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

Manuele Mancini, DDS, Roberto Felici, DDS,* Gabriele Conte, DDS,* Marco Costantini, MSc, MBA,† and Luigi Cianconi, MD, DDS**

Abstract

Introduction: The aim of this study was to determine in anterior teeth, bicuspids, 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 bicuspids. 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 bicuspids 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, Pro-Pex II, Pro-Train, Root ZX, working length

From the *Department of Restorative Dentistry and Endodontics, University of Rome "Tor Vergata," Rome; and †Private Statistician, Rome, Italy.

Address requests for reprints to Dr Manuele Mancini, Via Tuscolana 58/64, 00182 Rome, Italy. E-mail address: manuele.mancini@tiscali.it

0099-2399/$ - see front matter

doi:10.1016/j.joen.2011.02.011

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 kΩ; 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% ± 1 mm, depending on the K-file used.

The purpose of this study was to compare in anterior teeth, bicuspids, 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 bicuspids, 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 measurements (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, bicuspids, 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
Bicuspids (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
Bicuspids (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, bicuspids, and molars are shown in Table 1. EALs were more accurate in bicuspids 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 bicuspids, 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, bicuspids, 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 bicuspids, 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 bicuspids 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 bicuspids 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, bicuspids, 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 bicuspids 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.

Acknowledgments

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

References

1. Glossary of endodontic terms. 7th ed. Chicago, IL: American Association of Endodontists; 2003.
2. Kuttler Y. Microscopic investigation of root apexes. J Am Dent Assoc 1955;50:544–52.
3. Grove CJ. A new simple standardized technique producing perfect fitting impermeable root canal fillings extended to the dento-cemento junction. Dent Items Interest 1928;50:855–7.
4. Stein TJ, Corcoran JF, Zillich RM. The influence of the major and minor foramen diameters on apical electronic probe measurements. J Endod 1990;16:520–2.
5. Green D. A stereomicroscopic study of 700 root apices of maxillary and mandibular posterior teeth. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 1960;13:728–33.
6. Dummer PM, Mcginn JH, Rees DG. The position and topography of the apical canal constriction and apical foramen. Int Endod J 1984;17:192–8.
7. Stein TJ, Corcoran JF, Zillich RM. Influence of the major and minor foramen diameters on apical electronic probe measurements. J Endod 1990;16:520–2.
8. Martos J, Ferre Loque CM, Gonzales Rodriguez MP, Castro LAS. Topografical evaluation of the major apical foramen in permanent human teeth. Int Endod J 2009;42:329–34.
9. Pratten DH, McDonald NJ. Comparison of radiographic and electronic working lengths. J Endod 1996;22:173–6.
10. Goldman M, Pearson AH, Darzenta N. Endodontic success: who's reading the radiograph? Oral Surg Oral Med Oral Pathol Oral Radiol Endod 1972;33:432–7.
11. Green DA. stereo-binocular microscopic study of the root apices and surrounding areas of 100 mandibular molars. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 1955;8:1298.
12. Chunn CB, Zardiackas LD, Menke RA. In vivo root canal length determination using the forameter. J Endod 1981;7:515–20.
13. Welk AR, Baumgartner JC, Marshall JG. An in vivo comparison of two frequency-based electronic apex locators. J Endod 2003;29:497–500.
14. Custer LE. Exact methods of locating the apical foramen. J Natl Dent Assoc 1918;5:815–9.
15. Suzuki K. Experimental study on iontophoresis. J Jap Stomatol 1942;16:411.
16. Sunada I. New method for measuring the length of the root canal. J Dent Res 1962;41:375–87.
17. Ushiyama J. New principle and method for measuring the root canal length. J Endod 1983;9:97–104.
18. Weiger R, John C, Geigle H, Lost C. An in vitro comparison of two modern apex locators. J Endod 1999;25:765–8.
19. De Moor RJ, Hommez GM, Martens LC, De Boever JG. Accuracy of four electronic apex locators: an in vitro evaluation. Endodontics and Dental Traumatology 1999;15:77–82.
20. Martinez Lozano MA, Forner Navarro L, Sanchez Cortés JL, Llena Puy C. Methodological considerations in the determination of working length. Int Endod J 2001;34:371–6.
21. Shabahang S, Goon WWY, Gluskin AH. An in vivo evaluation of Root ZX electronic apex locator. J Endod 1996;22:616–8.
22. Dunlap CA, Remeikis NA, BeGole EA, Raushenberger CR. An in vivo evaluation of an electronic apex locator that uses the ratio method in vital and necrotic canals. J Endod 1998;24:48–50.
23. Pagavino G, Pace R, Baccetti T. An SEM study of in vivo accuracy of the Root ZX electronic apex locator. J Endod 1998;24:438–41.
24. Briseño-Marroquin B, Frajlich S, Goldberg F, Willershausen B. Influence of instrument size on the accuracy of different apex locators: an in vitro study. J Endod 2008;34:698–702.
25. Ibarrola JL, Chapman BL, Howard JH, Knowles KI, Ludlow MO. Effect of preflaring on Root ZX apex locators. J Endod 1999;25:625–6.
26. Cianconi L, Angotti V, Felici R, Conte G, Mancini M. Accuracy of three electronic apex locators compared with digital radiography: an ex vivo Study. J Endod 2010;36:2003–7.
27. Goldberg F, De Silvio AC, Manfre S, Nastri N. In vitro measurement accuracy of an electronic apex locator in teeth with simulated apical root resorption. J Endod 2002;28:461–3.
28. Gordon MP, Chandler NP. Electronic apex locators. Int Endod J 2004;37:425–37.
29. Nekoofar MH, Ghandi MM, Hayes SJ, Dummer PMH. The fundamental operating principles of electronic root canal length measurement devices. Int Endod J 2006;39:595–609.
30. El Ayouti A, Weiger R, Lost C. The ability of root ZX apex locator to reduce the frequency of overestimated radiographic working length. J Endod 2002;28:116–9.
31. Ebrahim AK, Wadachi R, Suda H. Ex vivo evaluation of the ability of four different electronic apex locators to determine the working length in teeth with various foramen diameters. Aust Dent J 2006;51:258–62.
32. Ebrahim AK, Wadachi R, Suda H. In vitro evaluation of the accuracy of five different electronic apex locators for determining the working length of endodontically retreated teeth. Aust Endod J 2007;33:7–12.
33. Meares WA, Steiman HR. The influence of sodium hypochlorite irrigation on the accuracy of the Root ZX electronic apex locator. J Endod 2002;28:595–8.
34. Baldi JV, Victorino FR, Bernardes RA, et al. Influence of embedding media on the assessment of electronic apex locators. J Endod 2007;33:476–9.
35. Goldberg F, Marroquin BB, Frajlich S, Dreyer C. In vitro evaluation of the ability of three apex locators to determine the working length during retreatment. J Endod 2005;31:676–8.
36. Herrera M, Abalos C, Planas AJ, Llamas R. Influence of apical constriction diameter on Root ZX apex locator precision. J Endod 2007;33:995–8.
37. Plotino G, Grande NM, Brigante L, Lesti B, Somma F. Ex vivo accuracy of three electronic apex locators: Root ZX, Elements Diagnostic Unit and Apex Locator and ProPex. Int Endod J 2006;39:408–14.
38. Lucena-Martin C, Robles-Gijon V, Ferrer-Luque CM, de Mondelo JM. In vitro evaluation of the accuracy of three electronic apex locators. J Endod 2004;30:231–3.
39. D'Assunção FL, de Albuquerque DS, de Queiroz Ferreira LC. The ability of two apex locators to locate the apical foramen: an in vitro study. J Endod 2006;32:560–2.
40. Jenkins JA, Walker WA 3rd, Schindler WG, Flores CM. An in vitro evaluation of the accuracy of the root ZX in the presence of various irrigants. J Endod 2001;27:209–11.
41. Ounsi HF, Naaman A. In vitro evaluation of the reliability of the Root ZX electronic apex locator. Int Endod J 1999;32:120–3.
42. Bernardes RA, Duarte MA, Vasconcelos BC, et al. Evaluation of precision of length determination with 3 electronic apex locators: Root ZX, Elements Diagnostic Unit and Apex Locator, and RomiAPEX D-30. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2007;104:e91–4.
43. Ricucci D. Apical limit of root canal instrumentation and obturation, part 1: literature review. Int Endod J 1998;31:384–93.
44. Ding J, Gutmann JL, Fan B, Lu Y, Chen H. Investigation of apex locators and related morphological factors. J Endod 2010;36:1399–403.
45. Tselnik M, Baumgartner JC, Marshall JG. An evaluation of Root ZX and Elements Diagnostic apex locators. J Endod 2005;31:507–9.
46. Ravanshad S, Adl A, Anvar J. Effect of working length measurement by electronic apex locator or radiography on the adequacy of final working length: a randomized clinical trial. J Endod 2010;36:1753–6.
47. Martos J, Lubian C, Silveira LFM, Suita de Castro LA, Ferrer Luque CM. Morphologic analysis of the root apex in human teeth. J Endod 2010;36:664–7.