

Evaluation of the effect of irrigants on the accuracy and repeatability of three electronic apex locators: an *ex vivo* study

Avaliação do efeito de irrigantes na precisão e repetibilidade de três localizadores de ápice eletrônicos: um estudo *ex vivo*

Evaluación del efecto de los irrigantes en la precisión y repetibilidad de tres localizadores apicales electrónicos: un estudio *ex vitro*

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Abstract

Objective: To evaluate the effect of 2% chlorhexidine (CHX) and 2.5% sodium hypochlorite (NaOCl) on the accuracy and repeatability of three Electronic Apex Locators (EALs). **Methodology:** Thirty one human teeth were connected to a platform, irrigated with 2.0% CHX, and obtained two readings, again irrigated with 2.5% NaOCl and obtained two more readings. The distance between the tip of the file and the apical constriction was measured. Repeatability was calculated using the intraclass correlation coefficient (ICC) and repeatability coefficient (CR). **Results:** For CHX 2%, with the Mini Apex Locator, 25 of 31 electronic measurements were accurate (80.6%), 28 of 31 measurements for iPex (90.3%) and for Root ZX II 26 (83, 9%). For 2.5% NaOCl, with the Mini Apex Locator, 25 of the 31 measurements were accurate (80.6%), 28 of the 31 measurements for the iPex (90.3%) and for the Root ZX II, 24 (77, 4%). There were no differences between the two irrigants ($p>0.05$). The values (ICC) were 0.975 and 0.994 for the Mini Apex Locator, 0.981 and 0.971 for the iPex and 0.994 and 0.995 for the Root ZX II. When using CHX, the (CR) was 0.196 for the Mini Apex Locator, 0.152 for the iPex and 0.088 for the Root ZX II. When using 2.5% NaOCl, the (CR) was 0.088 for the Mini Apex Locator, 0.196 for the iPex and 0.088 for the Root ZX II. **Conclusions:** The use of 2% CHX and 2.5% NaOCl did not affect the accuracy and repeatability of the three devices.

Keywords: Endodontics; Root canal treatment; Dimensional measurement accuracies; Odontometry.

Resumo

Objetivo: Avaliar o efeito da clorexidina 2% (CHX) e hipoclorito de sódio 2,5% (NaOCl) na precisão e repetibilidade de três Localizadores apicais eletrônicos (LAEs). **Metodologia:** trinta e um dentes humanos foram conectados a uma plataforma, irrigados com CHX 2,0%, e duas leituras obtidas, irrigou-se novamente com NaOCl 2,5% e obteve-se

mais duas leituras. A distância entre a ponta da lima e a Constrição apical foi medida. Calculou-se a repetibilidade usando coeficiente de correlação intraclasse (ICC) e o coeficiente de repetibilidade (CR). Resultados: Para CHX 2%, com o Mini Apex Locator, 25 das 31 medidas eletrônicas foram precisas (80,6%), 28 de 31 medidas para o iPex (90,3%) e para o Root ZX II 26 (83,9%). Para NaOCl 2,5%, com o Mini Apex Locator, 25 das 31 medidas foram precisas (80,6%), 28 das 31 medidas para o iPex (90,3%) e para o Root ZX II, 24 (77,4%). Não houve diferenças entre os dois irrigantes ($p > 0,05$). Os valores (ICC) foram 0,975 e 0,994 para o Mini Apex Locator, 0,981 e 0,971 para o iPex e 0,994 a 0,995 para o Root ZX II. Ao utilizar CHX, o (CR) foi 0,196 para o Mini Apex Locator, 0,152 para o iPex e 0,088 para o Root ZX II. Ao utilizar NaOCl 2,5%, o (CR) foi de 0,088 para o Mini Apex Locator, 0,196 para o iPex e 0,088 para o Root ZX II. Conclusões: O uso de CHX a 2% e NaOCl a 2,5% não afetou a precisão e repetibilidade dos três dispositivos.

Palavras-chave: Endodontia; Tratamento do canal radicular; Precisão da medição dimensional; Odontometria.

Resumen

Objetivo: Evaluar el efecto de la clorhexidina (CHX) al 2% y el hipoclorito de sodio (NaOCl) al 2,5% sobre la precisión y repetibilidad de tres localizadores apicales electrónicos (LAEs). Metodología: Se conectaron 31 dientes humanos a una plataforma, se irrigaron los conductos con CHX al 2%, se obtuvieron dos lecturas, se irrigaron nuevamente con NaOCl al 2.5% y se obtuvieron dos lecturas más. Se midió la distancia entre la punta de la lima y la constricción apical. La repetibilidad se calculó utilizando el coeficiente de correlación intraclase (ICC) y el coeficiente de repetibilidad (CR). Resultados: Para la CHX al 2%, con el Mini Apex Locator, 25 de las 31 mediciones electrónicas fueron precisas (80,6%); con el iPex, 28 de las 31 mediciones fueron precisas (90,3%), y 26 con el Root ZX II (83, 9%). Para el NaOCl al 2.5%, con el Mini Apex Locator, 25 de las 31 mediciones fueron precisas (80,6%), 28 de las 31 mediciones para el iPex (90,3%) y para el Root ZX II, 24 (77, 4%). No hubo diferencias entre los dos irrigantes ($p > 0.05$). Los valores (ICC) fueron 0.975 y 0.994 para el Mini Apex Locator, 0.981 y 0.971 para iPex, y 0.994 a 0.995 para el Root ZX II. Al usar CHX, el (CR) fue 0.196 para el Mini Apex Locator; 0.152 para el iPex y 0.088 para el Root ZX II. Cuando se usó NaOCl al 2.5%, el (CR) fue 0.088 para el Mini Apex Locator, 0.196 para el iPex y 0.088 para el Root ZX II. Conclusiones: El uso de CHX al 2% y NaOCl al 2,5% no afectó la precisión y repetibilidad de los tres dispositivos.

Palabras clave: Endodoncia; Tratamiento de conducto; Precisión de la medición dimensional; Odontometría.

1. Introduction

The success of endodontic therapy depends on the correct performance of all treatment stages, such as the determination of working length, a challenge to dentists because of the anatomy of the apical region (Mazzi-Chaves *et al.*, 2020). Root canal preparation and filling should be performed, as much as possible, close to the apical constriction in the root canal at the level of the cementodentinal junction (CDJ), which is about 1 to 2 mm from the radiographic apex of the root canal (Ricucci & Langeland, 1998).

Electronic apex locators (EALs) are widely utilized to determine working length during root canal treatment. Introduced in the classic study of Sunada in 1962, the EALs has become an invaluable tool in current endodontic practice. These devices, which work with an attached file, are able to detect the point at which the file leaves the root canal and enters the periodontal ligament. Early electronic apex locators relied on the principle that the electrical resistance between the oral mucous membranes and the periodontal ligament remained constantly at 6.5 k Ω regardless of patient age and tooth type or shape (Sunada, 1962).

Since its development, numerous electronic devices have been introduced in the market, and their accuracy has been analyzed. Current models can perform readings under different conditions inside the root canal (Çınar & Üstüm 2020; Bernardes *et al.*, 2021; Saritha *et al.*, 2021; Suguro *et al.* 2021). However, studies have found conflicting results for EALs using different irrigants (Baruah *et al.* 2018; Marek *et al.*, 2020).

The Mini Apex Locator, developed by SybronEndo (Anaheim, CA, USA), has a multifrequency measurement system and digital signal. According to the manufacturers this device locates the apical constriction without any influence of the root canal contents (D'Assunção *et al.*, 2014).

The iPex (NSK, Tochigi, Japan) is an apex locator that measures capacitance and resistance simultaneously, in order to determine the location of the file tip inside the root canal system (Stöber *et al.*, 2011).

The Root ZX II (J Morita Corp, Tokyo, Japan) is a commercial device that uses two different alternating currents with different frequencies. It calculates the ratio of impedances of two different frequencies. At the apical terminus, there is a sharp change in the impedance, and Root ZX II recognizes it as the apex. This device is composed of two parts: the root canal measurement module and the slow-speed handpiece (Nekoofar *et al.*, 2006).

An electronic apex locator must be both accurate and reliable. In statistics, a reliable measurement means measuring something consistently with minimal variance. However, according to Jung *et al.*, (2011), most authors only evaluated the accuracy of EALs to determine the length and did not assess the reliability of the measuring method.

Root ZX is considered the gold standard for locators, several studies have shown satisfactory results (Piasecki *et al.* 2016; Melo *et al.* 2020), even with its use with different irrigating solutions (Bolbolian *et al.* 2018). However, when comparing the influence of different irrigation solutions, commonly utilized in endodontics on the accuracy of Root ZX and Mini Apex Locator, different accuracy results were found (Mull *et al.* 2012).

Therefore, using a mounting model, the aim of this study was to evaluate and compare the accuracy and repeatability coefficient of measurements obtained by the Mini Apex Locator, iPex and Root ZX II, using two different irrigants: 2.5% sodium hypochlorite (NaOCl) and 2.0% chlorhexidine gluconate (CHX).

2. Methodology

This study was performed in accordance with the guidelines issued by the Department of Health of the state of Paraiba, Brazil and after approval by its Research Ethics Committee of the Federal University of Paraiba.

Forty single-rooted human teeth with straight roots, a single root canal and fully-formed apices were evaluated using a magnifying lens at 4x magnification and radiographed mesiodistally and buccolingually. Root canals with open apices, root fractures, obstructed foramen, root perforations and accessory canals were excluded from the sample. A k-type file #10 was introduced in the root canal to rule out possible root obstructions, and to ensure foramen opening at the root apex and foramen patency. The final sample after the exclusion criteria was 31 single-rooted human teeth, with single and straight root canals.

The crown of each tooth was removed using a diamond disk to standardize the specimen medium length at 13 mm. The contents of each root canal were removed using a conventional k-type file with a diameter compatible with the root canal, and a k-type file # 10 (Dentsply-Maillefer, Baillaigues, Switzerland) was used to confirm apical patency by introducing it into the root canal and pulling it back to 1 mm from the apical foramen. The middle and cervical thirds were pre-flared with Gates-Glidden burs # 2, and 3 (Dentsply-Maillefer, Baillaigues, Switzerland) according to the diameter of the root canals up to 5 mm short of total root length.

A model similar to the Mounting Model designed by Elayouti and Löst (2006) and adapted for (D'Assunção *et al.* 2014) was used for the measurement of electronic length obtained by the three electronic apex locators.

The Mini Apex Locator (SybronEndo, Orange, CA, USA) was utilized for electronic measurements. The teeth were connected to the mounting model and placed in contact with the 0.9% saline solution to simulate the periodontal. The lip clip of the electronic apex locator was attached to the 0.9% saline solution container and the electrode was connected to the measuring file. The electronic and actual lengths were measured by using a # 15 K-File (Dentsply- Maillefer, Ballaigues, Switzerland).

The EAL was turned on, and each root canal was irrigated with 2.0% chlorhexidine gluconate, inserted in a 5 ml disposable plastic syringe with Luer Lock (Ultradent, South Jordan, Utah, USA) and 27G Endo-Eze needles (Ultradent, South Jordan, Utah, USA). The apical constriction position was determined: the file was slowly introduced into the root canal and the micrometer connected to the file was moved apically up until the electronic apex locator displayed “apex” on the screen. After that, the file was pulled back to the point when the EAL reading was 0.5, which corresponded to the apical constriction. The

measurement at 0.5 was recorded and the instrument was pulled back to the cervical end {R = 0.0}. The measurements obtained using the EAL connected to the micrometer were acquired by moving the file cervically to avoid inaccurate measurements caused by curvatures along the root canal. The electronic measurement at 0.5 was repeated to confirm its repeatability. After recording the electronic measurements with 2.0% chlorhexidine gluconate, the root canals were rinsed with saline solution and irrigated with 2.5% sodium hypochlorite; after that, two other electronic measurements were made in the same method as for chlorhexidine gluconate. All procedures performed with the Mini Apex Locator were repeated for each specimen, using the iPex and the Root ZX II.

After the last electronic measurement was recorded, the file was cemented in place by using cyanoacrylate adhesive (Super Bonder; Henkel Technologies, Diadema, São Paulo, Brazil). Subsequently, the electronic length was checked again to confirm that the file was in the same position, and the file was kept in position for 30 minutes until the adhesive had set completely. The teeth were removed from the mounting model and a 3195F bur (K.G. Sorensen, São Paulo, Brazil) was used to expose the apical 4 mm of each root along the long axis of the tooth in a plane that showed the best representation of the minor diameter in relation to the file. This procedure was similar to the process described by Fadel *et al.* (2012). The last layer of dentin was then carefully removed using a # 15 scalpel blade. Each root was photographed with a digital camera (Sony Cyber-Shot-W70) and the images were projected onto a LCD screen and analyzed using the Image Tool 1.28 software (San Antonio, TX, USA). Two investigators, blinded to groups and procedures, marked and recorded the distance from the file tip to the minor diameter for each specimen. Seven teeth were lost during specimen preparation and after apical sectioning, 31 of the 40 specimens were prepared, and their apical constriction was visible.

The most incisal and most apical limits of apical constriction did represent the beginning and the end of the apical constriction and the smallest distance between the tip of the file and these limits was the reference for the actual length. An exact correlation between the file tip and the apical constriction indicated that the electronic length was the same as the actual length. However, a negative value indicated that the distance from the file tip to the apical constriction was shorter than actual length, and a positive value, that it was longer.

When a disagreement occurred between the evaluators, the distances were checked again, and the two evaluators reached a consensus.

Statistical Analysis

The Statistical Package for Social Sciences software (SPSS 13.0; SPSS Inc., Chicago, IL, USA) was used for statistical analyses.

The correlation coefficient was used to compare the reliability. The intraclass correlation coefficient (ICC) was calculated to demonstrate the strength of agreement between the apical constriction and the file tip, when using the two irrigating substances and the upper and lower limits of agreement for both measuring points. The repeatability of apex locators was determined by calculating the coefficient of repeatability for each electronic apex locator device. This corresponds to 2 standard deviations of the differences between the first and the second measurement (Elayouti & Löst, 2006).

The paired *t* test at a 0.05 significance level was used to determine the accuracy of the three electronic locators when using the two irrigating solutions within a clinical range of ± 0.5 mm.

3. Results and Discussion

Distance to the apical constriction

For 2% CHX, with the Mini Apex Locator, 25 of the 31 electronic measurements were located at the apical constriction (80.6%), for the iPex, 28 measurements were located at the apical constriction (90.3%) and for the Root ZX II 26

electronic measurements were located at the apical constriction (83.9%). For 2.5% NaOCl, with the Mini Apex Locator, 25 of the 31 electronic measurements were located at the apical constriction (80.6%), and with the iPex, 28 measurements were located at the apical constriction (90.3%). For the Root ZX II, 24 electronic measurements were located at the apical constriction (77.4%). The results of the paired *t* test for the three devices revealed no statistically significant differences between the electronic measurements ($p>0.05$), when the two irrigants were used (Table 1).

Table 1. Distribution of the differences between the actual length and electronic measurements for each irrigating solution, as determined by the three electronic apex locators.

Distance in mm to the apical constriction	Device											
	Chlorhexidine Gluconate						Sodium Hypochlorite					
	Mini Apex Locator		iPex		Root ZX II		Mini Apex Locator		iPex		Root ZX II	
	n	%	n	%	n	%	n	%	n	%	n	%
≤ -0.51*	1	3.2	2	6.5	2	6.5	1	3.2	2	6.5	2	6.5
-0.50 to -0.26*	1	3.2	3	9.7	1	3.2	2	6.5	5	16.1	2	6.5
-0.25 to -0.01*	5	16.1	11	35.5	6	19.3	4	12.9	9	29.0	3	9.7
0.00	0	0.0	1	3.2	0	0.0	0	0.0	4	12.9	1	3.2
0.01 to 0.25	8	25.8	10	32.2	16	51.6	11	35.5	6	19.4	15	48.3
0.26 to 0.50	11	35.5	3	9.7	3	9.7	8	25.8	4	12.9	3	9.7
≥ 0.51	5	16.1	1	3.2	3	9.7	5	16.1	1	3.2	5	16.1
TOTAL	31	100	31	100	31	100	31	100	31	100	31	100

* Negative value indicates the file position coronal to the apical constriction. Source: Authors,

Table 2 shows the descriptive values (mean and standard deviation) of the differences of the electronic measurements made by the Mini Apex Locator, iPex locator and the Root ZX II in relation to apical constriction. There were no statistically significant differences between accuracy of the two measurements for each of the irrigants, 2.0% CHX and 2.5% NaOCl in relation to the apical constriction determination ($p>0.05$). There was no influence of the irrigating solutions in the accuracy of the electronic apex locators.

Table 2. Descriptive values (mean absolute difference, standard deviation) of the electronic measurements obtained with the three electronic apex locators for both irrigants in relation to the apical constriction.

Statistics	Chlorhexidine Gluconate			Sodium Hypochlorite		
	Mini Apex Locator	iPex	Root ZX II	Mini Apex Locator	iPex	Root ZX II
Mean absolute difference	0.21	0.03	0.09	0.20	0.04	0.12
Standard deviation	0.329	0.291	0.322	0.316	0.285	0.317

Source: Authors,

Repeatability

The intraclass correlation values were 0.975 and 0.994 for the Mini Apex Locator, 0.981 and 0.971 for the iPex, and 0.994 and 0.995 for the Root ZX II, indicating an excellent agreement between measurements 1 and 2. When using 2.0% CHX,

the coefficients of repeatability were 0.196 for the Mini Apex Locator, 0.152 for the iPex and 0.088 for the Root ZX II. When using 2.5% NaOCl, the coefficients of repeatability were 0.088 for the Mini Apex Locator, 0.196 for the iPex, and 0.088 for the Root ZX II. There were no significant differences between the coefficient of repeated measurements, and more than 95% of the differences between repeated measurements were below the coefficient of repeatability for the three devices, for both irrigating solutions. These results demonstrated excellent repeatability (Table 3).

Table 3. Results of intraobserver repeatability of electronic measurements obtained by the Mini Apex Locator, iPex and the Root ZX II according to each irrigant.

Substances	Mini Apex Locator		iPex		Root ZX II	
	Intra-CC ⁺ (CI-95%)	Coefficient of Repeatability (r) [#]	Intra-CC ⁺ (CI-95%)	Coefficient of Repeatability (r) [#]	Intra-CC ⁺ (CI-95%)	Coefficient of Repeatability (r) [#]
2.0% Chlorhexidine Gluconate	0.975 (0.949 – 0.988)	0.196	0.981 (0.962 – 0.991)	0.152	0.994 (0.988 – 0.997)	0.088
2.5% Sodium Hypochlorite	0.994 (0.987 – 0.997)	0.088	0.971 (0.940 – 0.986)	0.196	0.995 (0.989 – 0.997)	0.088

⁺Average measures. One-way ANOVA

[#] Coeff. of repeatability - $r = 1,96 \times \sqrt{2s_w^2}$

Source: Authors,

4. Discussion

Electronic apical locators are very important devices in Endodontics. When compared with radiography, EAL decreases exposure to radiation and determines the position of the apical constriction or apical foramen, rather than of the radiographic apex (Bernardes *et al.* 2021; Abidi *et al.* 2020).

Some authors, following manufacturers' instructions, and using methods similar to those adopted in this study, analyzed the accuracy of EALs in locating apical constriction, or a distance 0.5mm short of the apical foramen (Piasecki *et al.* 2016; Connert *et al.* 2018; Serna-Peña *et al.* 2020).

The mounting model is simple, easy to use and provides close control over experimental conditions. Measurements were stable and coherent, and a large number of root canals could be evaluated in a short time period, which would not be possible in the clinical setting (Elayouti *et al.* 2006; Connert *et al.* 2018).

Studies evaluating electronic apex locators, which do not use a mounting model, may be conducted according to the adjustment of a silicone stop of the measurement file to a reference point in the dental crown, after which the distance from the silicone stop to the file tip is measured. This type of method has been utilized in many other studies (Piasecki *et al.* 2016; Melo *et al.* 2020; Saritha *et al.* 2020; Iparraguirre Nuñovero *et al.* 2021). However, may lead to inaccurate measurements due to the poor adaptation of the silicone stop to the reference point because of movements during measurement, the absence of a parallel relation between the long axis of the file and the reference.

The present study demonstrated the accuracy of the Mini Apex Locator, iPex and Root ZX II to identify the apical constriction in the presence of Chlorhexidine and sodium hypochlorite in a range of 77.4% to 90.3%. Some authors concluded that EALs may accurately determine working length in 90% to 100% of root canals with completely formed apices (Bolbolian *et al.*, 2018; Melo *et al.*, 2020; Serna-Peña *et al.* 2020), however, these cited studies did not utilize a mounting model.

In the present research, irrigants, 2.0% chlorhexidine gluconate and 2.5% sodium hypochlorite, did not affect the accuracy of electronic measurements made by the Mini Apex Locator, iPex or Root ZX II, the mean distances from the file tip to the apical constriction were in a range of 0.21mm to 0.09mm. These results are considered very accurate. Some studies revealed that EALs are not affected by the presence of irrigants inside the root canals (Duran-Sindreu *et al.* 2013; Çinar & Üstüm 2020). However, Marek *et al.* (2020) concluded that EALs had higher accuracy in root canals containing chlorhexidine in gel or in solution form than in the root canal containing sodium hypochlorite.

Results using EAL's mark 0.5 demonstrate that the EALs tested tend to obtain measurements near to the apical constriction. Nevertheless, majority of measurements obtained by the three devices, with both irrigating solutions did not surpass the apical foramen. These results are similar to that found in other studies which showed that the using EALs to determine the major foramen, in 0.0 EAL's mark led to overestimation of the working length (Connert *et al.* 2018; Chukka *et al.* 2020).

In the present study, periapical radiographs were also obtained for analyzing anatomy of root canals. Although Electronic apex locators has a great accuracy, when obtaining working length, these devices does not presents images. Therefore, periapical radiography remains essential for confirming working length during endodontic treatment (Mahmoud *et al.* 2021).

Working length was determined close to the apical constriction, these results are relevant because studies have already shown that working length must be determined inside the root canal to avoid treatments underestimated, which allow persistence of infections, and also, to avoid over-instrumentation and accidents during endodontic treatment, that leads to a negative prognosis for endodontic treatment's outcome (Ng *et al.* 2011; Ricucci *et al.* 2016; Aminoshariae *et al.* 2020)

The use of the mounting model increases the accuracy of the study (Elayouti & Löst 2006, D'Assunção *et al.* 2014; Connert *et al.* 2018), however, this research is an *ex vivo* study and, therefore, it has the limitations of a laboratory study. Future studies should evaluate other endodontic conditions, as foramen diameter, perforations, root resorptions, file diameter and others that may affect the performance of EALs, because *in vivo* situations differ from those found in controlled *in vitro* and *ex vivo* studies (Duran-Sindreu *et al.* 2012 Chukka *et al.* 2020).

5. Conclusion

The results of this study revealed that 2% chlorhexidine gluconate and 2.5% sodium hypochlorite did not affect the performance of the Mini Apex Locator, iPex or Root ZX II and these devices locate a very close point of the apical constriction.

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