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Accuracy of Four Different Apex Locators in Primary Molars: An In Vitro Study

Süt Molarlarda Dört Farklı Apeks Bulucunun Doğruluğu: Bir İn Vitro Çalışma

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ABSTRACT Objective: The aim of this study is to compare and evaluate the accuracy of 4 different electronic apex locators (EALs) (Root ZX Mini, Raypex 6, Propex Pixi, and E-Pex Pro) in primary molars with and without root resorption. **Material and Methods:** Forty-eight mandibular primary molar teeth with (24 teeth) and without (24 teeth) physiological root resorption, each with 4 root canals, were included in the study (96 canals in with resorption group and 96 canals in without resorption group) (n=192 root canals). The actual working length (AWL) was determined by subtracting 0.5 mm from the measured length for each canal. The differences between AWL and electronic working length readings of the 4 EALs and accuracy rates within specified tolerance intervals (TI; ±0.5 and ±1.0 mm) were calculated. **Results:** The presence of resorption in the teeth significantly affected the measurement using Root ZX Mini ($p<0.05$). In teeth without resorption, all EALs yielded an accuracy rate of 100% at ±1.0 mm TI, whereas the accuracy rates ranged from 91.7% to 95.8% at ±0.5 mm TI. In teeth with resorption, EALs yielded accuracy rates of 74.0%-65.6% at ±1.0 mm TI and 52.1%-60.4% at ±0.5 mm TI. **Conclusion:** At ±0.5 mm TI, Raypex 6 had greater accuracy in teeth without root resorption, whereas Propex Pixi had greater accuracy in teeth with root resorption. Apex locator preference may vary depending on the presence or absence of resorption.

Keywords: Primary tooth; electronic apex locator; working length; pediatric endodontics

ÖZET Amaç: Bu çalışmanın amacı, kök rezorpsiyonu olan ve olmayan süt azı dişlerinde 4 farklı elektronik apeks bulucunun (EAB) (Root ZX Mini, Raypex 6, Propex Pixi ve E-Pex Pro) doğruluğunu karşılaştırmak ve değerlendirmektir. **Gereç ve Yöntemler:** Fizyolojik kök rezorpsiyonu olan (24 diş) ve olmayan (24 diş), her biri 4 kanallı 48 mandibular süt molar diş çalışmaya dâhil edildi (96 kanal rezorpsiyon grubu için ve 96 kanal rezorpsiyon bulunmayan grup için) (n=192 kök kanalı). Gerçek çalışma uzunluğu (GÇU), her kanal için ölçülen uzunluktan 0,5 mm çıkarılarak belirlendi. Dört apeks bulucunun, GÇU ve elektronik çalışma uzunluğu okumaları arasındaki farklar ve belirtilen tolerans aralıkları (TA; ±0,5 ve ±1,0 mm) dâhilindeki doğruluk oranları hesaplandı. **Bulgular:** Dişlerde rezorpsiyon varlığı, Root ZX Mini kullanılarak yapılan ölçümü önemli ölçüde etkiledi ($p<0,05$). Rezorpsiyonsuz dişlerde, tüm EAB'ler ±1,0 mm TA'da %100 doğruluk oranı sağlarken, doğruluk oranları ±0,5 mm TA'da, %91,7-95,8 arasında değişmiştir. Rezorpsiyonlu dişlerde EAB'ler, ±1,0 mm TA'da %74,0-65,6 ve ±0,5 mm TA'da %52,1-60,4 doğruluk oranları vermiştir. **Sonuç:** ±0,5 mm TA'da Raypex 6, kök rezorpsiyonu olmayan dişlerde daha fazla doğruluğa sahipken, Propex Pixi kök rezorpsiyonu olan dişlerde daha fazla doğruluğa sahiptir. Rezorpsiyon varlığı veya yokluğuna göre apeks bulucu tercihi değişebilir.

Anahtar Kelimeler: Süt dişi; elektronik apeks bulucu; çalışma uzunluğu; pediatrik endodonti

The management of pulp treatment for primary teeth (PT) is critical in maintaining arch integrity until physiological exfoliation of PT, preventing abnormal oral habits and speech disorders due to the premature loss of PT, preserving dental aesthetics, and avoiding adverse psychological effects.[1,2] According to the American Academy of Pediatric Dentistry guidelines, root canal treatment is indicated in PT with irreversible pulpitis or pulp necrosis to protect dentition until the exfoliation process is com-

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pleted.[3] Periapical radiography is the most commonly used method in determining the working length (WL).[4] Failure to visualize all resorption areas in radiography may hamper the accurate determination of WL, leading to extruded fillings and damage to permanent tooth germs due to the over instrumentation of PT canals. Other disadvantages of periapical radiography include canal superposition and repeat radiographs due to inaccurate angulation of radiographs in noncooperative children.[5]

The use of electronic apex locators (EALs) for measuring the canal length of PT was first proposed in 1996.[6] Numerous studies on EALs have concluded that EALs have high accuracy even in the presence of physiological root resorption; provide fast, painless, and practical application in determining WL, particularly in children; reduce the number of radiographs, and overcome the limitations of radiographic examination in pediatric patients.[6-8]

With the advancement of technology since the introduction of EALs in dentistry, a new generation of EALs has been developed that increases the accuracy in measuring root canal length. Root ZX Mini (J. Morita, Tokyo, Japan) is a third-generation EAL. It measures the impedance value by ratio alternating current dual frequencies.[9] E-Pex Pro (Changzhou Eighteenth Medical Technology Co., China) is a fourth-generation EAL that uses two or more non-simultaneous continuous frequencies to measure the difference or ratio between two currents.[10] Propex Pixi (Dentsply Maillefer, Ballaigues, Switzerland) is a fifth-generation, calibration-free apex locator that can be used in wet or dry root canals. It measures the capacitance and resistance of the circuit separately.[11] Raypex 6 (VDW, Munich, Germany) is a sixth-generation (modified fifth-generation) EAL. A study showed that this EAL gives high-accuracy measurements in the case of root perforation and apical root resorption.[12]

Root canal treatment of PT can be complicated by the hard tissue deposits formed during the eruption of permanent teeth and physiological resorption.[13] In addition, different root anatomy of PT and displacement of the apical foramen due to resorption can further complicate the determination of the WL. The accuracy of electronic WL (EWL) measurements can be hampered by tooth resorption, dental trauma, and pathological tooth resorption.[7] The aim of this study is to compare and evaluate the accuracy of four different EALs (Root ZX Mini, Raypex 6, E-Pex Pro, and Propex Pixi) in primary second molar teeth with and without root resorption.

MATERIAL AND METHODS

This study was conducted following the Principles of the Declaration of Helsinki and received ethics committee approval from the Dicle University Faculty of Dental Medicine Local Ethics Committee (date: December 29, 2021, no: 2021-67). Based on a previous study, the mean values between the electronic length and the actual length (in millimeters) were used to calculate the effect size as 0.18.[14] Using the 5% α type error, 95% power, the sample size was calculated as 86 root canals in each group. For %10 drop-out possible, 96 root canals were required in each group.

The study included 48 extracted human mandibular primary second molar teeth [24 teeth without root resorption (96 root canals) and 24 teeth with root resorption (96 root canals)], i.e., 192 root canals, stored in a saline solution.

The teeth without resorption included in the study were too devastated to be treated conservatively and had more than 1/3 radiolucency in the bifurcation region. The teeth with less than 1/3 root resorption were included in the study as teeth with resorption group. All tooth surfaces were cleaned with a scaler and curette. The coronal parts of the teeth were flattened underwater using a high-speed diamond bur to obtain a fixed reference surface for measurements. Then, conventional endodontic access cavities were created on the teeth. Two roots and four canals (Variant 3) were identified in each primary molar tooth.[14] Distal roots were of Vertucci Type 4, 5, 6, or 7 each terminating in 2 separate foramen.[15]

DETERMINATION OF ACTUAL WORKING LENGTH

To determine the lengths of primary molar canals, K-files of size #10-15 for teeth without resorption and size #20-45 for teeth with resorption were inserted

under stereomicroscope (15x) along the canal. A double silicone stopper was placed on the reference point when the file tip was visible in the major apical foramen. In teeth with root resorption, a major apical foramen was identified at the most coronal end of the resorption cavity (Figure 1). The distance between the silicone stopper and the tip of the file was measured with a caliper (Mitutoyo Corp, Tokyo, Japan) with 0.01 mm accuracy. The WL measurements were repeated 3 times and averaged. Then, 0.5 mm was subtracted from the measurements to determine the actual working length (AWL).

MEASUREMENT OF EWL

Each tooth was embedded separately in a plastic box containing freshly prepared alginate (Dentsply Sirona, New York, USA) up to the enamel-cement boundary. For measurement, the lip hook of the EAL was placed in the alginate next to the plastic box, and the file clip was placed between the stopper and the handle of the file. The lip hook was placed as far as possible from the tooth to prevent interference. Groups were formed as in Figure 2. Then, the double stoppers of the files were placed on the reference point, and after waiting for 5 seconds, the files were removed and measured using a caliper (Figure 1). Each measurement was repeated three times, and the average was considered the EWL. Then, the EWL measurements of the teeth were subtracted from the AWL measurements.

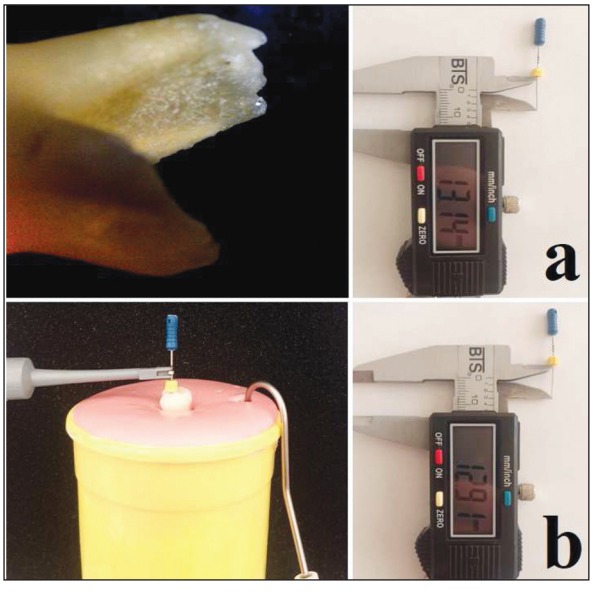

FIGURE 1: WL determinations procedures: a) AWL: The distance between the file's tip visible through the major foramen and double silicone stopper was measured with a digital caliper. Then, 0.5 mm was subtracted from this measurement. b) EWL: The file was advanced until the "Apex" or "00" was displayed on the screen, and its length was measured.
WL: Working length; AWL: Actual working length; EWL: Electronic working length.

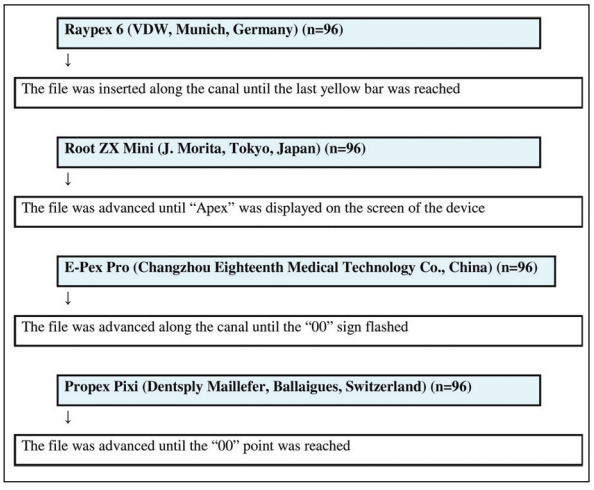

FIGURE 2: The representation of EALs and measurements used in our study.
EALs: Electronic apex locators.

STATISTICAL ANALYSIS

Kolmogorov-Smirnov test was used to examine the assumption of normality. Within-group comparisons by resorption status were made using Kruskal-Wallis H test. Mann-Whitney U and independent samples t-tests were used for pairwise comparisons of a single EAL for teeth with and without resorption (SPSS 20.0 software, IBM Corp., Armonk, NY, USA). The significance level was set at 5%.

RESULTS

Median, minimum, and maximum values are shown in Table 1. The median values obtained by subtracting the lengths measured by all EALs from the AWL were as follows: -0.17, -0.11, -0.26, and -0.13 mm, respectively, for teeth without resorption and 0.00, 0.08, -0.17, and -0.18 mm, respectively, for teeth with resorption. There was no statistically significant difference among the four EALs in PT with and without resorption ($p>0.05$). The presence of resorption in the tooth only affected measurements of Root ZX Mini ($p<0.05$) (Table 1).

TABLE 1: Descriptive statistics in teeth with and without resorption.

Group	Primary teeth without resorption (n=96) Median (minimum-maximum)	Primary teeth with resorption (n=96)	p value
AWL-Raypex 6	-0.17 (-0.96-0.98)	0.00 (-1.18-1.08)	0.287∞
AWL-Root ZX Mini	-0.11 (-0.94-0.96)	0.08 (-1.21-1.47)	0.009∞
AWL-E-Pex Pro	-0.26 (-1.00-1.00)	-0.17 (-1.40-1.40)	0.178§
AWL-Propex Pixi	-0.13 (-1.00-0.96)	-0.18 (-1.31-1.50)	0.693∞
p*	0.533	0.212	

*Kruskal-Wallis H test; ∞Independent samples t-test; §Mann-Whitney U test; AWL: Actual working length.

TABLE 2: Accuracy of EALs in teeth with and without resorption.

Apex locator	Accuracy (%) Primary teeth without resorption		Primary teeth with resorption	
	±0.5 mm	±1 mm	±0.5 mm	±1 mm
Raypex 6	74.0	100	58.3	92.7
Root ZX Mini	65.6	100	52.1	93.8
E-Pex Pro	69.8	100	55.2	91.7
Propex Pixi	68.8	100	60.4	95.8

EALs: Electronic apex locators.

In PT without resorption, all EALs showed an accuracy rate of 100% at ±1.00 mm tolerance interval (TI). In PT without resorption, Raypex 6, E-Pex Pro, Propex Pixi, and Root ZX Mini had accuracy rates of 74.0%, 69.8%, 68.8%, and 65.6%, respectively, at ±0.5 mm TI.

In PT with resorption, Propex Pixi, Root ZX Mini, Raypex 6, and E-Pex Pro had accuracy rates of 92.7%, 93.8%, 91.7%, and 95.8%, respectively, at ±1.00 mm TI. In PT with resorption, Propex Pixi, Raypex 6, and E-Pex Pro and Root ZX Mini, had accuracy rates of 60.4%, 58.3%, 55.2%, and 52.1%, respectively, at ±0.5 mm TI (Table 2).

DISCUSSION

PT root resorption is a physiologic event that has yet to be fully understood. This process continues in PT throughout the lifespan. Since there is no apical constriction due to root resorption, it is difficult to determine the WL by the radiographic method alone.[15] To date, many apex locators have been introduced to the dental market. Many studies are comparing these apex locators with each other and radiographic methods.[4,7,8,12,15-17]

To the best of our knowledge, no in vitro study investigated AWL in primary molars with Root ZX Mini, Raypex 6, E-Pex Pro, and Propex Pixi. According to the results of the present study, there was no statistically significant difference among the four EALs in terms of median AWL-EWL difference in teeth with resorption. Similarly, there was no difference among the four EALs in terms of AWL-EWL difference in teeth without resorption. When the resorption status of the teeth was examined, there was no significant difference between Raypex 6, E-Pex Pro, and Propex Pixi in terms of AWL-EAL difference. However, Root ZX Mini was the only EAL affected by resorption.

The cooperation of children receiving endodontic treatment is critical to the success of PT treatment. The management of dental treatment in children requires the physician to work in a controlled, confident, and fast manner. Root anatomy is another critical factor in the endodontic treatment of PT.[18] The lack of an apical constriction due to physiological root resorption, in contrast to permanent teeth, and the constant displacement of the apical foramen in the buccal-lingual direction due to resorption makes

it challenging to determine the reference landmark at which WL should be terminated in the root canals.[19] Histological examinations suggest that canal enlargement and filling procedures should be terminated in the minor apical foramen of the teeth or slightly before the foramen.[20] Depending on PT resorption, there are differing views on the termination level of WL. Camp stated that the WL should be 1-2 mm shorter than the radiographic apex, and in the presence of prominent resorption, this length should be 2-3 mm shorter than the radiographic apex to prevent the extrusion of the filling.[19] Garcia-Godoy claimed that the position of permanent tooth germs should be taken into account in determining the WL of PT. It is reasonable to work along the entire canal length when permanent teeth are located below the roots of PT; however, when permanent tooth germs are located at the furcation zone, it should be kept in mind that the apical foramen is displaced in the coronal direction due to root resorption occurring on the internal surfaces of the roots. As a result, WL should be determined using the occlusal plane level of permanent tooth germs as a reference landmark.[21]

Radiography is a reliable method of determining WL in a clinical setting. However, repeat radiography during treatment in pediatric patients can cause increased radiation exposure, and the presence of resorption can lead to misleading results.[22] Some studies have reported that EALs provided similar results to radiographic techniques in PT.[8,23] EAL has been validated as a reliable method for comparing EWL with AWL and determining WL, even at different levels of physiological root resorption in PT.[22]

Our study found it difficult to visually check the distance between the reference point and the caliper due to the lack of minor apical constriction in the teeth with root resorption. Therefore, to minimize potential measurement errors, canal length was measured under magnification from the root canal wall without resorption as soon as the file was visible. Each measurement was repeated three times, and the average value was calculated. While some studies in the literature report that a difference of ±0.5 mm between AWL and EWL is acceptable, others report that a difference of ±1 mm is also acceptable.[17,24-26] The present study evaluated measurements at both TIs (±0.5 and ±1.00 mm) and compared the results. The measurement accuracy of EAL becomes controversial when the file does not come into contact with the canal walls in the apical region if the apical region is wider than the coronal region in the PT with resorption; thus, the researchers in the present study used files with an appropriate D0 diameter for each root canal.[27]

Some in vitro studies that evaluated EALs in the PT with physiological root resorption found no difference in the accuracy of WL measurements between teeth with and without root resorption.[4,28] One study observed that Tri Auto ZX had lower accuracy in measurements taken in PT with resorption.[29] Beltrame et al. concluded that root resorption did not affect the accuracy of EAL.[30] In this study, the presence of resorption significantly affected the measurement of Root ZX Mini. The other three EALs were not affected by resorption in the teeth.

Several studies show that Root ZX has high accuracy.[17,25,26] Bertoli et al., using similar TI's to our study, recorded accuracy rates ranging from 72.5%-85% in teeth without resorption and 54.7%-72.9% in teeth with resorption.[31] Our study found that another version of this EAL, Root ZX Mini, was affected by root resorption. Moreover, Root ZX Mini showed the lowest accuracy rate in teeth with resorption.

Bodur et al. observed that the measurement accuracy decreased in teeth with resorption.[26] We observed that the measurement accuracy decreased in teeth with resorption for all EAL in the present study. This may be due to the absence of apical reconstruction in teeth with resorption.

In a in vitro study, Propex II, iPex II, and Raypex 6 were compared in PT at ±0.5 and ±1 mm TIs. No significant difference was found between the EALs in the measurements. Also, the accuracy rates of the EALs were similar.[32] While Raypex 6 showed similar accuracy rates in our study, there was no significant difference between them and other EALs. In Srivastava et al. study, measurements were made on teeth with intentionally created perforations, and Raypex 6 was found to be significantly better than

Propex Pixi.[33] Our study did not find a significant difference between these two EALs. However, in resorption teeth, the measurement accuracy was higher in Propex Pixi than in Raypex 6. Our result contradicted Srivastava et al. study. This may be due to selecting the perforated tooth group from single and multi-rooted teeth. We used only mandibular primary molars in our study.

In a in vivo study, two different multifrequency-ratio type EALs (Propex Pixi and Ipex) were used, and the EALs yielded similar results.[16] Moreover, the authors stated that EALs improve the accuracy of determining WL. However, the performance of EALs affected by the presence of liquids such as blood, saline, local anesthetics, and endodontic irrigants still needs to be determined. In our study, Propex Pixi had higher accuracy rates in teeth with and without resorption. The accuracy rates may be affected due to our study's in vitro nature and using alginate for electrical conductivity in the periapical region.

E-Pex Pro is a commercially available modern EAL that measures the impedance between the file tip and root canal at different frequencies. It provides precise measurements even in the presence of blood, apsis, or pulp tissue.[9] No study has investigated the use of E-Pex Pro on PT. The present study found that E-Pex Pro was not significantly different from other EALs measurements of WL in PT. Further studies are needed to investigate the measurement accuracy of this EAL.

LIMITATIONS OF STUDY

Although resorption levels did not exceed one-third of the apical root in the present study, nonstandardized apical foramen may have affected measurement accuracy. In addition, the electrical conductivity of periapical tissue mimicked by alginate does not match the electrical conductivity of pulp tissue, which does not reflect clinical conditions.

CONCLUSION

The application of EALs in pediatric endodontics, the correct determination of the WL, and the shortening of the treatment time by simplifying the procedure help to provide cooperation between the patient and the dentist. All tested EALs determined WL in PT with and without root resorption. Propex Pixi and Raypex 6 showed high accuracy rates in teeth with and without root resorption, respectively. Root ZX Mini was affected by resorption. For the reason that, this EAL may be preferred according to the case in pediatric endodontics. Since there is no study on using E-Pex Pro in PT in the literature, studies with this EAL are needed to compare it with other EALs.

Source of Finance

During this study, no financial or spiritual support was received neither from any pharmaceutical company that has a direct connection with the research subject, nor from a company that provides or produces medical instruments and materials which may negatively affect the evaluation process of this study.

Conflict of Interest

No conflicts of interest between the authors and / or family members of the scientific and medical committee members or members of the potential conflicts of interest, counseling, expertise, working conditions, share holding and similar situations in any firm.

Authorship Contributions

Idea/Concept: *Merve Yeniçeri Özata;* ***Design:*** *Merve Yeniçeri Özata, Ebru Akyelin;* ***Control/Supervision:*** *Merve Yeniçeri Özata, Ebru Akyelin;* ***Data Collection and/or Processing:*** *Merve Yeniçeri Özata, Ebru Akyelin;* ***Analysis and/or Interpretation:*** *Merve Yeniçeri Özata, Ebru Akyelin;* ***Literature Review:*** *Merve Yeniçeri Özata, Ebru Akyelin;* ***Writing the Article:*** *Merve Yeniçeri Özata, Ebru Akyelin;* ***Critical Review:*** *Sadullah Kaya;* ***References and Fundings:*** *Merve Yeniçeri Özata, Ebru Akyelin;* ***Materials:*** *Sadullah Kaya.*

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