


The Precision of Propex Pixi with Different Instruments and Coronal Preflaring Procedures

 Inês FERREIRA,  Ana Cristina BRAGA,  Irene PINA-VAZ

ABSTRACT

Objective: This study aimed to evaluate the influence of the instrument regarding the apical fit and type of the alloy and coronal preflaring procedures in the accuracy of Propex Pixi.

Methods: A total of 40 extracted human single-rooted permanent teeth with apical diameters of 200 μm were selected. A #10 K-file was inserted in the root canal until its end could be observed by a dental microscope to obtain the actual working length (WL). Electronic measurements were performed using Propex Pixi to the root apex ("0.0"). Different file alloys (stainless steel [SS] and nickel titanium [NiTi]) and sizes (#10, #15, and #20) were used before and after coronal flaring. Statistical analysis was performed by a factorial analysis of variance ($P \leq 0.05$).

Results: Results showed that the measurements of electronic length (EL) were closer to the actual working length (WL) after coronal flaring ($P < 0.05$). A significant intraclass correlation was observed between EL and WL. In addition, results showed no significant differences between files with different sizes or alloys.

Conclusion: Under the conditions of this study, Propex Pixi demonstrated adequate precision. Its accuracy was enhanced by coronal preflaring procedures regardless of the instrument type used (SS or NiTi) and the apical fit.

Keywords: Dental instruments, endodontics, odontometry

HIGHLIGHTS

- This study evaluated the accuracy of Propex Pixi regarding the instrument of measure and preflaring procedures.
- Propex Pixi demonstrated adequate precision when using the files inserted up to the apical foramen ("0.0") regardless of the size of the alloy or instrument.
- Preflaring positively influenced the accuracy.

INTRODUCTION

Electronic apex locators (EALs) were developed to determine a working length (WL) with high accuracy and predictability and are recommended as an adjunct to conventional radiography (1).

The goal of WL identification is to prepare the root canal as close as possible to the apical constriction, which is located between 0.5 and 2 mm from the radiographic

apex (2). Furthermore, the extension of the root canal preparation and filling has been associated with the outcome of endodontic treatment (3). The possibility of determining the apical constriction radiographically as an exact point was disregarded after recognizing that no distance from the radiographic apex could be an accurate indicator of the apical limit of the endodontic treatment (4).

Owing to their multifrequency technology, recently developed EALs provide precise measurements regardless of the canal condition or endodontic procedure (5). Nevertheless, some authors still claim that EAL readings may be influenced by file size, type, or alloy (6–8), whereas other researchers (9, 10) view these factors as clinically irrelevant. Literature shows that preflaring may enhance the accuracy of some EAL devices (11). Nevertheless, controversy still exists regarding the file size and type or the technical procedure that would improve the accuracy of readings.

Propex Pixi (Dentsply Maillefer) is a pocket-sized EAL that aims to detect minor apical foramen related to the "0.0" reading. To ensure optimal performance, the manufacturer recommends the use of a file size that is adjusted to the canal diameter. To our knowledge, few studies have reported the performance of this device (7, 12–15).

Please cite this article as: Ferreira I, Braga AC, Pina-Vaz I. The Precision of Propex Pixi with Different Instruments and Preflaring Procedures. *Eur Endod J* 2019; 4: 75-9

From the Department of Endodontics (I.F., I.P.-V. ✉ igapv@sapo.pt) Faculty of Dental Medicine of University of Porto, Porto, Portugal; Department of Production and Systems (A.C.B.), ALGORITMI Center, University of Minho, Braga, Portugal

Accepted 30 January 2019

Published online: 10 July 2019
DOI 10.14744/eej.2019.52724

This work is licensed under a Creative Commons Attribution-NonCommercial 4.0 International License.



Considering the evolution of EALs regarding accuracy levels, the aim of this study was to assess the influence of the instrument of measure (apical fit and type of alloy) and preflaring procedures on the accuracy of Propex Pixi.

MATERIALS AND METHODS

Sample size calculation was performed using G*Power v3.1.9.2 via analysis of variance (ANOVA): fixed effects, special, main effects, and interactions. The alpha-type error of 0.05 had a power (1- β) of 0.95, and the number of groups was 12. Forty specimens were indicated as the ideal number of specimens.

After obtaining approval from the research ethics committee, 40 human single rooted maxillary incisors and canines with single canals (Vertucci type I) were preserved in 1% thymol solution. Roots with resorption, fractures, open apices, and radiographically invisible canals were excluded. Soft tissue and calculus were removed from the root surfaces with hand instruments. Access cavities were prepared, and the cusps were flattened to establish a stable and reproducible surface reference for all measurements. The patency was confirmed using a #10 K-file (Dentsply Maillefer). No irrigation solutions were used. Only teeth with patent apical foramens were included. For actual working length (WL) determination, a manual #10 K-file (Dentsply Maillefer) with silicone stop was inserted in the root canal until the tip was just visible at the level of the minor apical foramen (MAF) via a dental microscope (OPMI Pico, Carl Zeiss, Germany) at 12.5x magnification. The silicone stopper was then adjusted to the occlusal/incisal reference plane. The distance between the file tip and stop was measured three times with an endodontic ruler to the nearest 0.5 mm. The WL was determined as the average of these measurements. For improved standardization, only teeth with apical diameters of 200 μ m were included.

For the electronic length (EL) measurement, each tooth was embedded in an alginate model. The alginate model was stored and wrapped in a wet paper, refrigerated when not in use, and was kept in a moist environment throughout the experiment (2 days) (16).

Hand K-files with different alloys, stainless steel (SS) and nickel titanium (NiTi) (NITiflex; Dentsply Maillefer) and sizes (#10, #15, and #20) were associated with the EAL Propex Pixi (Dentsply Maillefer) and were gradually introduced with slow clockwise turns to the apex designation ("0.0") according to the manufacturer's recommended operating procedures. The measurements were recorded after the reading of the EAL was stable for at least five seconds. These measurements were noted as EL. Thereafter, all root canals were preflared with the SX ProTaper instrument (Dentsply Maillefer) inserted in the cervical third of the canal. The patency was checked using a #10 K-file (Dentsply Maillefer), and the canals were irrigated with saline. They were dried with paper points and were electronically measured by repeating the above procedure. Three electronic measurements were performed for each tooth before and after preflaring. To reduce variations, a single calibration operator who was blinded to the WL measurements performed the EL measurements.

Statistical analysis

Statistical analysis was performed using IBM SPSS Statistics 25.0 software (SPSS Inc., Chicago, IL). The intraclass correlation coefficient (ICC) estimates and their 95% confident intervals were calculated using SPSS statistical package version 25 (SPSS Inc., Chicago, IL) on the basis of the mean rating ($k=2$), consistency, and two-way mixed-effects model. ICC was performed to evaluate the reliability of the EL. The difference between EL and WL was made in pairs and was considered the dependent variable. To evaluate the effects of different factors (file size, alloy type, and coronal flaring) and their interactions, factorial ANOVA was performed by taking into account this dependent variable. The differences were considered significant at a value of $P<0.05$. The accuracy was defined as the percentage of EL that is equal to WL by considering a tolerance range of ± 1 mm.

RESULTS

Table 1 shows the values of EL and WL measurements (in pairs) obtained with each file size and alloy type before and after coronal flaring. Positive and negative values were attributed for readings beyond and below the WL, respectively.

TABLE 1. Summary statistics of the difference between electronic length (EL) and actual working length (WL) with K-files of different alloys (SS: stainless steel; NiTi: nickel titanium) and sizes (#10, #15, and #20) before (unflared) and after (preflared) coronal flaring

		SS						NiTi					
		Unflared			Preflared			Unflared			Preflared		
		10 mm	15 mm	20 mm	10 mm	15 mm	20 mm	10 mm	15 mm	20 mm	10 mm	15 mm	20 mm
EL-WL	Count	120	120	120	120	120	120	120	120	120	120	120	120
	Mean	-0.79	-0.86	-0.78	-0.70	-0.70	-0.62	-0.78	-0.76	-0.78	-0.64	-0.73	-0.70
	Standard deviation	0.48	0.52	0.53	0.55	0.56	0.53	0.60	0.54	0.48	0.57	0.54	0.57
	Standard error of mean	0.04	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.04	0.05	0.05	0.05
	Median	-1.00	-1.00	-1.00	-0.50	-0.50	-0.50	-1.00	-1.00	-1.00	-0.50	-0.50	-0.50
	Minimum	-2.50	-3.50	-3.00	-3.00	-3.50	-3.00	-3.50	-3.00	-2.50	-3.50	-3.50	-3.50
	Maximum	0.00	0.50	0.00	0.50	1.00	0.00	0.50	0.50	0.00	0.50	0.50	0.50

*n (%); EL: Electronic length, WL: Actual working, SS: Stainless steel, NiTi: Nickel titanium

To evaluate the effect of the different factors (alloy, size, and coronal flaring) and their interactions, factorial ANOVA was performed on the fixed effects. The evaluation of the applicability conditions indicated the normality of the residues (qq-plot) with zero mean and homogeneity of variance (Levene's test: $P > 0.05$). However, the existence of outliers (box plot) could compromise the applicability; thus, they were eliminated, and the analysis was repeated.

The analysis of the results did not reveal significant differences in the mean values of EL owing to individual factors, except for the coronal flaring (Fig. 1)

The analysis of the results showed significant differences in EL mean values owing to coronal flaring because the mean values of the difference in EL-WL obtained by the preflaring procedures were significantly lower than those without coronal preflaring ($F [1.1408] = 26.405, P < 0.05$). Therefore, the mean values of ELs were closer to those of WLs for the preflared procedures.

Table 2 shows the percentage of EL measurements that consider the position of the file tip relative to the WL (EL-WL).

The obtained ICC value was 0.951 (excellent reliability), and its 95% confidence interval ranges between 0.946 and 0.956, thus

indicating that there was a 95% chance that the true ICC value is between 0.946 and 0.956. Therefore, according to statistical inference, it would be more appropriate to conclude that the level of reliability was "excellent."

DISCUSSION

This study evaluated the influence of previous coronal flaring and the different types and sizes of the instruments of measure on the accuracy of Propex Pixi. Results showed a significant difference between the EL and WL measurements before preflaring. On the contrary, after preflaring, EL-WL decreased significantly, with EL being closer to WL (i.e., more accurate or precise independent of the size or type of instrument). This was corroborated by other studies but with different EALs, namely, the gold standard Root ZX (11, 17). Thus far, no study has assessed the influence of preflaring procedures on the performance of Propex Pixi.

It has been suggested that preflaring procedures could prevent files from binding before reaching the apical foramen by removing coronal interferences and creating a glide path, thus increasing the efficacy of the EAL measurements (11, 18). Most investigations on EAL accuracy and teaching guidelines advocate coronal flaring because of the many benefits it can

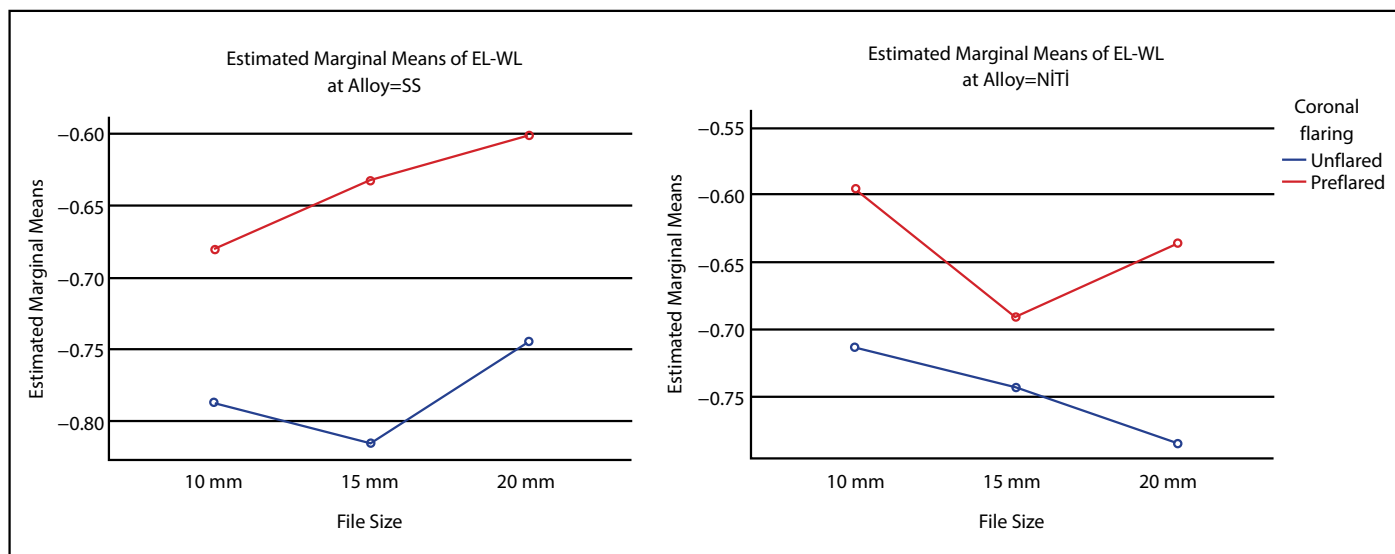


Figure 1. Mean differences between the values obtained with unflared and preflared procedures according to the files of different alloys (SS and NiTi) and sizes (#10, #15, and #20)

TABLE 2. Position of the tip of the file relative to the apex foramen in the measurements performed until 0.0 (negative values indicate that the file is positioned inside the canal)

EL-WL	SS						NiTi					
	Unflared			Preflared			Unflared			Preflared		
	10 mm	15 mm	20 mm	10 mm	15 mm	20 mm	10 mm	15 mm	20 mm	10 mm	15 mm	20 mm
≤-1.50	10 (8.3)	15 (12.4)	11 (9.2)	8 (6.7)	5 (4.1)	5 (4.1)	11 (9.2)	11 (9.1)	12 (10.0)	5 (4.0)	5 (4.0)	5 (4.2)
-1.00	60 (50.0)	58 (48.3)	54 (45.0)	48 (40.0)	44 (36.7)	42 (35.0)	55 (45.8)	55 (45.8)	49 (40.8)	43 (35.8)	54 (45.0)	46 (38.3)
-0.50	33 (27.5)	38 (31.6)	38 (31.7)	41 (34.2)	55 (45.8)	42 (35.0)	32 (26.7)	33 (27.5)	47 (39.2)	44 (36.7)	44 (36.7)	50 (41.7)
0.00	17 (14.2)	8 (6.7)	17 (14.2)	21 (17.5)	15 (12.5)	31 (25.8)	21 (17.5)	20 (16.7)	12 (10.0)	27 (22.5)	16 (13.3)	18 (15.0)
0.50	0 (0.0)	1 (0.8)	0 (0.0)	2 (1.7)	0 (0.0)	0 (0.0)	1 (0.8)	1 (0.8)	0 (0.0)	1 (0.8)	1 (0.8)	1 (0.8)
1.00	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	1 (0.8)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)

*n (%); EL: Electronic length, WL: Actual working, SS: Stainless steel, NiTi: Nickel titanium

provide, namely, a lower risk of extrusion or easier access to the apical foramen (19, 20).

There are controversial results about the influence of different file alloys in EAL accuracy. Although these results may be attributed to the different principles of EALs (e.g., operator sensitivity, experimental design, or the diameter of the apical foramen) (21), they are not completely understood (7). Nevertheless, studies have reported that the file alloy had no significant effect on the accuracy of the majority of EALs (7, 8, 10, 21, 22) independent of the adjustment of the file, thus corroborating our findings. If the file alloy was statistically significant, they were reported as not clinically relevant (9).

Under actual conditions, no significant difference was observed between the file sizes (apical diameters of 200 μm) studied. Other investigations corroborate our findings (9, 10, 17), whereas some studies found differences with apical diameters up to 0.6 mm (6, 12, 21) or found that the critical diameter of foramens was 0.3–0.4 mm (23). Recently, the greatest error was recorded for the measurements performed with the instruments with the smallest diameter compared with the size of the prepared root canal (8). On the contrary, Briseno-Marroquin et al. (10) reported that the accuracy was not enhanced with increasing instrument size. The unstable measurements with a #15k file were attributed to the higher friction experienced by this instrument in a root canal with a relatively small diameter. It has also been suggested that the differences may not only be caused by the size of the foramen but also by the surface of the contact of the increased diameter instrument/electrode with the walls, thus indicating a shorter distance from the apex (12). Although the use of files that fit the apical foramen is often recommended, it is still a controversial issue from the perspective of more accurate readings (7, 12, 14). Furthermore, it was not fully demonstrated in root canals with apical diameters of less than 0.6 mm.

The model of this investigation, which simulates the clinical periapical conditions with alginate as an electroconducting medium, is commonly used because of its low cost and easy assembly (6, 7, 9, 11, 17, 24). It has been used for periods of 1 hour (7) or 45 days (16). As long as it is stored under 100% humidity, it can provide reliable results during a long-term study (25).

One limitation of this study is the precision of the instrument of measure, and this limitation may account for the different levels of accuracy reported. The use of the endodontic ruler was considered to simulate the clinical condition (21), although it is not as precise as a caliper (7, 14). Similar to other studies (6, 7, 10), the WL was measured by inserting a small K-file with a silicone stop until the file was visible at the level of the MAF under a dental microscope.

Although most manufacturers have no specifications regarding the root canal conditions during the WL measurement, the effect of the electroconductivity of some irrigation solutions on the accuracy of certain EALs is disputed (5, 8, 16, 26, 27). Electronic measurements in dry canals showed similar results to those obtained in the presence of sodium hypochlorite in contrast to those obtained in the presence of distilled water, which presented a negative effect on the precision of EALs

(26). Therefore, in the present study, no other solution that could interfere was used after an initial irrigation with a saline solution. The effect of irrigants on the accuracy of Propex Pixi has not yet been reported.

Studies on the prognosis of endodontic treatment are unanimous in suggesting that staying short of the apex with a homogeneous obturation is the key to obtaining the highest success rate of 90%–94% when respecting the standard of care procedures (3, 4). However, the apical limit of root canal instrumentation and obturation remains a controversial issue.

Micro-CT studies confirmed that the actual apical constriction should be the apical section of the most apical narrowest canal area, which is often parallel and extends along a distance of 0.1 mm or more of the traditional canal flaring; apical constriction has been detected in only 10% of root canals (28, 29). It was found that the apical limit of this area (apical constriction) was near the MAF ($\approx 0.2\text{mm}$). The accuracy of EALs could then be measured in relation to MAF. The assessment method of the EL might influence the interpretation of the results. To avoid this type of bias, we followed the manufacturer's instructions strictly and considered that the highest accuracy for the device studied would be achieved at the "0.0" reading. Furthermore, it was reported to be an accurate protocol (14).

Although different parameters and landmark definitions might also influence the results, EALs have a tendency to make short measurements rather than long measurements (10, 17, 30). They have been reported independently of the protocols used (14). However, in the present study, only a small percentage (0.8%) of measurements with Propex Pixi surpassed the WL.

Some investigations reported certain levels of EAL accuracy by considering strictly the exact measurements to the MAF, which was also denominated as physiologic foramen. However, when they allowed a tolerance of ± 0.5 or ± 1 mm, the accuracy increased (10, 18). Other reports may reflect different reference points considering the WL vs. MAF or even the "0.0" vs. "0.5" mark of the display screen of the EAL. Although the level of tolerance and the experimental design may affect these percentages, the potential of EAL devices is clear when they are correctly used as an adjuvant of the radiographic examination. They can be crucial to the avoidance of overfilling, and its reliability has been emphasized (13), thus corroborating the present investigation. Nevertheless, specific characteristics and protocols must be clearly exposed even though they might be more relevant in some devices than others (14).

On the basis of the present findings, the most important outcome to consider should be the reliability (i.e., the positive correlation Propex Pixi showed to the WL) at the "0.0" reading in apical diameters of 200 μm , particularly after preflaring. Furthermore, clinicians should be aware that SS and NiTi files can be used interchangeably without compromising EL accuracy.

CONCLUSION

Within the limitations of this in-vitro study, it can be concluded that the preflaring procedures increased the accuracy of Propex Pixi regardless of the size of the alloy or instrument.

Disclosures

Conflict of interest: The authors deny any conflicts of interest related to this study.

Ethics Committee Approval: Ethics committee approval was received for this study from the The Ethics Committee Centro Hospitalar São João/Faculty of Medicine, University of Porto.

Peer-review: Externally peer-reviewed.

Financial Disclosure: The authors declared that this study has received no financial support.

Authorship contributions: Concept – I.P.V., I.F.; Design – I.P.V., A.C.B., I.F.; Supervision – I.P.V.; Funding - None; Materials - I.P.V., I.F.; Data collection &/or processing – I.P.V., I.F.; Analysis and/or interpretation – I.P.V., A.C.B., I.F.; Literature search – I.P.V., I.F.; Writing – I.P.V., A.C.B., I.F.; Critical Review – I.P.V., A.C.B.

REFERENCES

- Kim E, Marmo M, Lee CY, Oh NS, Kim IK. An in vivo comparison of working length determination by only root-ZX apex locator versus combining root-ZX apex locator with radiographs using a new impression technique. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 2008; 105(4):e79–83.
- European Society of Endodontology. Quality guidelines for endodontic treatment: consensus report of the European Society of Endodontology. *Int Endod J* 2006; 39(12):921–30. [\[CrossRef\]](#)
- Ng YL, Mann V, Gulabivala K. A prospective study of the factors affecting outcomes of nonsurgical root canal treatment: part 1: periapical health. *Int Endod J* 2011; 44(7):583–609. [\[CrossRef\]](#)
- Ricucci D, Langeland K. Apical limit of root canal instrumentation and obturation, part 2. A histological study. *Int Endod J* 1998; 31(6):394–409.
- Tsesis I, Blazer T, Ben-Izhack G, Taschieri S, Del Fabbro M, Corbella S, et al. The Precision of Electronic Apex Locators in Working Length Determination: A Systematic Review and Meta-analysis of the Literature. *J Endod* 2015; 41(11):1818–23. [\[CrossRef\]](#)
- Orosco FA, da Silva GF, Weckwerth PH, Lopes MTM, Garcia AMR, Duarte MAH, et al. Influence of different sized files on the accuracy of two electronic apex locators. *Aust Endod J* 2018; 44(3):251–4. [\[CrossRef\]](#)
- Gehlot PM, Manjunath V, Manjunath MK. An in vitro evaluation of the accuracy of four electronic apex locators using stainless-steel and nickel-titanium hand files. *Restor Dent Endod* 2016; 41(1):6–11. [\[CrossRef\]](#)
- Janecek M, Kosior P, Piesiak-Pañczyszyn D, Dudek K, Chrószcz A, Czajczyńska-Waszkiewicz A, et al. The Effect of File Size and Type and Irrigation Solutions on the Accuracy of Electronic Apex Locators: An In Vitro Study on Canine Teeth. *Biomed Res Int* 2016; 2016:8594087. [\[CrossRef\]](#)
- Thomas AS, Hartwell GR, Moon PC. The accuracy of the Root ZX electronic apex locator using stainless-steel and nickel-titanium files. *J Endod* 2003; 29(10):662–3. [\[CrossRef\]](#)
- Briseño-Marroquín B, Frajlích S, Goldberg F, Willershausen B. Influence of instrument size on the accuracy of different apex locators: an in vitro study. *J Endod* 2008; 34(6):698–702. [\[CrossRef\]](#)
- de Camargo EJ, Zapata RO, Medeiros PL, Bramante CM, Bernardineli N, Garcia RB, et al. Influence of preflaring on the accuracy of length determination with four electronic apex locators. *J Endod* 2009; 35(9):1300–2.
- Kolanu SK, Bolla N, Varri S3, Thummu J, Vemuri S, Mandava P. Evaluation of Correlation Between Apical Diameter and File Size Using Propex Pixi Apex Locator. *J Clin Diagn Res* 2014; 8(12):ZC18–20. [\[CrossRef\]](#)
- Saxena D, Saha SG, Bharadwaj A, Vijaywargiya N, Dubey S, Kala S. A comparative evaluation of accuracy of three electronic apex locators using histological section as gold standard: An ex vivo study. *J Conserv Dent* 2017; 20(4):251–4. [\[CrossRef\]](#)
- Oliveira TN, Vivacqua-Gomes N, Bernardes RA, Vivan RR, Duarte MAH, Vasconcelos BC. Determination of the Accuracy of 5 Electronic Apex Locators in the Function of Different Employment Protocols. *J Endod* 2017; 43(10):1663–7. [\[CrossRef\]](#)
- Üstün Y, Aslan T, Şekerci AE, Sağsen B. Evaluation of the Reliability of Cone-beam Computed Tomography Scanning and Electronic Apex Locator Measurements in Working Length Determination of Teeth with Large Periapical Lesions. *J Endod* 2016; 42(9):1334–7. [\[CrossRef\]](#)
- Kaufman AY, Keila S, Yoshpe M. Accuracy of a new apex locator: an in vitro study. *Int Endod J* 2002; 35(2):186–92. [\[CrossRef\]](#)
- Brito-Júnior M, Camilo CC, Moreira-Júnior G, Pecora JD, Sousa-Neto MD. Effect of pre-flaring and file size on the accuracy of two electronic apex locators. *J Appl Oral Sci* 2012; 20(5):538–43. [\[CrossRef\]](#)
- Pascon EA, Marrelli M, Congi O, Ciancio R, Miceli F, Versiani MA. An ex vivo comparison of working length determination by 3 electronic apex locators. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 2009; 108(3):e147–51. [\[CrossRef\]](#)
- Topçuoğlu HS, Üstün Y, Akpek F, Aktı A, Topçuoğlu G. Effect of coronal flaring on apical extrusion of debris during root canal instrumentation using single-file systems. *Int Endod J* 2016; 49(9):884–9. [\[CrossRef\]](#)
- Davis RD, Marshall JG, Baumgartner JC. Effect of early coronal flaring on working length change in curved canals using rotary nickel-titanium versus stainless steel instruments. *J Endod* 2002; 28(6):438–42. [\[CrossRef\]](#)
- Herrera M, Ábalos C, Lucena C, Jiménez-Planas A, Llamas R. Critical diameter of apical foramen and of file size using the Root ZX apex locator: an in vitro study. *J Endod* 2011; 37(9):1306–9. [\[CrossRef\]](#)
- Sadeghi S, Abolghasemi M. The accuracy of the Raypex5 electronic apex locator using stainless-steel hand K-file versus nickel-titanium rotary Mtwo file. *Med Oral Patol Oral Cir Bucal* 2010; 15(5):e788–90. [\[CrossRef\]](#)
- Fouad AF, Rivera EM, Krell KV. Accuracy of the Endex with variations in canal irrigants and foramen size. *J Endod* 1993; 19(2):63–7. [\[CrossRef\]](#)
- Lucena-Martín C, Robles-Gijón V, Ferrer-Luque CM, de Mondelo JM. In vitro evaluation of the accuracy of three electronic apex locators. *J Endod* 2004; 30(4):231–3. [\[CrossRef\]](#)
- Kumar S, Chacko Y, Lakshminarayanan L. A simple model to demonstrate the working of electronic apex locators. *Endodontology* 2004; 16:50–3.
- Lucena C, López JM, Martín JA, Robles V, González-Rodríguez MP. Accuracy of working length measurement: electronic apex locator versus cone-beam computed tomography. *Int Endod J* 2014; 47(3):246–56. [\[CrossRef\]](#)
- Duran-Sindreu F, Gomes S, Stöber E, Mercadé M, Jané L, Roig M. In vivo evaluation of the iPex and Root ZX electronic apex locators using various irrigants. *Int Endod J* 2013; 46(8):769–74. [\[CrossRef\]](#)
- ElAyouti A, Hülber-J M, Judenhofer MS, Connert T, Mannheim JG, Löst C, et al. Apical constriction: location and dimensions in molars—a micro-computed tomography study. *J Endod* 2014; 40(8):1095–9. [\[CrossRef\]](#)
- Connert T, Judenhofer MS, Hülber-J M, Schell S, Mannheim JG, Pichler BJ, et al. Evaluation of the accuracy of nine electronic apex locators by using Micro-CT. *Int Endod J* 2018; 51(2):223–32. [\[CrossRef\]](#)
- de Vasconcelos BC, do Vale TM, de Menezes AS, Pinheiro-Junior EC, Vivacqua-Gomes N, Bernardes RA, et al. An ex vivo comparison of root canal length determination by three electronic apex locators at positions short of the apical foramen. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 2010; 110(2):e57–61. [\[CrossRef\]](#)