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Accuracy of Four Apex Locators in Premolars with Root Resorption: An *In vitro* Study

Astrid López-Maekawa [a*], **Carmen Rosa García Rupay** [b]

a Endodontics Specialist, Master Program in Stomatology, School of Stomatology, Universidad Cientifica del Sur, Lima, Peru; b Endodontics Specialist, Master of Stomatology, School of Stomatology, Universidad Cientifica del Sur, Lima, Peru

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**Corresponding author*: Astrid López-Maekawa, Endodontics Specialist, Master Program in Stomatology, School of Stomatology, Universidad Cientifica del Sur, Lima, Peru

E-mail: astrid_vlm@hotmail.com

ABSTRACT

Introduction: The aim of the present *in vitro* study was to compare the accuracy of the working length measurements of four foramen locators: Root ZX mini, Raypex 6, Woodpex III and Propex Pixi in uniradicular premolars with simulated root resorption. **Materials and Methods:** For this study, 30 single-rooted permanent premolars were selected. The samples were divided into two groups: 15 teeth with simulated external root resorption and 15 teeth with internal resorption. Each sample was immersed in containers with alginate covering only the root part. Measurements were acquired from the four foramen locators and compared with the working length measurements that have been previously obtained with the direct visual technique and the use of a Digital USB Microscope under 5×. Next, the Shapiro-Wilk normality test was applied. The ANOVA test and *t*-test for related samples were performed, in order to analyze the measurements obtained. **Results:** In the teeth with external resorption, no statistically significant differences in the measurements were obtained with Raypex 6 and Propex Pixi foramen locators, but there were statistically significant differences with Root ZX mini and Woodpex III Root Zx mini [Root Zx mini (P=0.040) and Woodpex III (P=0.000)]. On the other hand, in the samples with internal root resorption, there were no statistically significant differences in measurements with the Root ZX mini, Propex Pixi and Raypex 6 foramen locators. However, there were significant differences with Woodpex III. **Conclusions**: Based on this *in vitro* study, Raypex 6 had the highest accuracy in premolars with simulated external resorption and Root ZX mini was the most accurate in teeth with simulated internal resorption. Furthermore, external root resorption affects the accuracy of foramen locators more than internal resorption.

Keywords: Apical Foramen; Electronic Apex Locator; Root Resorption

Introduction

The determination of the working length is one of the most important factors that contribute to the success of endodontic treatment [1]. Thus, determining a correct working length (WL) constitutes an essential step to avoid over-instrumentation, which allows the passage of irritating substances beyond the apical foramen [2]. In addition, it also avoids under instrumentation that prevents total sealing of the root canal up to the apical constriction [1, 2].

The determination of the working length carried out with the radiographic technique presents many limitations, such as: the difficulty in interpretation because it is a two-dimensional image [3]; and technical errors in angulation and developing made by the operator [4]. This traditional method makes it impossible to accurately determine the position of the apical constriction and the apical foramen [5].

Currently, Foramen locators are one of the most reliable tools to obtain a more accurate measurement of the working length [1]. These instruments reduce the number of required radiographies and minimize the subjectivity involved in radiographic interpretation [6].

In addition, the use of these devices has become widespread today, proving to be indispensable in endodontic practice due to

Figure 1. Tooth with internal resorption preparation verified by periapical radiography

their high levels of accuracy 97.4% [7]; even under conditions in which it would have previously been unthinkable to achieve an accurate measurement, such as in the presence of blood, hypochlorite or pus [7].

However, despite its accuracy in locating the apical foramen; there are several anatomical variations such as C-shaped canals, dens invagination, root dilaceration, *etc.* [8, 9] which may affect the measurement obtained with the foramen locator. Among these pathologies, we find root resorption.

Root resorption is a loss of hard dental tissues as a result of clastic activity [10, 11]. Root resorption can be broadly classified into external and internal resorption by the location of the resorption in relation to the root surface [10, 11].

Also, external root resorption is an irreversible pathological process [12] which can occur in situations as a dental trauma, apical infection, internal bleaching, periodontal treatment, ectopically erupting and most commonly in the presence of orthodontic movements [13].

In addition, another pathology of endodontic interest is internal root resorption that was reported as early as 1830 [11, 14]. Internal resorption is usually caused by chronic infections, trauma, or inflammatory reactions of the pulp cells. Plus, internal resorption is usually asymptomatic, and is detected on routine radiographic examinations [10, 14]. Compared with root external resorption, it has a rare occurrence, and its etiology and pathogenesis have not been completely elucidated [11].

Furthermore, there is little information of the impact in the accuracy of foramen locators in permanent teeth with external root resorption [15]. Moreover, there are currently no studies on internal resorption.

As previously explained, it is important to study foramen locators in these types of pathology, as these may alter the determination of the working length in our clinical practice.

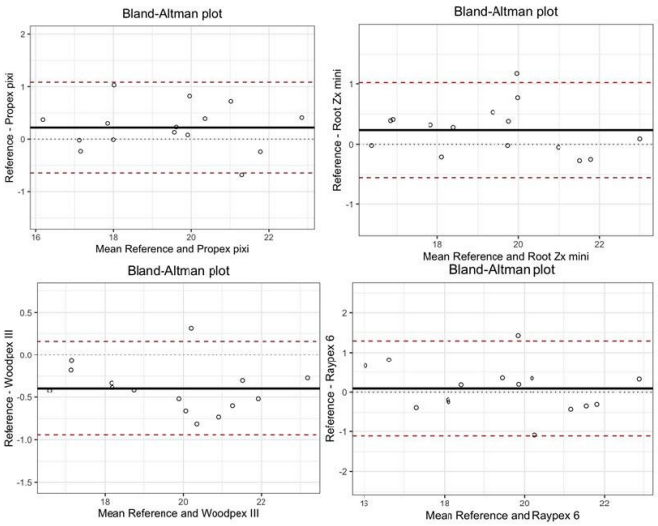

Figure 2. Bland-Altman plot in external resorption

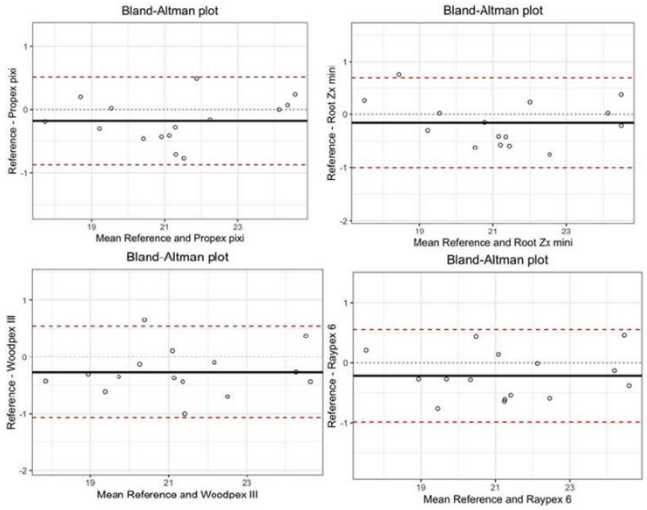

Figure 3. Bland-Altman plot in internal resorption

For this reason, the purpose of the present study is to compare the accuracy of the working length measurements of four foramen locators in single-rooted premolars with simulation of external and internal resorption.

Materials and Methods

The present study was approved by the Ethics Committee of Universidad Científica del Sur University in the City of Lima, Perú with Evidence N 193-CIEI-SCIENTIFIC-2020. A sample size was determined from the results of the pilot test, after which it was considered to use 30 freshly extracted teeth. Moreover, these had indication for tooth extraction for orthodontic, periodontal or pulp disease reasons and were donated for this study. Plus, periapical radiographs were taken

in buccolingual and mesiodistal directions in each tooth to verify the presence of a single root.

Afterwards, they were subjected to dental calculus removal using an ultrasonic device (UDS-J; Woodpecker, Guangzhou, China). Then, they were disinfected in 5.25% sodium hypochlorite for 2 h to remove traces of organic tissue from the outer surface of the root. Finally, they were stored in a sterile 0.9% saline solution until evaluation. [15]

The samples were divided into two groups: 15 teeth with external resorption and 15 with simulated internal resorption (n=15). Standard endodontic access was performed with a high speed medium round and fissure diamond burs (Micro Diamonds Technology, Israel) with water cooling.

After endodontic access, the cusps edges of the teeth were flattened with a medium round diamond bur (Micro Diamonds Technology, Israel) by approximately one millimeter, to facilitate measurements by means of a stable reference point [5].

Next, the coronal portion of each canal was flattened [5] using SX rotary files (Denstply Maillefer, Ballaigues, Switzerland). Then, a # 10 k-file (Dentsply Maillefer, Ballaigues, Switzerland) was passed into the canal until the tip of the file emerged from the apical foramen, to determine the location of the apical foramen (central or lateral).

Each of the teeth was stored and codified with correlative numbers to identify them.

Table 1. Comparison of the measurement of the working length using the apical locators with respect to the real length, in single-rooted teeth with external apical resorption

Locators	Mean (SD)	T	*P* *	ICCs**	*P*
Propex pixi	19.26 (1.95)	1.93	0.074	0.96	0.00
Root ZX mini	19.25 (2.00)	2.26	0.040	0.97	0.00
Woodpex III	19.88 (1.99)	-5.40	0.000	0.97	0.00
Raypex 6	19.39 (2.08)	0.56	0.583	0.95	0.00
AWL	19.48 (1.92)				

** Statistical Analysis with ANOVA test (P<0.05); ** ICCs: Interclass correlation coefficient (P<0.05)*

Table 2. Comparison of the measurement of the working length using the apical locators with respect to the real length, in single-rooted teeth with internal resorption

Locators	Mean (SD)	T	*P**	ICCs**	*P*
Propex pixi	21.35 (1.99)	-1.96	0.07	0.98	0.00
Root ZX mini	21.33 (2.14)	-1.40	0.18	0.97	0.00
Woodpex III	21.44 (2.02)	-2.50	0.02	0.97	0.00
Raypex 6	21.38 (2.04)	-2.12	0.05	0.97	0.00
AWL	21.17 (2.06)				

** Statistical Analysis with ANOVA test (P<0.05); ** ICCs: Interclass correlation coefficient (P<0.05)*

First, to create the artificial internal resorptions, the roots were horizontally sectioned with a 7.0/2.0 thick diamond disc (New Technology Instruments, Germany) at a distance of 7 mm from the apex. Then, semicircular cavities were made with No. 016 low speed steel bur (Denstply-Maillefer, Tulsa, Okla, USA) near the periphery of each sectioned piece. Plus, they were glued with Superglue (Pelikan cyanoacrylate adhesive; Istanbul, Turkey). Finally, the resorption was verified by means of a periapical radiograph [16] (Figure 1).

Furthermore, to simulate external apical resorption, a 45-degree oblique cut was made at the root apex with a thin 7.0/2.0-thick diamond disc (New Technology Instruments, Germany), in such a way that the palatal wall is shorter than the vestibular by 3 mm [15].

Actual working length

All the canals were measured with a # 10 k-file (Maillefer) to have an *actual working length* (AWL) with the direct vision technique and the use of a digital USB microscope with a magnification of 50× (Fuzhou Conic Industrial Co., Fuzhou, Fujian, China):

First, in premolars with external resorption, the file was passively introduced through the canal until the tip of the file was visible through the palatal wall [15]. Second, the silicone stop was carefully adjusted to the reference point and proceeded to remove the file from the root canal. Third, it was measured with an Ubermann digital vernier caliper a digital vernier caliper (Ubbermann®, Chile) from the silicone stop to the tip of the file. From this measurement obtained, 1 mm was subtracted manually and the measurement was registered.

In the case of teeth with internal root resorption, the file was introduced until the tip was visible through the apical foramen. Then, the silicone stop was then adjusted to the reference point and the file was removed from the canal. Next, it was measured with an Ubermann digital caliper (China) from the top to the tip of the file. Finally, from this measurement, 1 mm was subtracted.

Subsequently, all the teeth were placed in an alginate mold, in which once the impression material had set, the labial electrode of the locator was inserted in the mold in order to perform the measurements. These measurements are performed within the first 30 min of preparing the models to ensure that alginate retains enough moisture. [17]

Prior to electronic measurement, training and calibration intra and inter-observer were performed in the pilot study. The inter-observer calibration was carried out with a professor of endodontics with more than 10 years of experience from Universidad Científica del Sur.

Electronic measurement

Before electronic measurement, the canal was irrigated with 0.5 mL of 2.5% sodium hypochlorite to maintain humidity. The excess solution present in the root canal was dried using a #50 paper cone [18].

For electronic measurement, we used the following foramen locators: Raypex 6 (VDW, Munich, Germany), Woodpex III (Guilin Woodpecker Medical Instrument Co., Guilin, Guangxi, China), Propex Pixi (Dentsply Maillefer, Ballaigues, Switzerland) and Root ZX mini (J Morita Corp, Tokyo, Japan) with K-files #15 (Dentsply Maillefer, Ballaigues, Switzerland). All foramen locators were calibrated according to the manufacturers' instructions before measurements.

The foramen locator electrode was attached to a file and carefully inserted into the root canal. The measurements were taken according to the manufacturers' instructions:

In the Root ZX mini, which is based on the same functioning method of the Root ZX mini but has a compact size [18], the file was carefully inserted into the canal until it passed through the apical foramen; in this case a single sustained beep will sound, and the word "APEX" and the little triangle next to the Flash Bar will start to flash on and off. Then the file is moved back until the LCD screen shows us that the file is in the first green bar (the bar color changes to green to indicate you have reached a critical area), that indicates the file tip reaches a position near the apex [19].

In the case of the Propex Pixi, the file was carefully inserted into the root canal until it passed the apical foramen, which was showed in the foramen locator with a red "OVER" segment and an audio warning signal (rapid intermittent signal), and the file was moved back where the Propex Pixi indicates '0.0'. Then the file was placed onto an endodontic ruler and the apical length was measured. Finally, a minimum of 0.5 mm was subtracted from the measured file length. This is a safety precaution suggested by the manufacturer to avoid over-instrumentation and allowed us to make sure that we are in the apical zone [20].

In the case of Raypex 6, the file was carefully inserted into the canal until it passed through the apical foramen, this was indicated on the screen by the appearance of a red warning point underneath the apical zoom image and brief warning sounds. Then, the file was moved backward until the locator screen indicated that we were within the first two green bars. This corresponds to the section of the apical constriction up to the apical foramen, that is the relevant region for determining the working length [21].

In Woodpex III, the file was carefully inserted into the root canal until it passed through the apical foramen. This is indicated when red bars are displayed on the foramen locator, along with a continuous sound "beep" sound. The file was retracted until the screen indicated that the file is within the first green bar, which indicates the file has gone the position near by the apical foramen [22].

All the measurements were considered valid if the reading remained stable for 5 sec [18]. The file was then removed and measured with an Ubermann digital caliper (China) from the silicone stop to the tip of the file.

Statistical methods

Each sample was evaluated twice: one for measuring the actual working length and then using the four foramen locators. Later, we proceeded to compare both measurements.

All the measurements were collected in a database in Excel. Then, all the data was recorded in the STATA statistical program (STATA version 14; STATA, Texas, USA) and statistical analysis was performed.

A descriptive analysis was carried out in which the measurements obtained with the different locators were described: means, standard deviation and range were obtained. Subsequently, an inferential analysis was performed, where the working length measurements were compared with the measurements obtained with all the foramen locators in both types of resorption. First, the Shapiro-Wilk normality test was applied. Then, as the results were within a normal distribution, the ANOVA test was performed, and *t*-test for related samples, in order to analyze the measurements obtained.

Results

In the comparison of the measurement of the working length obtained with the foramen locators, regarding the actual length in the teeth with external resorption. It was found that there were no statistically significant differences in measurements obtained with Raypex 6 (P=0.58) and Propex Pixi (P=0.07) locators; while there were significant differences in the measurements of the Root

Table 3. Comparison of the accuracy obtained by foramen locators in teeth with external resorption

Locators	Mean (SD)	F	*P*
Propex pixi	-0.27 (0.49)	7.32	0.00
Root ZX mini	-0.23 (0.49)		
Woodpex III	0.46 (0.28)		
Raypex 6	-0.64 (0.61)		

Table 4. Comparison of the accuracy obtained by the foramen locators in teeth with internal resorption

Locators	Mean (SD)	F	*P*
Propex pixi	0.12 (0.42)	0.216	0.885
Root ZX mini	0.13 (0.44)		
Woodpex III	0.20 (0.36)		
Raypex 6	0.21 (0.39)		

ZX mini (P=0.04) and Woodpex III (P=0.00) compared to the AWL. The most accurate foramen locator in this group was the Raypex 6. In the Interclass correlation coefficient all the values obtained with all the foramen locators were more than 0.90 (P=0.00), that means that there is a good correlation between the foramen locators (Table 1). Bland and Altman plots show the accuracy of the foramen locators in relation to the actual working length, proving to be a good estimator of the real value of the variable (Figure 2).

On the other hand, in the comparison of the measurement of the working length obtained with the foramen locators related to the actual working length in teeth with internal root resorption, it is evident that there were no statistically significant differences in the measurements obtained with the foramen locators Root ZX mini (P=0.18), Propex Pixi, (P=0.07), Raypex 6 (P=0.05), but there were significant differences in the measurements obtained with the Woodpex III (P=0.02) compared to the actual working length in this group. Root ZX mini was the most accurate foramen locator in this group. In the interclass correlation coefficient all the foramen locators obtained values more than 0.90 (P=0.00), that means that there is a good correlation between the foramen locators (Table 2). Bland and Altman plots show the accuracy of the foramen locators in relation to the reference measurements, proving to be a good estimator of the real value of the variable (Figure 3).

Furthermore, regarding the accuracy obtained by the foramen locators in teeth with external root resorption, there is a statistically significant difference (P=0.00) between the four foramen locators (Table 3).

Finally, according to the accuracy obtained by the foramen locators in teeth with internal resorption, there is no statistically significant difference (P=0.88) between the four foramen locators (Table 4).

Discussion

The purpose of this study was to determine the accuracy in the measurements of the working length of four foramen locators in premolars with two different pathological variants. Likewise, there is little research in the use of foramen locators in teeth with external resorption and no studies in teeth with internal root resorption. Therefore, this study is of relevance for being the first to investigate the accuracy of foramen locators in teeth with internal resorption.

The methodology for preparing the teeth with external root resorption in this research is based on the study of Jadhav *et al.* [15] who performed the simulation of the external resorption through a 45 degrees cut in the apex, and alginate was used as an electro conductive medium. Moreover, they obtained the accuracy of Raypex 6, Root ZX and iPex (NSK, Nakanishi Inc., Tochigi, Japan). As a result, it was found that Raypex 6 showed significant accuracy in teeth with simulated external root resorption. Plus, this finding matches the results of the present study in which the Raypex 6 show the greatest accuracy in teeth with simulated external root resorption.

Various factors may influence the accuracy of foramen locators such as the diameter of the apical foramen [23], the foramen locator used [24] and the moisture content of the root canal [25].

In a study of Herrera *et al.* [23], artificial enlargement of the diameter of the apical constriction was made in 10 single-rooted teeth. They found that the accuracy of Root ZX varies depending on the diameter of the apical constriction. This study coincides that of Aydin *et al.* [26], which found that the accuracy of Root ZX decrease with the increase of the apical diameter. Furthermore, according to the manufacturer of the Root ZX mini, this locator can show short measurements in the presence of an exceptionally large apical foramen [19].

Plus, according to Pawar *et al.* [27] the Raypex 6 is the locator with the best performance in teeth with wide apical diameters. This agrees with our results in which the accuracy of the Raypex 6 was not altered in teeth with external resorption.

Teeth with external root resorption offer difficulties to contemporary methods of determining working length. Moreover, apical constriction, which is considered the most appropriate place to end endodontic therapy, is not present in teeth with root resorption and open apices [28, 29]. Thus, it can be infer that with the increase of the apical foramen, the taper towards the apex disappears and the walls of the root canal become more parallel [26], this may be the reason that the accuracy of the Root ZX mini was altered.

Other factor that influence the measurement of the foramen locator is the device used. Root ZX mini is a fourth locator generation which measures the impedance of tooth at two different frequencies [30]; and it disadvantage is that it need to be in a relatively dry or partially dry canal. In some cases additional drying is required; and it cannot function in a root canal with high exudate and blood [19, 31].

Raypex 6 is a sixth generation foramen locator [32] that overcome the disadvantages of 4th generation foramen locators. The foramen locator sixth generation adapts immediately in a dry or wet canal. In this way, it can be used in dry and wet canals, root canals with blood or exudates [33].

All the samples both with internal and external root resorption followed the same irrigation and drying protocols previous to the electronic reading. Root canals with external resorption are more difficult to dry, because the roots canals at the apical level are wider than the root canals with internal

resorption. In this study, the moisture content in the canal at the apical level possibly modified the results. For this reason, the Raypex 6 locator obtained the best accuracy in teeth with external root resorption.

On the other hand, in regard to teeth with internal root resorption, the Root ZX mini was the locator that achieved the highest accuracy. Morita's Root ZX mini, which is considered the gold standard of locators, has obtained excellent results in studies on permanent teeth with mature apices [34].

In an *in vivo* study by Serna-Pena *et al.* [18] the accuracy of the Root ZX mini and Propex Pixi in single rooted teeth was studied. They found that the accuracy of the Root ZX mini in establishing the AWL was 100% range of ±1mm. Then, the accuracy of Propex Pixi in establishing the AWL was 89.99% range of ±1mm. This result coincides with our study in which the Root ZX mini was the most accurate foramen locator, followed by Propex Pixi in teeth with internal resorption.

Additionally, in clinical practice we find various morphological variants such as C-shaped canals and root curvatures. The Root ZX mini foramen locator has also been shown to have good accuracy against these anatomical variants [35-37] where the diameter of the apical foramen was not altered.

Even though there is loss of surrounding dentine and this tissue is thinner in the site of the resorption, internal resorption did not affect the accuracy of the foramen locators. The reason is the presence of dentin. Root canals are surrounded by dentine and cementum that are insulators to electric current. Plus, insulators cannot conduct electric currents because all their electrons are tightly bound to their atoms [38]. In the present study, internal resorption has no communication with the periodontal ligament that is a conductor of electric current. Further studies with perforating internal root resorption are necessary, in these cases where there is communication with the periodontal ligament.

On the other side, when comparing the accuracy obtained by all the foramen locators in this study, it can be seen that the four foramen locators obtained greater accuracy in teeth with internal resorption than with teeth with external resorption.

Underestimation of length by apex locator may be explained by the fact that the device alarms when the file tip contacts the periapical tissue. In many cases, the periapical tissue penetrates into the canal to some extent. This penetration is greater in open apex teeth and those with a wide apex and thus file tip contacts the tissue penetrated into the canal before reaching the apical foramen resulting in underestimation of the length [39].

All in all, the results of this study will guide the operator in selecting the ideal foramen locator to use in teeth with external root resorption and internal dentin resorption; and in this way, provide the dentist with greater accuracy in determining the working length, which is the key factor in the success of root canal treatment [40]. In addition, this study will encourage an increase in the use of foramen locators in the management of various clinical situations such as pathological variants.

Conclusions

Based on this *in vitro* study, the most accurate locator in teeth with external resorption is the Raypex 6 and the most accurate foramen locator in teeth with internal resorption is the Root ZX mini. External root resorption affects more the accuracy of the foramen locators than internal resorption.

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Conflict of Interest: 'None declared'.

References

1. Rodríguez-Niklitschek C, Oporto V GH. Determinación de la Longitud de Trabajo en Endodoncia: Implicancias Clínicas de la Anatomía Radicular y del Sistema de Canales Radiculares. Int J Odontostomatol. 2014;8:177-83.
2. Welk AR, Baumgartner JC, Marshall JG. An in vivo comparison of two frequency-based electronic apex locators. J Endod. 2003;29(8):497-500.
3. Katz A, Tamse A, Kaufman AY. Tooth length determination: a review. Oral Surg Oral Med Oral Pathol. 1991;72(2):238-42.
4. Tamse A, Kaffe I, Fishel D. Zygomatic arch interference with correct radiographic diagnosis in maxillary molar endodontics. Oral Surg Oral Med Oral Pathol. 1980;50(6):563-6.
5. 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.
6. Morais A, Alencar A, Estrela C, Decurcio D, Estrela C. Working Length Determination Using Cone-Beam Computed Tomography, Periapical Radiography and Electronic Apex Locator in Teeth with Apical Periodontitis: A Clinical Study. Iran Endod J. 2016;11:164-8.
7. Meza M. Meza: Guía para el uso del Localizador de foramen Guía para el uso del Localizador de foramen Apex Locator: A Reliable and Easy Guide. Actas Urol Esp. 2015;1:29-39.
8. Forghani M, Moghim Farooji E, Abuchenari J, Bidar M, Eslami N. Conservative Treatment of an Invaginated Maxillary Lateral Incisor with a C-shaped Canal Using Cone-Beam Computed Tomography. Iran Endod J. 2015;10(4):281-3.

9. Jafarzadeh H, Abbott PV. Dilaceration: Review of an Endodontic Challenge. J Endod. 2007;33(9):1025-30.
10. Keskin C, Sariyilmaz E, Sariyilmaz Ö. Efficacy of XP-endo Finisher File in Removing Calcium Hydroxide from Simulated Internal Resorption Cavity. J Endod. 2017;43(1):126-30.
11. Patel S, Ricucci D, Durak C, Tay F. Internal root resorption: a review. J Endod. 2010;36(7):1107-21.
12. Nayak MT, Nayak A. External Inflammatory Root Resorption in Mandibular First Molar: A Case Report. Malays J Med Sci. 2015;22(6):63-6.
13. Schröder Â, Westphalen F, Schröder J, Fernandes Â, Westphalen V. Accuracy of Digital Periapical Radiography and Cone-beam Computed Tomography for Diagnosis of Natural and Simulated External Root Resorption. J Endod. 2018;44.
14. Mahmoudi E, Madani Z, Moudi E, Bijani A, Hashemian MB, Solati S. Diagnostic Accuracy of High Resolution Cone-beam Computed Tomography and Standard Mode Cone-beam Computed Tomography in Internal Root Resorption. Iran Endod J. 2019;14(3):211-5.
15. Jadhav G, Mittal P, Patil V, Kandekar P, Kulkarni A, Shinde S, Syed S, Elahi S. Accuracy of Different Apex Locators in Teeth with Simulated Apical Root Resorption: an In Vitro Study. Folia Medica. 2018;60:624-31.
16. Goldberg F, Massone EJ, Esmoris M, Alfie D. Comparison of different techniques for obturating experimental internal resorptive cavities. Endod Dent Traumatol. 2000;16(3):116-21.
17. Lipski M, Trąbska-Świstelnicka M, Woźniak K, Dembowska E, Droździk A. Evaluation of alginate as a substitute for root-surrounding tissues in electronic root canal measurements. Aust Endod J. 2013;39(3):155-8.
18. Serna-Peña G, Gomes-Azevedo S, Flores-Treviño J, Madla-Cruz E, Rodríguez-Delgado I, Martínez-González G. In Vivo Evaluation of 3 Electronic Apex Locators: Root ZX Mini, Apex ID, and Propex Pixi. J Endod. 2020;46(2):158-61.
19. Root Zx mini (Morita, USA) Manufacturer's Manual. Available from: https://www.morita.com/.
20. Propex Pixi (Denstply USA) Manufacturer's Manual Available from: https://www.dentsplysirona.com/en.
21. Raypex 6 (VDW, Germany) Manufacturer's Manual. Available from: https://www.vdw-dental.com/en/.
22. Woodpex III Manufacturer's Manual. (Woodpecker, China). Available from: http://www.glwoodpecker.com/index.html.
23. Herrera M, Abalos C, Planas AJ, Llamas R. Influence of apical constriction diameter on Root ZX apex locator precision. J Endod. 2007;33(8):995-8.
24. Tsesis I, Blazer T, Ben-Izhack G, Taschieri S, Del Fabbro M, Corbella S, Rosen E. 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.
25. Huang L. An experimental study of the principle of electronic root canal measurement. J Endod. 1987;13(2):60-4.
26. Aydin U, Karataslioglu E, Aksoy F, Yildirim C. In vitro evaluation of Root ZX and Raypex 6 in teeth with different apical diameters. J Conserv Dent. 2015;18(1):66-9.
27. Pawar K, Jethwani D, Daokar S, Wahane K, Raktade P, Tambake D. Evaluation Of Root Zx, Apex Id, Propex Pixi And Raypex 6 In Teeth With Wide Apical Foramen An In-Vitro Study. 2020.
28. Saraswathi V, Kedia A, Purayil TP, Ballal V, Saini A. Comparative evaluation of the accuracy of two electronic apex locators in determining the working length in teeth with simulated apical root resorption: An in vitro study. J Conserv Dent. 2016;19(5):402-5.
29. Plascencia H, Díaz M, Gascón G, Garduño S, Guerrero-Bobadilla C, Márquez-De Alba S, González-Barba G. Management of permanent teeth with necrotic pulps and open apices according to the stage of root development. J Clin Exp Dent. 2017;9(11):e1329-e39.
30. Davalbhakta RN, Gokhale NS, Hugar SM, Badakar CM, Gowtham A, Soneta SP. Comparative evaluation of root ZX Mini® apex locator and radiovisiography in determining the working length of primary molars: An In Vivo study. J Oral Biol Craniofac Res. 2021;11(2):257-62.
31. Dimitrov S, Roshkev D. Sixth Generation Adaptive Apex Locator. J IMAB, Annual Proceeding (Scientific Papers). 2010;15, book 2.
32. Srivastava V, Jain N, Bagchi S, Negi M, editors. Evaluation of the Use of Sixth Generation Apex Locators as a Diagnostic Tool to Detect Root Perforations. 2015.
33. Vinayak pdv. Electronic Apex Locators. J Dent Sci Oral Reh. 2013.
34. Aguiar BA, Reinaldo RS, Frota LM, do Vale MS, de Vasconcelos BC. Root ZX Electronic Foramen Locator: An Ex Vivo Study of Its Three Models' Precision and Reproducibility. Int J Dent. 2017;2017:5893790.
35. Piasecki L, José Dos Reis P, Jussiani EI, Andrello AC. A Micro-computed Tomographic Evaluation of the Accuracy of 3 Electronic Apex Locators in Curved Canals of Mandibular Molars. J Endod. 2018;44(12):1872-7.
36. Jafarzadeh H, Beyrami M, Forghani M. Evaluation of Conventional Radiography and an Electronic Apex Locator in Determining the Working Length in C-shaped Canals. Iran Endod J. 2017;12(1):60-3.
37. Saatchi M, Iravani S, Akhavan Khaleghi M, Mortaheb A. Influence of Root Canal Curvature on the Accuracy of Root ZX Electronic Foramen Locator: An In Vitro Study. Iran Endod J. 2017;12(2):173-8.
38. Nekoofar MH, Ghandi MM, Hayes SJ, Dummer PM. The fundamental operating principles of electronic root canal length measurement devices. Int Endod J. 2006;39(8):595-609.
39. Karami Nogorani M, Zare Jahromi M, Dehghan Z, Talaei R. Clinical Accuracy of Ipex Apex Locator for Measurement of Root Canal Length of Primary Molars. Eur Arch Paediatr Dent. 2014;26(1):13-7.
40. Pishipati V. An In Vitro Comparison of Propex II Apex Locator to Standard Radiographic Method. Iran Endod J. 2013;8:114-7.

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