10.5005/jp-journals-10024-2444

ORIGINAL ARTICLE

Comparison of Four Electronic Apex Locators in Detecting Working Length: An *Ex Vivo* Study

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ABSTRACT

Aim: To compare the accuracy of four different electronic apex locators (EALs) in detecting a position 0.5 mm short of the major foramen.

Materials and methods: The actual working length of thirty-five extracted human teeth was determined visually as 0.5 mm short of the apical foramen. After actual working length measurements, electronic working length was measured with four different EALs (Apex Pointer+, Raypex 5, Apex ID, and Raypex 6). Measurements were repeated three times by different operators. The data were analyzed using the intraclass correlation coefficient (ICC), the repeated measure analysis of variance (rANOVA) and Bonferroni post hoc tests. The significance level was set at $p \leq 0.05$.

Results: The mean differences between electronic and actual working length were–0.305 mm, 0.098 mm, 0.037, and 0.144 mm for the Apex Pointer+, the Raypex 5, the Apex ID, and the Raypex 6, respectively. Multiple paired comparisons (Bonferroni test) also showed the Apex Pointer+ is significantly different from the Raypex 5, Apex ID and Raypex 6 ($p = 0.000$, $p = 0.001$, and $p = 0.001$ respectively).

Conclusion: All EALs showed an acceptable determination of the working length between the ranges of ± 0.5mm except for the Apex Pointer+ device, which had the lowest accuracy. Further studies may be beneficial especially to better evaluate the accuracy of the Apex Pointer+.

Clinical significance: This article shows that Apex ID, which has only recently been introduced into the market, showed an acceptable determination of the working length. Its accuracy was similar to that of Raypex 5 and 6.

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Keywords: Apex ID, Apex Pointer+, Apical constriction, Electronic apex locator, Raypex 5, Raypex 6, Working length determination.

How to cite this article: Yolagiden M, Ersahan S, Suyun G, Bilgec E, Aydin C. Comparison of Four Electronic Apex Locators in Detecting Working Length: An *Ex Vivo* Study. J Contemp Dent Pract, 2018;19(12):1427-1433

Source of support: Nil

Conflict of interest: None

INTRODUCTION

Working length (WL) is defined as 'the distance from a coronal reference point to the point at which canal preparation and filling should terminate.'[1] The correct determination of the WL is a key factor for successful root canal treatment, because it reduces the possibility of insufficient debridement of the canal or damage to the periapical tissues due to over-instrumentation.[2] Commonly, the apical constriction (AC), also defined as a minor diameter, is considered the end of the area for canal preparation and filling. Its position is typically near the cementodentinal junction (CDJ), where the pulpal tissues transition to the periodontal tissues.[3] Anatomical studies have shown the AC to be located 0.5 to 1.0 mm from the major apical foramen (AF).[4]

Due to the pivotal role of WL determinations in root canal therapy, several methods have been introduced as follows; tactile sensation, the paper point method, apical periodontal sensitivity, and radiography. However, among all these methods, none of them was singly able to accurately determine the apical constriction. The radiographic method has long been the most commonly used for WL determination. The most obvious drawback to this method is that it is impossible to accurately determine the position of the AC and the AF on the basis of conventional radiographs alone.[5] The radiographic apex does not usually coincide with the anatomical apex,

nor with the AF; in cases where the AF is eccentric of the root apex. Thus, radiographic method is often inaccurate and usually results in overextension of the endodontic preparation.[6] Furthermore, radiographs provide a two-dimensional image of a three-dimensional structure; they are subject to distortion and magnification and are difficult to interpret. Besides, the superimposition of bony structures may hinder the identification of the radiographic apex of some teeth.[5]

The electronic apex locators (EALs) have been presented as valid instruments for identifying the AC and determining WL alternatively to the radiographic method. Their advantages include higher accuracy in estimation of the WL compared with the radiographic method as shown by previous studies,[7-9] continuous monitoring of the WL in combination with intelligent rotary systems,[10] and reducing the total needed radiographs and radiographic exposure as a result. The principal design and development of the early apex locators date back to Suzuki[11] who investigated on dogs and found that the electrical resistance between the periodontal membrane and the oral mucosa was a constant value. This point was introduced into clinical practice by Sunada,[12] which almost measured the electrical resistance between the oral mucosa and the periodontal ligament. Since then, several generations of EALs have been released and they are now widely used for locating the AC and WL. The Raypex 5 claims to be a fourth-generation device; the unit uses two separate frequencies (i.e., 400 Hz and 8 kHz), and its measurements are based on the root mean square of the signals. It was able to detect the correct WL (± 0.5 mm) in 80 to 85.59% of the cases.[13] One of the shortcomings in these devices is that they need relatively dry or in partially dried canals to be able to measure WL properly.

The fifth generation of EALs has been developed based on a comparison of the impedance with different frequencies and further mathematical processing to tackle those problems. In this way, they can detect the WL very well in the presence of blood and exudate. The Raypex 6 (VDW, Munich, Germany), Apex Pointer+ (MicroMega, Besançon, France), and Apex ID (SybronEndo, Glendora, CA, USA) are recently introduced fifth-generation EALs. Raypex 6 is VDW's updated version of the Raypex 5. To the best of our knowledge, only a few studies evaluated the performance of this new device.[14,15] The accuracy of the Raypex 6 has been successful to determine the root canal working length within ± 0.5 mm in 72.7 and 76.7% of the specimens observed by Marigo et al.[14] and Lucena et al.,[15] respectively. But, its accuracy has not been compared with various EALs. Apex ID, a new multi-frequency EAL, developed to further increase the efficacy of these devices. Apex ID has been designed to work in almost any canal condition. Only two recent studies have evaluated the accuracy of Apex ID.[16,17] One of them, conducted in teeth without foraminal patency, has compared this with measurements that are at the apical foramen.[16] The precision rates at the apical foramen and the obstructed apical foramen were 75% and 93%.[16] The other one compared the accuracy of Apex ID with that of Root ZX and found that these two EALs were equally precise in determining the WL.[17] The Apex Pointer+ is a new EAL whose accuracy has not been tested and reported in the literature to date. Given the absence of reports related to the accuracy of the most recent generation of EALs, the aim of this ex vivo study was to investigate the ability of 3 recently developed EALs, Raypex 6, Apex ID and Apex Pointer+, to detect the WL and to compare their accuracy with each other and with that of a fourth-generation EAL (Raypex 5).

MATERIALS AND METHODS

Preparation of Teeth

Thirty-five human mandibular premolars extracted for periodontal or orthodontic reasons were selected. The selected teeth had a single canal and fully formed roots and were devoid of caries, endodontic treatments, and restorations. Specimens were radiographed buccolingually and mesiodistally to identify aberrant canal morphology and to confirm the presence of a single canal. Teeth were then placed in 5.25% sodium hypochlorite for 2 hours. Soft tissue and calculus remnants were removed with an ultrasonic scaler. After being cleaned, each root was carefully examined by stereomicroscopy (Carl Zeiss GmbH, Oberkochen, Germany) at 20× magnification for the detection of external cracks, open apices, or apices undergoing resorption, which might alter the accuracy of the WL measurements. After microscopic examination, the teeth were stored in 2% thymol solution at room temperature and used within one week. The teeth were decoronated at the cementoenamel junction, and Gates-Glidden drills (Dentsply-Maillefer, Ballaigues, Switzerland) numbers 1 through 3 were used to flare the coronal two-thirds of each root canal. A sodium hypochlorite solution (1%) was used for irrigation during the process, and the patency of the apical foramen was maintained with a #10 K-file.

Actual Working Length (AWL) Determination Under the Microscope

Two operators determined the root canal length under 20× magnification (Carl Zeiss GmbH, Oberkochen, Germany) of the stereomicroscope. A #15 K-file with a silicone stop was advanced apically until the tip was visible at the level of the most coronal border of the apical foramen; when the tip was visible, the stop was stabilized at the coronal

edge of the tooth, the file was removed, and the distance between the stop and the file tip was measured with a digital caliper (TCM, Tchibo GmbH, Hamburg, Germany) to the nearest 0.01 mm. Each measurement was repeated twice and the average value was recorded. Then, 0.5 mm was subtracted from the average value, and the result was recorded as the actual working length (AWL).[18]

Electronic Working Length Determination

The electronic working length (EWL) was established by using an experimental model described by Chen et al.19 The lily cups were filled with floral foam soaked in 0.9% saline. The working length was determined for each canal using four EALs following the manufacturers' instructions. All canals were irrigated with 1% solution of sodium hypochlorite. The lip electrode was immersed in the respective orifice in contact with the conductive medium, and the same size K-file used for the AWL measurement was then connected to the other electrode for electronic measurement (Fig. 1). For each one of the appliances, the file was gently inserted into the root canal until the 'APEX' signal was seen on the LED or display screens. This reading was confirmed by the audible signal emitted from the EAL. The K-file was gently retracted until the light emitting diode (LED) or display showed the 0.5-mm mark (the third green bar limit for the Raypex 5 and Raypex 6, the third green bar limit for Apex ID, and 0.5 value on the bar scale for Apex Pointer+). A rubber stop was then carefully adjusted to the reference level, and the distance between the rubber stop and the file was measured with the digital caliper to the nearest 0.01 mm. Because four EALs were used with each canal, we alternated the first EAL to be used in each successive canal. After finishing the EWL measurements of all specimens with the first EAL, we reinserted the same size K-file to determine the working length using the second, third and fourth EALs and measured in the same manner. To assess the repeatability, each measurement was made with each electronic device in triplicate, and the mean value was calculated and recorded as the EWL. EWL and AWL measurements were performed by two trained examiners independently.

Electronic working length (EWLs) were compared with AWLs by deducting the AWL from the EWL. A resulting positive value indicates that the EWL exceeds the AWL, while a negative value indicates that EWL measurement is short of the AWL.

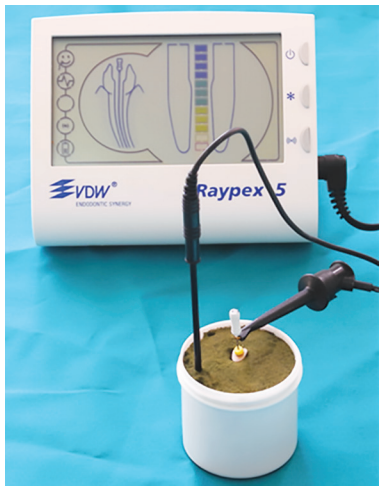


Fig. 1: Diagram of the experimental set-up

Statistical Analysis

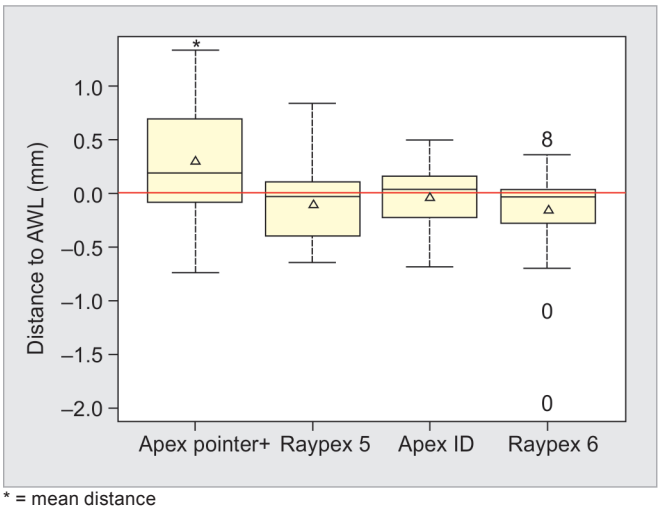
The reproducibility of the methods was tested by the values of intra-examiner according to the Interclass Correlation Coefficient (ICC) and the data were analyzed using repeated measures analysis of variance (rANOVA) and Bonferroni post hoc tests. The significance level was set at $p \leq 0.05$. All analyzes were performed using SPSS 22.0 (IBM Corp., Armonk, NY, USA) and R 3.2.2 (R Foundation for Statistical Computing, Vienna, Austria).

RESULTS

The means and standard deviations for the measurements obtained with each EAL are shown in Table 1. The mean differences between EWL and AWL were 0.31 mm, –0.11 mm, –0.04, and –0.14 mm for the Apex Pointer+, the Raypex 5, the Apex ID, and the Raypex 6, respectively. Graph 1 shows

Table 1: Mean and standard deviation (SD) of measurements using four EALs

	n	*Mean*	*SD*
Actual working length (AWL)	35	14.70	2.21
Apex Pointer+	35	15.01	2.16
Raypex 5	35	14.59	2.14
Apex ID	35	14.67	2.23
Raypex 6	35	14.56	2.17



* = mean distance

Graph 1: Box and whisker plots depicting the cumulative frequency of the distance (mm) between the values obtained with each apex locator to the AWL (*p <0.05)

Table 2: Frequency and percentages of EWL measurements that prove precise, short and long with respect to AWL

Method	Shorter than actual WL (-1.0 mm to -0.5 mm) (%)	Shorter than actual WL (-0.5 mm to 0.0 mm) (%)	Precise (%)	Longer than actual WL (0.0 mm to 0.5 mm) (%)	Longer than actual WL (0.5 mm to 1.0 mm) %)
Apex Pointer+	2 (6)	8 (23)	0 (0)	13 (37)	8 (23)
Raypex 5	4 (11)	15 (43)	0 (0)	15 (43)	1 (3)
Apex ID	2 (6)	15 (43)	0 (0)	17 (49)	1(3)
Raypex 6	4 (11)	14 (40)	1 (3)	13 (37)	2 (6)

Table 3: Intraclass Correlation Coefficient values of each EAL

	ICC
Raypex 5	0.993
Raypex 6	0.999
Apex Pointer+	0.986

that the Apex Pointer+ gives a statistically significant overestimation of the AWL (p = 0.014). Multiple paired comparisons (Bonferroni test) also showed the Apex Pointer+ was significantly different from the Raypex 5, Apex ID and Raypex 6 (p = 0.000, p = 0.001, and p = 0.001, respectively). No significant differences were found between Raypex 5 and Raypex 6 (p = 1.000) or between Raypex 5 and Apex ID (p = 1.000) or between Raypex 6 and Apex ID (p = 1.000).

Table 2 shows the frequency and percentages of EWL measurements that prove precise, short and long with respect to AWL. The accuracy of the Apex Pointer+, Raypex 5, Apex ID and Raypex 6 in locating the minor diameter within ± 0.5 mm was 60%, 86%, 92%, and, 80% respectively, the accuracy within ±1.0 mm was 89%, 100%, 100%, and 97%, respectively.

The consistency of measurements among different examiners was calculated for each method by ICC analysis. It showed high levels of agreement between examiners for all EALs, ranging from 0.986 to 0.999 (Table 3).

DISCUSSION

The recently introduced fifth-generation EALs are claimed by their manufacturers to perform successfully in WL determination. Given the absence of reports related to the accuracy of the most recent generation of EALs, the aim of this study was to evaluate the ability of 3 recently developed EALs, Raypex 6, Apex ID and Apex Pointer+ to detect the WL and to compare their accuracy with each other and with that of a fourth-generation EAL (Raypex 5).

The accuracy of EALs in determining the location of the apical constriction of the root canal or the major foramen has been examined by numerous investigators.[3,6,9,16] However, there are problems with adopting this apical constriction limit. For example, the existence of an apical constriction might be more conceptual than real because fewer than half of the teeth examined have a traditionally conceptualized single apical constriction.[20] Moreover, several researchers have suggested that the precise location of the AC cannot be determined,[21,22] and there might not always be an apical constriction.[21,22] Consequently, we and many others have evaluated the accuracy of EALs in determining the WL, taking as a reference point the major foramen or a point 0.5 mm short of the major foramen.[23,24] In this study, the control WL was established to be 0.5 mm coronal to the major foramen and WL determination method by EALs involved detection of the point indicated as '05' on the EAL screen. This method is very simple, involving no calculation, and avoids the files passing through the major foramen and overestimating the working length.[25] Clinicians who understand the indicators displayed on the EAL can easily use this method.

The present methodology used an in vitro model. Some authors have compared the accuracies of EALs in establishing the final working lengths under in vivo and in vitro conditions and concluded that these accuracies are not significantly different between the in vivo and in vitro models.[23] However, it is important to highlight that there was no direct comparison of in vivo and in vitro techniques, because the teeth used were not the same teeth.[25] Precise comparison of the accuracy of different types of EAL in determining the WL is possible only if the same teeth are assessed by all the devices. Therefore, we followed the protocol used by Wrbas et al.,[25] which allowed us to calculate the accuracy of the four EALs in the same teeth. Teeth were horizontally sectioned at the cementoenamel junction for obtaining reproducible reference points and were mounted in a plastic container filled with saline solution media. In the present study, saline solution was selected as the embedding medium because it has been used in research with high accuracy[26,27] and is similar to biological tissue because of an ionic composition similar to blood plasma.[28] The measurements obtained were stable and coherent, and a large number of canals can be evaluated in a short time period with this method, which is not possible in the clinical settings. In addition, the slight standard deviation values show the accuracy of these devices and appropriateness of the mechanism used to determine AWLs regardless of the root canal anatomy.

Among the four EALs tested, Raypex 5, Apex ID and Raypex 6 showed similar and more accurate WL

measurements when compared with Apex Pointer+. The results showed that there was no significant difference in the accuracy between the Raypex 5, Apex ID, and Raypex 6 in determining the WL. Considering a clinically acceptable variation of ± 0.5 mm in relation to the actual WL (control) as suggested by various studies,[29,30] the results of the present study showed 86 and 92%, and 80% accuracy for the Raypex 5, Apex ID, and Raypex 6, respectively, in relation to the control measurement. Within the limits of ± 1 mm, these 3 EALs measured the WL accurately over 97% of specimens.

Raypex 5 is a widely used EAL that uses two separate frequencies (400 Hz and 800 Hz) and determines the working length via an impedance ratio (4th generation). Its reliability has been confirmed by a large number of studies and the findings of this study were similar to those of other studies.[25,31-33] The multiple frequency processing technologies and use of RMS (root mean square) incorporated into the Raypex 6 may have theoretical advantages for increasing the accuracy of the working length measurements, by reducing the electrical noises affecting other physical parameters like amplitude or phase of the electrical signal that is used by other EALs. But the technology improvements were not enough to make the Raypex 6 significantly more accurate than the Raypex 5 ($p > 0.05$), which appears to be an extremely accurate fourth-generation EAL. The Raypex 6 gave root canal working lengths of 0.14 mm (0.64 mm short of the major foramen, because in this study the control WL was set at 0.5 mm from the major foramen). This result is similar to those obtained by Marigo et al.[14] and Lucena et al.[15] who reported that the file tip was identified 0.38 mm and 0.08 mm short of the major foramen when using the Raypex 6, respectively. Although our results are similar to the results of both studies, their measurements usually exceeded the major foramen.[14,15] This finding can be explained by their use of the 'apex' signal on the EAL.[14,15] On the other hand, we noted almost no overestimation of the working length with neither Raypex 5 nor Raypex 6 (when '0.5' mark was used). Consequently, to avoid the risk of over instrumentation, use of '0.5' mark would be better than the use of 'apex' mark. The accuracy of the Raypex 5 and Raypex 6 measurement to within 0.50 mm of the control root canal length 86% and 80% of the time, respectively, and within 1 mm 100% and 97% of the time, respectively, in the present study, appears consistent with previous research.[15,25,32-34] These high levels of accuracy appear to be beneficial to the practice of endodontics, and since both EALs had similar levels of accuracy, both the Raypex 5 and Raypex 6 EALs can be recommended for use in endodontics.

Apex ID, which has only recently been introduced into the market, has not been described in the literature; however, it works by measuring the ratio of the impedances measured simultaneously at frequencies of 0.5 and 5.0 kHz.[35] According to the manufacturer, its firmware is more developed than that of the EALs available.[35] In the present study, Apex ID offered the best results at AWL (a position 0.5 mm short of the major foramen) within the limits of ± 0.5 mm (0.04 mm, 92%). Only two recent studies have evaluated the accuracy of Apex ID.[16,17] In a recent study, the accuracy of Apex ID with that of Root ZX was compared. It was found that the file tip was identified as 0.10 mm short of the AWL when using the Apex ID (with '0.5' mark on the locator) and these two EALs were equally precise in determining the WL.[17] These results are in line with those obtained in the present study. The other study evaluated the accuracy of Apex ID in root canals with an obstructed apical foramen and compared this with measurements that were at the apical foramen.[16] The results obtained with Apex ID at the obstructed apical foramen were highly acceptable (75%) and statistically similar to those observed at the apical foramen (93%).[16] This suggests that the presence of dentin plugs, which make the passage of a current through the root canal difficult, and the inability to reach the AF did not interfere with the accuracy of this device and shows that an obstruction does not influence its operating mechanism.[16]

Recently, a new electronic apex locator, Apex Pointer+, has been introduced. Apex Pointer+ is described by its manufacturer as an accurate EAL that uses a high-frequency current of constant amplitude and thus provides consistent measurement along the canal. However, no information is available regarding the accuracy of Apex Pointer+ to measure WL. In only one earlier study using a mounting model, El Ayouti et al.[36] found that within the limits of ±1 mm Apex Pointer, the old version of the Apex Pointer+ was accurate in 71% of cases. In the present study, within the limits of ±1 mm Apex Pointer+ located the AC in 89% of cases. The Apex Pointer+ also showed a strong tendency to overestimate the WL (23% of cases). Although the Apex Pointer+ has been improved and is now much better than the older version of its own, it still lacks adequate accuracy in determining the AWL (AC) when compared with the other 3 EALs (60%, within the limits of ±0.5 mm).

CONCLUSION

Under the conditions of this in vitro study, all the EALs showed an acceptable determination of the working length between the ranges of ± 0.5 mm except for the Apex Pointer+ device, which had the lowest accuracy. Further studies may be beneficial especially to better evaluate the accuracy of the Apex Pointer+.

CLINICAL SIGNIFICANCE

This article shows that Apex ID, which has only recently been introduced into the market, showed an acceptable determination of the working length. Its accuracy was similar to that of Raypex 5 and Raypex 6.

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