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# Would the Accuracy of Dental Apex Locators in Determining the Apical Constriction be Influenced by the Activation Sequence? An *Ex vivo* Study

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***Authors' contributions***

*This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.*

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## ABSTRACT

**Aims:** To evaluate the accuracy of three electronic foraminal locators (EFLs) – Root ZX II, Propex Pixi, and Romiapex A-15 – when used in different activation sequences, focusing on the influence of these sequences on the working length determination.
**Study Design:** Experimental study conducted in a laboratory setting using extracted human teeth.
**Methodology:** Thirty single-rooted human teeth with standardized apical foramina were used to assess the accuracy of the EFLs. Measurements were taken after canal preparation and determination of the RCL with the aid of a digital caliper. The devices were tested in four activation sequences: DA/LC/FC/FI, DA/LC/FI/FC, LC/DA/FC/FI, and LC/DA/FI/FC. The EFL measurements were compared with the manually determined RCL, and results were analyzed using non-parametric statistical tests.
**Results:** No significant differences were observed between the devices across the different activation sequences ($P > 0.05$). However, the Root ZX II showed the lowest mean error (0.13 mm) in the DA/LC/FC/FI sequence, performing better than the other devices ($P < 0.05$).
**Conclusion:** The activation sequence of EFLs did not significantly influence measurement accuracy. However, the DA/LC/FC/FI sequence favored the accuracy of the Root ZX II, suggesting that this sequence may be the most effective for this device.

*Keywords: Endodontics; odontometry; dental equipment; root canal treatment.*

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## 1. INTRODUCTION

Electronic foraminal locators (EFLs) have become indispensable tools in the working length determination phase of endodontic treatment, capable of determining the actual root canal length (RCL) with an accuracy ranging from 80% to 100% (Aguiar et al., 2017, Melo et al., 2020, Bernardes et al., 2007, Vasconcelos et al., 2015, Serna-Peña et al., 2020). This high accuracy has contributed to its widespread use, especially as it overcomes many of the limitations associated with conventional radiographic measurements, such as two-dimensional images, overlapping anatomical structures, and radiation exposure (Gehlot et al., 2016, Sayed et al., 2024). Several studies have demonstrated that electronic odontometry is superior to the radiographic method, allowing for quick, repeatable measurements without radiation, in addition to detecting perforations and over-instrumentation (Sayed et al., 2024, Saha et al., 2024, ElAyouti et al., 2009, Mello, 2014, Mahmoud et al., 2021).

Over the years, different models of EFLs have been developed, incorporating various electronic mechanisms to estimate the distance between the coronal reference point and the apical foramen (Nekoofar et al., 2006, Pereira et al., 2021, Guimarães et al., 2014). Currently, these devices operate using alternating current that flows through the tooth, circulating between the lip clip and the file in both directions. Based on impedance measured at two or more frequencies, mathematical operations are performed to calculate the position of the instrument tip relative to the apical foramen (Vasconcelos et al., 2020).

One of the most studied devices, the Root ZX II (J. Morita, Tokyo, Japan), uses the ratio method, simultaneously measuring impedance values at two frequencies and calculating their ratio (Serna-Peña et al., 2020). Other models, such as the Propex Pixi (Dentsply/Maillefer, Ballaigues, Switzerland) and the Romiapex A-15 (Romidan LTDA, Kyriat Ono, Israel), are based on the ratio between the square roots of the impedance values measured at two frequencies (Oliveira et al., 2017). These devices indicate the position of the file in relation to the apical foramen using values stored in their internal memory. According to the manufacturers, this technology allows the devices to operate based on signal energy rather than amplitude (Serna-Peña et al., 2020, Miletic et al., 2011).

Given the high electronic complexity of these devices, several factors may interfere with their

accuracy, such as the apical fit of the instrument (Brito-Júnior et al., 2012), cervical preflaring (Brito-Júnior et al., 2012, de Camargo et al., 2009), apical penetration limit (Vasconcelos et al., 2015, Oliveira et al., 2017), EFL activation sequence (Oliveira et al., 2017), and foraminal condition (Serna-Peña et al., 2020, Akisue et al., 2014, Piasecki et al., 2016).

Despite the clinical relevance of these factors, a thorough literature review did not identify any studies specifically investigating the influence of EFL activation sequence on their accuracy. Furthermore, there is a lack of clear instructions in manufacturers' manuals regarding the order of use for components such as the lip clip, file clip, and file insertion into the canal.

In this context, the present study aimed to evaluate the influence of different EFL activation sequences on the accuracy of RCL determination, as well as to verify whether any of the tested devices performed better within the tested sequences. The null hypothesis considered was that there would be no variation in EFL accuracy as a function of the activation sequence, and that there would be no significant differences among the devices regardless of the sequence used.

## 2. METHODOLOGY

This study is characterized as an experimental research project, conducted in a laboratory setting, with the aim of evaluating, under ex vivo conditions, the accuracy of electronic devices in determining the actual root canal length (RCL). The study followed the guidelines of the Preferred Reporting Items for Laboratory Studies in Endodontology (PRILE) (2021). Sample size calculation was based on similar previous studies, such as those by Borges et al. (2016) and Vasconcelos et al. (2012), resulting in a sample size of 30 units.

The sample consisted of 30 extracted human teeth indicated for prosthetic, periodontal, or orthodontic reasons, collected after approval by the local Research Ethics Committee (approval number 4.297.881). Included were single-rooted lower premolars with apparently straight canals and no alterations such as calcifications, curvatures, previous endodontic treatments, or fractured instruments. Teeth with open apices or non-patent canals were excluded and replaced when necessary.

Coronal access was performed using diamond burs (#1012 and #3081; KG Sorensen Ind. e Com. Ltda., Barueri, Brazil) in high-speed rotation. Then, #10 K-type manual files (Dentsply/Sirona, Ballaigues, Switzerland) were inserted into the canals with exploratory movements until the tip of the file was visible at the apical foramen under optical microscopy (DF Vasconcelos, São Paulo, SP, Brazil). At that moment, the rubber stop was positioned at the occlusal reference, and the provisional RCL was determined using a digital caliper (Mitutoyo, Suzano, SP, Brazil).

The cervical and middle thirds of the canals were prepared using #30.10 files from the ProDesign S system (Easy Equipamentos Odontológicos, Belo Horizonte, Brazil), in a crown-down direction up to 5.0 mm short of the provisional RCL. During preparation, the canals were irrigated with 2.5% sodium hypochlorite (NaOCl; Biodinâmica, Ibiporã, PR, Brazil). After cervical preparation, apical foramina were standardized to a diameter of 300 µm, and new RCLs were determined to enable subsequent comparisons.

For electronic working length determination, each tooth was individually placed into plastic containers filled with freshly mixed alginate (Jeltrate II; Dentsply Ind. e Com. Ltda., Petrópolis, Brazil), in which the lip clip was also positioned. Teeth were fixed so that their apical portions remained immersed in the material. The canals were filled with NaOCl, and measurements were performed using #30 K-type nickel-titanium files (K-Nitifkex; Dentsply/Sirona), connected to the device's electrode (clip). If the file did not adapt properly, larger-diameter files were used.

Three electronic devices were tested: Root ZX II (RZX), Propex Pixi (PRO), and Romiapex A-15 (ROM), all used either fully charged or with new batteries. Measurements followed four different activation protocols, varying the order of the following steps: device activation (DA), lip clip attachment (LC), file connection to the clip (CL), and file insertion into the canal (FI). The tested sequences were: DA/LC/FC/FI, DA/LC/FI/FC, LC/DA/FC/FI, and LC/DA/FI/FC, totaling 12 experimental groups.

Electronic length determination was performed by slowly introducing the file into the canal until the device displayed the "0.0" or "Apex" reading. Once the reading was obtained, the clip was disconnected, and the file length was measured using the digital caliper. The values obtained were compared to the RCL determined after cervical preparation.

For statistical analysis, the mean error values obtained by the three devices in each of the four sequences were tested for normality. As the data presented a non-parametric distribution, the Kruskal-Wallis and Dunn tests were used, with the level of significance set at 5%.

## 3. RESULTS AND DISCUSSION

The mean error values obtained in the working length measurements performed with the three electronic devices, according to the different activation sequences tested, are summarized in Table 1.

No statistically significant differences were observed between the activation sequences for the same device ($P > 0.05$). However, when comparing the devices, the Root ZX II showed statistically superior performance in the DA/LC/FC/FI sequence ($P < 0.05$), presenting the lowest mean error value among all experimental groups (0.13 mm).

This study evaluated the accuracy of three electronic apex locators (EALs) – Root ZX II, Propex Pixi, and Romiapex A-15 – used under different activation sequences. The Root ZX II, often considered the gold standard in the literature (Aguiar et al., 2017, Serna-Peña et al., 2020, Piasecki et al., 2016, Stöber et al., 2011), showed superior performance under one of the tested conditions.

Four distinct EAL activation sequences (DA/LC/FC/FI, DA/LC/FI/FC, LC/DA/FC/FI, and LC/DA/FI/FC) were compared to investigate whether the order of steps interferes with measurement accuracy. To date, no studies in the literature have assessed this variable, highlighting the originality and relevance of the proposed research. Results indicated that the different activation sequences did not significantly affect the accuracy of the devices tested ($P > 0.05$), thereby confirming the first null hypothesis. However, a significant difference was observed between the devices, with Root ZX II showing the lowest mean error (0.13 mm) in the DA/LC/FC/FI sequence, partially rejecting the second null hypothesis.

Alginate was used as a conductive medium to simulate clinical conditions, which is widely validated in the literature (Bernardes et al., 2007, Oliveira et al., 2017, Baldi et al., 2007) for its stability, ease of handling, and low cost (Baldi et al., 2007, Borges et al., 2016, Iparraguirre Nuñovero et al., 2021). To standardize the sample and minimize methodological bias, single-rooted teeth with previously standardized apical foramina were selected (Vasconcelos et al., 2015, Oliveira et al., 2017, Akisue et al., 2014, Baldi et al., 2007). Electronic determinations were performed after cervical preparation (Melo et al., 2020, de Camargo et al., 2009) using properly adapted nickel-titanium files (Melo et al., 2020, Gehlot et al., 2016, Akisue et al., 2014) inserted to the apical foramen (Melo et al., 2020, Oliveira et al., 2017, de Camargo et al., 2009).

The mean error values observed in this study (ranging from 0.13 mm to 0.29 mm) are consistent with those found in other investigations on EAL accuracy (Melo et al., 2020, Vasconcelos et al., 2015, Oliveira et al., 2017, Stöber et al., 2011). These findings reinforce that, for the devices tested, the activation order – device activation, pole connection, and instrument insertion – does not interfere with reading accuracy.

Nevertheless, the DA/LC/FC/FI sequence yielded better performance for the Root ZX II, corroborating previous studies that demonstrate its superior precision (Bernardes et al., 2007, Ding et al., 2010, Piasecki et al., 2016, Borges et al., 2016). This sequence begins with device activation before assembling the conductive system, possibly allowing for calibration free from electrical interference from the moist canal environment. Subsequently, the system (lip clip, file clip, and file) is fully assembled, enabling readings to occur with all components already connected and calibrated. This approach may optimize the device's electronic circuit and provide more stable readings.

According to Vasconcelos et al. (2020), accurate working length determination must consider the position of the apical foramen, regardless of the apical preparation strategy. This finding underscores the importance of electronic working length determination in clinical practice[4]. However, the lack of standardization in manufacturers' manuals regarding activation sequences may cause confusion among practitioners. In this context, the data presented here suggest that although the activation sequence does not compromise the precision of the EALs tested, the DA/LC/FC/FI sequence may offer an additional advantage, particularly when using the Root ZX II.

**Table 1. Median error values of the electronic devices tested under the four activation sequences**

| Device | Activation sequence | | | |
|---|---|---|---|---|
| | DA/LC/FC/FI | DA/LC/FI/FC | LC/DA/FC/FI | LC/DA/FI/FC |
| Root ZX II | 0,13$^{a,A}$ | 0,20$^{a,A}$ | 0,19$^{a,A}$ | 0,21$^{a,A}$ |
| RomiApex A15 | 0,29$^{b,A}$ | 0,25$^{a,A}$ | 0,26$^{a,A}$ | 0,25$^{a,A}$ |
| Propex PiXi | 0,26$^{b,A}$ | 0,26$^{a,A}$ | 0,22$^{a,A}$ | 0,29$^{a,A}$ |

*Legend: $^{a,b}$Different lowercase letters indicate statistically significant differences between devices within the same sequence (Kruskal-Wallis and Dunn tests, P < 0.05). $^{A,B}$ Different uppercase letters indicate significant differences for the same device across the different activation sequences (Kruskal-Wallis test, P < 0.05).*

## 4. CONCLUSION

Under the tested conditions, it was concluded that variations in the activation sequences of the electronic apex locators Root ZX II, Propex Pixi, and Romiapex A-15 did not interfere with the accuracy of electronic working length measurements. However, a statistically significant difference was observed between the devices in the DA/LC/FC/FI sequence, where the Root ZX II showed superior performance with the lowest mean error.

## ETHICAL APPROVAL AND CONSENT

This study was approved by the local Research Ethics Committee at the Universidade Federal do Ceará (UFC), under protocol number 4.297.881. All procedures were conducted in accordance with ethical standards for research involving human tissues, and informed consent was obtained where applicable. The study adhered to the principles outlined in the 1964 Declaration of Helsinki.

## DISCLAIMER (ARTIFICIAL INTELLIGENCE)

The author(s) hereby declare that generative AI technologies, such as large language models, were used during the writing and translation of this manuscript. AI was employed to perform linguistic revision and translate the content of the article into the desired language.

Details of the AI usage are given below:

1. Tool used: ChatGPT (OpenAI), latest version.
2. Purpose: text revision and translation.
3. Inputs provided: the original manuscript text for linguistic revision and translation.

## COMPETING INTERESTS

Authors have declared that no competing interests exist.

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