

Accuracy of Three Electronic Apex Locators in Anterior and Posterior Teeth: An *Ex Vivo* Study

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Abstract

Introduction: The aim of this study was to determine in anterior teeth, bicuspid, and molars (1) the accuracy of 3 different electronic apex locators (EALs) in detecting the apical foramen and (2) the accuracy of digital radiography in determining the working length (WL), compared with visible control under a microscope. **Methods:** By using radiovideography (RVG), we measured the lengths of 120 root canals with 3 different EALs (Endex, ProPex II, and Root ZX) and compared them with the actual lengths. The accuracy of EALs and RVG was related to each dental category. An endodontic training kit (Pro-Train) was used during experimental procedures. **Results:** Statistical analysis showed that the 3 EALs and RVG were less accurate in anterior teeth and molars than in bicuspid. The paired-sample *t* test showed no statistically significant difference between mesiodistal plane and buccolingual plane digital radiography in all groups. **Conclusions:** The 3 EALs tested were more accurate in detecting the apical foramen in bicuspid than in both molars and anterior teeth. Radiographic measurements were not reliable for determining WL in all dental groups in both radiographic planes. (*J Endod* 2011;37:684–687)

Key Words

Digital radiography, electronic apex locator, Endex, ProPex II, Pro-Train, Root ZX, working length

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Working length (WL) has been defined as “the distance from a coronal reference point to the point at which canal preparation and obturation should terminate” (1). Instrumentation and obturation of the root endodontic system should be terminated at the apical constriction (2). The apical constriction, also defined as a minor diameter, represents the histologic point of transition between the pulpal and the periodontal tissue at the cement-dentinal junction (CDJ). It has been suggested that the canal filling should terminate at the CDJ (3, 4). Anatomical studies have shown the apical constriction to be located 0.5–1.0 mm from the external or major foramen (2, 5). The mean distance between the CDJ and the apical foramen is 0.5–0.8 mm (6, 7). In the majority of cases, the apical foramen is located on the lateral surface of the root at an average distance of 0.36 mm for anterior teeth and 0.48 for posterior teeth. Martos et al (8) have found that the average distance between the apical foramen and the anatomical apex is 0.69 mm. This distance is greater in posterior teeth (0.82 mm) than in anterior teeth (0.39 mm); thus, in 60% of cases, the apical foramen is located on a lateral surface of the root and in 40% of cases on the anatomical apex. The same authors showed that the lateral position of the apical foramen has been detected in 43% of posterior teeth and in 17% of anterior teeth. WL can be determined with radiographs, tactile sensation, and electronic apex locators (EALs). However, radiographs are subject to distortion, magnification, interpretation variability, and lack of three-dimensional representation; as a result, WL is generally measured about 0.5–1 mm short of the radiographic apex. Pratten and McDonald (9) showed that considering the position of the apical constriction located 1 mm short of the radiographic apex will result in an underestimation of WL. Vertical and horizontal cone angulations, film position, tooth inclination, and film processing issues could influence WL determination from radiographs (10). In some teeth, the apical foramen might be located on the lateral root surface up to 3.5 mm from the radiographic apex (11). In such teeth, if the canal terminates coronal to the anatomical apex and in the plane of the film, the radiographic appearance will be short, and any adjustment will result in an overestimation of the WL. This has been shown *in vitro* and *in vivo* (12, 13).

Custer (14) was the first to introduce an electrical method of locating the apical foramen. Suzuki (15) discovered that electrical resistance between the periodontal ligament and oral mucosa has a constant value of 6.5 k Ω ; this led to the development by Sunada (16) of the first EAL. One of the first EALs (Endex; Osada Electric Co, Tokyo, Japan), created in 1984 by Yamaoka on the basis of studies by Ushiyama (17), was based on the difference in impedance between 2 wavelengths (1 and 5 kHz).

For this EAL several studies (18–20) have shown precision measurements with ± 0.5 mm from the WL in 59%, 100%, and 68% of the specimens tested, respectively. Advances in technology have led to the development of the ratio method with 2 frequencies of impedance; a quotient of impedance is then calculated and expressed as the position of the file in the canal. The Root ZX (J. Morita Co, Tustin, CA) works according to this principle. *In vivo* studies have demonstrated the Root ZX to be accurate in locating the minor diameter to within 1 mm (13, 21–23). The ProPex II (Dentsply-Maillefer, Tulsa, OK) has been recently developed. Rather than using the amplitude of the signal as for all EALs, it measures the energy of the signal with multi-signal frequencies. As described by Briseño-Marroquin et al (24), precision in determination of the apical foramen is 83.45% and 91.41% with standard deviation of ± 0.5 mm and $97.66\% \pm 1$ mm, depending on the K-file used.

The purpose of this study was to compare in anterior teeth, bicuspid, and molars (1) the accuracy of Endex, Root ZX, and ProPex II in detecting the apical foramen *ex vivo* under clinical conditions and (2) the accuracy of digital radiography in determining the WL, compared with visible control under a microscope.

Materials and Methods

We selected 80 periodontally involved human teeth (total of 120 canals: 40 in molars, 40 in bicuspid, and 40 in anterior teeth) extracted from 35- to 60-year-old patients, with the approval of the Ethics in Research Committee of the Centre of Health Sciences of the University of Rome “Tor Vergata.” After extraction, teeth were placed in 5% sodium hypochlorite to remove the ligament tissue, stored in 2% thymol solution at room temperature, and used within 1 week. Before being used, each root was carefully examined by stereomicroscopy (Universal 300; Moeller Wedel, Wedel, Germany) at 20× magnification for detection of the presence of external cracks, wide-open apices, or apices undergoing resorption, which might alter the accuracy of the WL measurements. The teeth were devoid of caries, endodontic treatments, or restorations. Each crown was sectioned at mid-level by means of a crosscut carbide bur (Dentsply-Maillefer) in a high-speed handpiece with water spray to produce a flat surface for the precise location of the coronal reference point. Endodontic access to the pulp chamber was gained with a round diamond-coated bur (Dentsply-Maillefer). Pulp canal debris was removed from the coronal third of the canal with a #4 Gates Glidden bur (25). To verify canal patency, 3 different K-files (#06, #08, and #10) (Dentsply-Maillefer) were passed through the apex. Excess fluid was removed from the pulp chamber, but no attempt was made to dry the canal. The specimens were placed in an endodontic training kit, Pro-Train (Simit Dental, Mantova, Italy), with an eco-electroconductive gel (Farmacare S.r.l., San Pietro, Casale, Italy), as recently described by Cianconi et al (26).

EAL Measurements

To make multiple electronically determined WL readings in each canal by using the 3 EALs, we used 3 different K-files (#10, #15, and #20) with a silicone stop. We alternated the first EAL to be used in each successive canal, because 3 EALs were used with each canal. Initially, the WL was determined with K-file #10; after recording the WL with the first EAL, we withdrew the file, measured with a digital caliper (Mitutoyo 571-202-20; Mitutoyo Italiana S.r.l., Linate, Italy), and recorded it to the nearest 0.5 mm. In the same manner, we reinserted the same file to determine the WL by using the second and third EALs. The same procedure was repeated for each specimen with K-files #15 and #20. For each specimen, we obtained 9 electronic measure-

ments (3 for each K-file). To reduce variables, according to manufacturers’ instructions, only one calibrated operator carried out the electronic readings. For Endex, the file was advanced until the analog numeric bar read 0.0 within the red interval. For Root ZX, the file was advanced until the LCD display indicated the flashing word *APEX*. For ProPex II, the file was advanced until the LCD display indicated the flashing word *APEX* and 0.0, indicating the location of the foramen according to the manufacturer’s instructions.

Digital Radiography Measurements (Radiovideography Measurements)

We used the average of the 9 electronic measurements for each specimen to take digital radiographs. We used the K-file that showed the mean of measurements closest to the average. If the 3 files showed the same electronic measurement mean, the largest was used. Digital radiographic measurements were taken with a zero-degree inclination in both mesiodistal and buccolingual planes by using an experimental apparatus previously described by Cianconi et al (26). The distance from the end of the file and the radiographic apex was measured (Image Easy Managing; Anthos Impianti S.r.l., Imola, Italy) and recorded; we also measured the difference between the radiographic position of the K-file and the actual position of the file. A consensus in the measurements was always reached among 3 investigators after examining 40 specimens jointly for calibration purposes. Intraexaminer and interexaminer reliability for digital radiography assessment was verified by the kappa test.

Actual WL Measurements

After the electronic and radiovideography (RVG) analyses, we removed the specimen from the socket of the Pro-Train, ensuring that it had not been displaced during the experimental procedures. We measured the root length (actual WL) by using the same K-file used for the RVG measurement. With a microscope at 5× magnification (Carl Zeiss GmbH, Oberkochen, Germany), we inserted the K-file with a silicone stop into the canal until its 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. Blind evaluation was performed independently by 3 observers after examining 40 specimens jointly for calibration purposes. Intraexaminer and interexaminer reliability for actual WL assessment was verified by the kappa test. With the paired *t* test, we compared the average EAL measurements with the actual WL values for each tooth. We used the same statistical analysis to determine the accuracy of the radiographic method for anterior teeth, bicuspid, and molars.

TABLE 1. Statistical Analysis of Accuracy of EALs and Actual WL for Anteriors, Bicuspids, and Molars (mm)

	Mean	Standard deviation	Minimum	Maximum	t value	Pr > [t] (P value)
Endex (n = 120)						
Anteriors (n = 40)	0.27	0.37	-0.33*	1.00	7.51	>.001
Bicuspids (n = 40)	0.15	0.25	-0.50*	0.67	5.96	<.001
Molars (n = 40)	0.25	0.36	-0.33*	1.00	7.22	>.001
Root ZX (n = 120)						
Anteriors (n = 40)	0.52	0.46	0	1.67	12.09	>.001
Bicuspids (n = 40)	0.34	0.29	-0.17*	1.50	9.75	<.001
Molars (n = 40)	0.52	0.47	-0.17*	1.67	12.11	>.001
ProPex II (n = 120)						
Anteriors (n = 40)	0.32	0.4	-0.33*	1.00	8.45	>.001
Bicuspids (n = 40)	0.14	0.27	-0.17*	0.83	6.13	<.001
Molars (n = 40)	0.26	0.34	-0.67*	1.50	7.32	>.001

*Negative values indicate that K-file’s tip is inside the root canal.

TABLE 2. Statistical Analysis of Accuracy of RVG System Measurements and Actual Position of K-File for Each Dental Category (mm)

	Mean	Standard deviation	Minimum	Maximum	t value	Pr > [t] (P value)
Buccolingual plane						
Anteriors (n = 40)	16.25	2.24	12.4	21.67	66.49	>.001
Bicuspid (n = 40)	16.41	2.25	12.8	22.07	65.58	>.001
Molars (n = 40)	16.36	2.29	12.5	21.63	64.93	>.001
Mesiodistal plane						
Anteriors (n = 40)	16.28	2.20	12.64	22.81	68.45	>.001
Bicuspid (n = 40)	16.35	2.20	12.65	22.07	67.88	>.001
Molars (n = 40)	16.22	2.26	12.58	21.53	67.53	>.001

Results

Kappa test results, with a significance set at 0.5, showed good intraexaminer and interexaminer agreement, with values of 0.90 and above for the different groups. EAL accuracy values in anterior teeth, bicuspid, and molars are shown in Table 1. EALs were more accurate in bicuspid than in both molars and anterior teeth. The apical foramen (± 0.5 mm) was determined for Endex, Root ZX, and ProPex II: (1) in anterior teeth, 80.8%, 61.5%, and 76.9%, respectively; (2) in bicuspid, 93.1%, 69%, and 89.7%, respectively; and (3) in molars, 80.4%, 58.7%, and 82.6%, respectively. All EALs showed a significant tendency toward overestimation. No measures were underestimated. The mean overestimation was 0.37, 0.29, and 0.35 mm for anterior teeth, bicuspid, and molars, respectively. The radiographic position of the file's tip was consistent with the actual position in the buccolingual and mesiodistal planes: (1) in anterior teeth, 38.5% and 46.2%, respectively; (2) in bicuspid, 41.4% and 55.2%, respectively; and (3) in molars, 50% and 52.2%, respectively. Radiographic measurements showed a high tendency toward underestimation. The mean distances between the file tip and the actual position are shown in Table 2.

Statistical Analysis

We used a paired-sample *t* test to compare the results and determined a significant difference at a 99.9% confidence level. The analysis was performed with the SAS System (SAS Institute SRL, Milan, Italy). Statistical analysis showed a significant difference between Root ZX (*P* < .001) and both ProPex II and Endex measurements. There was no statistically significant difference between ProPex II and Endex. The *t* test showed no statistically significant difference between the accuracy of the 2 radiographic planes examined.

Discussion

Numerous authors have studied the accuracy of EALs for determining WL (13, 21–23, 27). EALs can accurately determine the WL in 75.0%–96.5% of the root canals with mature apices (28–30). The validity of measurements made with an *in vitro* experimental protocol (ie, the extent to which they depict the clinical accuracy of EALs) is unknown (31). However, they are able to reproduce the clinical condition of EAL use and facilitate an objective examination of several variables that is not practical in *in vivo* studies (31, 32). EALs are highly accurate in determining the location of minor constriction, but the mean distance from the file tip to the minor constriction always has a positive value (13, 28, 29). Thus, EALs normally overestimate WL. In the present study the mean distance beyond the minor diameter was 0.3 mm, with a range of –0.5 to 1 mm. Different *ex vivo* experimental protocols have been used to examine the accuracy of EALs. In several studies the apical portion of the root was not shaved, and the actual canal length was measured with a caliper and compared with the electronic reading (30, 32–42). The position

of apical constriction and its relationship with the CDJ are highly irregular (28, 29, 36, 43). Thus, for the identification of apical constriction, it is necessary to shave the apical portion of the root. In the present study the choice of the APEX mark on the EAL display (and, consequently, the choice of the apical foramen as a landmark) rendered the shaving of the apical portion unnecessary. A review of the current literature showed a dearth of reports regarding the relation among EALs, digital radiography accuracy, and dental groups. In this study we found that EAL accuracy was greater in bicuspid than in both molars and anterior teeth. This finding is probably due to the anatomical characteristic of the major foramen; the apical foramen in molars and anteriors is probably wider than that in bicuspid or is probably in a lateral position. Regarding the position of apex, Ding et al (44) found that EALs are more accurate in roots with lateral major foramen. More experiments are required to support this hypothesis, focusing primarily on the different anatomical characteristics in multi-rooted teeth. The Root ZX showed less accuracy in comparison with both Endex and ProPex II in all the dental groups. The mean accuracy of Endex, ProPex II, and Root ZX in locating the apical foramen within 0.5 mm was 86.1%, 83.2%, and 65.3%, respectively, with mean distances of 0.31, 0.45, and 0.57 mm, respectively, past the minor diameter. In all specimens, EALs showed a high tendency toward overestimation: 0.37, 0.29, and 0.35 mm for anteriors, bicuspid, and molars, respectively. This is in agreement with results of previous studies (30, 38). The overestimation shown in this study could be due to our decision to use the APEX landmark on the EAL displays. These findings raise the questions of whether the WL should be established at the point where the EAL indicates the apical foramen or at some distance coronal to that point (41–43, 45), and whether it is necessary to establish a different landmark for each dental group. Regarding digital radiographic measurements, we found that the position of the K-file is generally more coronal than the actual position. This is in contrast with results shown by Ravanshad et al (46) but in agreement with results of previous studies (12, 13) and might depend on the frequent non-axial position of the apical foramen, as recently shown by Martos et al (47).

Conclusions

On the basis of the results of the present study, EAL accuracy depends on the dental groups, and it is greater in bicuspid than in both molars and anterior teeth. To prevent overestimation of the root canal length by the 3 different EALs tested, 1 mm should be subtracted from the measurement on the APEX mark. The radiographic method is not reliable for determining the WL in both radiographic planes in any dental group.

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

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