p<0.001$. *More than one answer was possible for each response.

Brazil, São Paulo, SP, Brazil). After the adhesive was set, the canal length measurements were confirmed, the rubber dam was removed, and the tooth was extracted.

In order to expose the canal, the apical 4.0 mm of each root was ground from buccal to lingual, under 16× magnification using an operating microscope (DF Vasconcellos, São Paulo, SP, Brazil). To prevent disruption of the file, the last layer was carved with a scalpel. With the aid of the microscope (20×), each specimen was photographed and the images were stored for further analysis. The distance between the tip of each file and the apical foramen was determined with the Image Tools 3.0 software (UTHSCSA, San Antonio, TX, USA), by two previously calibrated examiners who were blinded to the used device. In case of disagreement, a third examiner was consulted. Negative and positive values were attributed to measurements that were short and beyond the apical foramen, respectively. In order to prevent biased interpretation, the most coronal border of the major foramen was used as an anatomical reference for this evaluation. The difference in length (mm) between the file that was fixed (measurement with the last EFL) and the first file used (first EFL) was also calculated for each canal. Due to the nonparametric nature of the mean error values, certified by the goodness-of-fit Shapiro-Wilks test, the data were statistically evaluated by the Wilcoxon test for paired groups, with significance level set at 5%. The number of teeth with measurements registered by the devices at each position were statistically compared by the chi-squared test, with significance level also set at 5%.

Results

Two roots fractured during extraction and two were damaged during preparation, reducing the number of canals from 28 to 24. Table 1 presents the mean distance from the tip of the instrument to the apical foramen, considering absolute values, for Root ZX (0.30 ± 0.29 mm) and Propex II (0.32 ± 0.27 mm). Paired statistical analysis revealed no significant differences between the devices with respect to the accuracy of apical foramen location (p=0.587).

The distribution of the measurements obtained from both EFLs is shown in Table 2. Root ZX had precision rates ranging from 75% to 100%, while the precision of Propex II ranged from 66.7% to 100%, with tolerance intervals set at ± 0.5 mm and ± 1.0 mm, respectively. The analyses performed by the chi-squared test did not show statistical differences. The percentages of measurements beyond the apex were 37.5% for Root ZX and 20.9% for Propex II.

Discussion

Despite the fact that *in vitro* and *ex vivo* results cannot be directly extrapolated to the clinical settings, these studies serve as valuable tools for assessing the precision of EFLs (7-9,14,20,21). In fact, *in vivo* studies, in addition to providing normal clinical conditions, also determine directly the relationship between the tip of the instruments and the apical anatomical structures, therefore being an efficient and precise evaluation method (8,9,14,21).

The present work evaluated the precision of two EFLs for establishing the location of the apical foramen, while attempting to minimize anatomical or external interferences. For this reason, only teeth with vital pulps (3,22), subjected to coronal preflaring (11,23,24), and with patent apical foramina (5,20) were included in the study. In order to further limit potential interferences, the used files were well fitted to the diameter of each canal (6,11) and 2.5% sodium hypochlorite was the only irrigating solution (5,7,11,17,18). Moreover, both EFLs were used alternately in all root canals to ensure absolutely similar clinical conditions, as reported elsewhere (8,9).

The anatomical structure that should be used as an apical reference for the calculations of EFL error is not completely defined among different researchers. Some recommend using the apical constriction (8,9,15,20), while others prefer the apical foramen (7,12,14). Many authors have suggested that determining the accurate location of the apical constriction is extremely difficult, almost impossible in some cases (12,14,18), therefore the use of the apical foramen as a reference for the measurements, as described above (14).

The precision rates presented by Root ZX in this study were 75% (± 0.5 mm) and 100% (± 1.0 mm), with a mean discrepancy of 0.30 mm from the apical foramen. These results corroborate findings by other authors, who observed percentages ranging from 60% to 100%, depending on the tolerance margin, and mean error values near 0.0 mm (7-11,20). These values certify the efficiency of the Root ZX measurement approach, confirming that the evaluation of the quotient of impedances of two frequencies measured simultaneously may be considered a strongly reliable method. Measurements beyond the foramen occurred in 37.5% of the measurements, which agrees with other authors who reported 40% (9) and 25.0% (5). However, the occurrence of measurements beyond the foramen could be due to a greater proximity to this anatomical reference. These occurrences make up for only 12.5% of the cases if only measurements beyond the apex with distance greater than the tolerance margin were considered.

Precision of 66.7% (± 0.5 mm) and 100% (± 1.0 mm) was observed for Propex II with a mean distance of 0.32 mm from the apical foramen. These results were in agreement with another *in vivo* study performed by Somma et al. (25) who reported a precision rate of 100% (± 0.5 mm) with a mean discrepancy of 0.14 mm, using also the major foramen as apical reference. This small difference can be explained

by slight variations in experimental design, as the number of specimens and the evaluation method. Other previous *ex vivo* studies show a precision of 82.2% (± 0.5 mm), with a mean discrepancy of 0.27 mm (13) and a precision of 89.7% (± 0.5 mm) with a mean discrepancy of 0.14 mm (15). Comparisons of these results with those from the present study reveal that while the discrepancy values were similar, the *in vivo* precision rates of Propex II were lower. Such differences may be attributed to factors inherent to these *ex vivo* studies, such as the use of an electroconductive gel to simulate the periodontal tissues. The percentage of measurements beyond the MF for Propex II (20.7%) was lower than that of Root ZX, which agrees with reports from previous *ex vivo* studies, where measurements beyond the apical foramen accounted for 17.8% (15,18).

Unquestionably the inclusion of EFLs in the arsenal of clinicians and endodontists reflects an increase of treatment quality, mainly with regards to the determination of the root canal length, often confused by the radiographic interpretation (3,4). However, while using them it is important to reach the apical foramen as a means to provide the electronic devices with all the information (capacitance/resistance) of the root canal system (4). To achieve this goal, the best reference is to reach "APEX" or "0.0" on the device display. Nevertheless, the results presented here corroborate those of numerous other studies that state that the EFLs cannot exactly detect the foraminal position (3,8,9,12,20), but they can indicate a point located between the apical constriction and the major foramen. Thus, the "APEX" presented by the devices should not be interpreted by the clinicians as literally the foraminal position, but a reference only, as advised by Haffner et al. (3).

Considering the tested devices, the absence of statistically significant differences between Propex II and Root ZX measurements suggests that the operating mechanism of the novel EFL, which is based on evaluating the energy of the current signal by calculating the mean square root of impedances in two frequencies, seems to be reliable. This device was capable of exceeding interferences in the resistance/capacitance system, since its mean error was close to the apical foramen and similar to the gold standard device. Moreover, this system demonstrated to be safe, since the percentage of measurements beyond the apical foramen with distances greater than the tolerance margin was only 4.2%.

Under the conditions of this *in vivo* study, Root ZX and Propex II were capable of locating the apical foramen region with high precision suggesting, despite their operating modes, they can surpass the difficulties in determining the root canal length and could be confirmed as reliable tools. The present data revealed no differences in accuracy between the EFLs. Although Root ZX presented a higher percentage of readings beyond the apex, the differences were not significant when statistically compared.

Resumo

O presente estudo teve como objetivo avaliar, *in vivo*, a precisão de dois localizadores eletrônicos foraminais (LEFs) baseados em diferentes mecanismos de funcionamento, Root ZX e Propex II, na determinação do forame apical, sendo utilizados nos mesmos dentes. Após o acesso coronário e o pré-alargamento, e anteriormente à exodontia, os comprimentos de 24 canais radiculares foram determinados eletronicamente alternando-se os dois LEFs. As odontometrias foram realizadas até que os dispositivos apontassem o FA (APEX), utilizando-se limas tipo-K ajustadas. O último instrumento utilizado foi fixado em posição, o dente extraído e os 4,0 mm apicais de cada canal desgastados de forma a possibilitar a determinação da distância entre a ponta dos instrumentos e o forame apical. Os erros médios em função dos valores absolutos das discrepâncias foram, respectivamente, 0,30 ± 0,29 mm (Root ZX) e 0,32 ± 0,27 mm (Propex II). A análise estatística realizada por meio do teste de Wilcoxon para amostras pareadas demonstrou a semelhança entre as determinações do forame apical realizadas pelos dois LEFs (p=0,587). O comprimento radicular até o forame apical foi corretamente determinado em 75% (Root ZX) e 66,7% (Propex II) dos casos, considerando margem de ± 0,5 mm, sem diferenças estatísticas quando analisados pelo teste qui-quadrado. Os LEFs avaliados e consequentemente seus mecanismos de funcionamento, foram capazes de determinar o comprimento dos canais radiculares com precisão em condições *in vivo*. Nas condições do presente estudo, Root ZX e Propex II apresentaram resultados semelhantes.

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