Received: 15 May 2022 | Accepted: 3 September 2022

DOI: 10.1111/aej.12688

Australian Endodontic Journal

ORIGINAL RESEARCH

An in vitro evaluation of the WIRELE-x electronic apex locator

Lucas Brand DDS[1] | **Craig A. Dunlap DDS**[1] | **Raymond Scott DDS MSD**[1] | **Anna Arias DDS MS PhD**[2] | **Ove Peters DMD MS PhD**[1,3]

[1]Department of Endodontics, University of the Pacific, Arthur A. Dugoni School of Dentistry, San Francisco, California, USA

[2]Department of Conservative and Prosthetic Dentistry, School of Dentistry, Complutense University, Madrid, Spain

[3]Oral Health Centre, University of Queensland, Herston, Queensland, Australia

Correspondence
Craig A. Dunlap, Department of Endodontics, University of the Pacific, Arthur A. Dugoni School of Dentistry, 155 5th Street, San Francisco, CA 94013, USA.
Email: cdunlap@pacific.edu

Funding information
American Association of Endodontists Foundation

Abstract

This study evaluated the accuracy of the Wirele-X (Forum Tec, Ashkelon, Israel), a novel Bluetooth-enabled wireless electronic apex locator. Thirty-one extracted teeth with mature apices were used. Under 10X magnification, the actual canal lengths were determined. The teeth were embedded in alginate and electronic canal lengths were obtained using the Root ZX II and Wirele-X electronic apex locators. The actual canal lengths and electronic canal lengths were compared with Student's t-test. The average distance from the file tip to the actual canal length was −0.11 mm (±0.16) for the Root ZX II, and −0.07 mm (±0.21) for the Wirele-X. There were no statistically significant differences between the two electronic apex locators in their ability to determine the actual canal length ($p > 0.05$). The wireless apex locator (Wirele-X) and the wired apex locator (Root ZX II) were found to be equally accurate.

KEYWORDS

electronic apex locator, root canal length, root ZX II, Wirele-X, working length

INTRODUCTION

Determining the correct apical limit of the root canal system is critical during root canal treatment. The apical foramen (AF) is defined as the main apical opening of the root canal. Working length (WL) is defined as the distance from a coronal reference point to the point at which canal preparation should terminate [1]. An accurate WL allows for thorough mechanical and chemical disinfection of the root canal system [2]. The correct WL protects the periodontal tissues from instrumentation beyond the AF and helps prevent the extrusion of debris which may cause inflammation [3]. A systematic review found that success rates are lower when root canal obturation extends beyond the radiographic apex as well as when the root canal obturation terminates short of the radiographic apex by more than 2 mm [4].

Historically, a periapical (PA) radiograph has been the primary method for determining the WL [5]. PA radiographs have several disadvantages. For example, they do not accurately show the location of the AF [6]. Obtaining PA radiographs is technique sensitive and require precise sensor placement and cone beam angulation. PA radiographs are also subject to subjective interpretation [7]. Other methods of WL determination include tactile feel and the paper point technique [8]. The paper point

All authors have contributed significantly, and all authors are in agreement with the manuscript.

technique has been shown to have some validity [9]; however, tactile feel has been shown to be unreliable [10]. A recent systematic review found that cone beam computed tomography (CBCT) scans may be helpful in WL determination. This is due to minimal image distortion on CBCTs resulting in more reliable linear measurements compared with other dentomaxillofacial radiographic images [11].

In 1942, Suzuki demonstrated that the electrical resistance was constant between the periodontal ligament and the oral mucosa at 6.5 kiloohms [12]. This information was applied by Sunada in 1962 to construct the first electronic apex locator (EAL) [13]; however, this primitive apex locator was inaccurate in the presence of vital tissue or moisture [14]. To overcome this problem, Kobayashi developed the Root ZX apex locator (J. Morita, Tokyo, Japan) which uses alternating current (AC) and calculates the ratio of impedances at two frequencies, 0.4 kHz and 8 kHz. This modification allowed for accurate measurements in the presence of moisture and pulp tissue [15]. The Root ZX has been studied extensively and found to be accurate 82%–100% of the time [16, 17].

Recently, the Wirele-X EAL (Forum Tec, Ashkelton, Israel) has been developed which uses a wireless Bluetooth connection between the file holder and lip clip to the EAL. This eliminates the cord connecting the patient to the EAL. The Wirele-X uses two frequencies of AC at 0.5 kHz and 8 kHz and a patented Root Mean Square (RMS) signal measuring system to calculate the canal measurement. The company claims that using RMS instead of amplitude or phase eliminates signal noise and increases accuracy. Because the Wirele-X is a new device, there is a need to evaluate its accuracy.

In a previous study, it was shown that there were no significant differences between EAL measurements in vivo when compared to EAL measurements in vitro on extracted teeth mounted in alginate [18].

The present study compared EAL measurements of the Root ZX II and the Wirele-X in vitro to the actual canal length (ACL) using the alginate model described by Lipski et al [18]. The null hypothesis is that there is no significant difference in the accuracy of the Root ZX II and Wirele-X EALs in determining ACL in vitro.

MATERIALS AND METHODS

This research was approved by the University Institutional Review Board (#20–87). Thirty-one extracted single rooted human teeth with mature apices were included in this study. For each tooth, the remaining periodontal tissue was removed by soaking the roots in 2.5% NaOCl. The crowns were removed at the cementoenamel junction with a diamond disc to create a flat reproducible reference point. Teeth were stored in 0.5% thymol throughout the study.

The actual canal length of each root was determined by placing a #10 K-file (Dentsply Maillefer, Ballaigues, Switzerland) under 10X magnification (Carl Zeiss, Jena, Germany) until the file tip was just visible at the AF. The file stopper was moved to the flat reference point and fixed in place with cyanoacrylate. The length of the file was measured three times to the nearest 0.01 mm using a digital calliper (General Ultratech, Secaucus, New Jersey, USA) to ensure reproducibility of measurement. The three measurements were then averaged and recorded as the ACL for each root.

EAL lengths were obtained by embedding each root in alginate and placing the lip hook in the alginate surrounding the root as described by Lipski et al [18]. An aliquot of 8.25% sodium hypochlorite was placed in the root canal, and electronic lengths were obtained by advancing a #10 K-file until the EAL indicated that the file tip was beyond the AF (in the red). The file was then retracted until the device indicated that the file was at the apical foramen as described in the directions for use (DFU) of each EAL (the last green indicator bar of the Root ZX II and the "APEX, 0" first red indicator bar of the Wirele-X). The stopper was moved to the reference point and then rechecked with the EAL to ensure that the stopper had not moved, and the file was still at the apical foramen. The stoppers were then fixed in place with cyanoacrylate, and the files were placed in randomly numbered containers. The process was repeated three times, which yielded three files for each EAL, per tooth. All measured lengths were performed within 30 minutes of alginate preparation.

An independent examiner, who was blinded as to which EAL was used, measured each file length from the tip to the stopper. Measurements were made to the nearest 0.01 mm using a digital calliper (General Ultratech). The average of the three electronic lengths for each experimental root were calculated. In each case, the actual canal length was subtracted from the electronic length. Differences greater than the ACL were given positive values, while differences less than the ACL were given negative values. Data were found to be compatible with a normal distribution. Reliability among the three measurements for each EAL was calculated with the intraclass correlation coefficient for both consistency and absolute agreement. The Pearson correlation coefficient was calculated to assess the strength of the linear relationship between the readings from both EALs and the ACL. Differences between ACL and average measurements from EALs were compared with Student's t-test for related samples. Moreover, the percentage of measurements longer and shorter than the ACL was compared between EALs with chi-square test. Statistical Package IBM SPSS Statistics for Macintosh,

Version 25.0. (IBM Corp. Armonk, NY, USA) was used for the statistical analysis, and statistical significance was set at $p < 0.05$.

RESULTS

Average, standard deviations and minimal and maximal distances between the ACL and electronic lengths from each EAL are shown in Table 1.

Intra-rater reliability for both EALs was high for both consistency (ICC = 0.997; 95% confidence interval (CI) 0.994–0.999 for Root ZX II/ ICC = 0.995; 95% confidence interval (CI) 0.99–0.998 for Wirele-X) and absolute agreement (ICC = 0.996; 95% confidence interval (CI) 0.984–0.998 for Root ZX II/ ICC = 0.995; 95% confidence interval (CI) 0.989–0.998 for Wirele-X). There was a significant correlation between the measurements from both EALs and the ACL ($p < 0.01$) with a Pearson correlation coefficient 0.996 for the three measurements with Root ZX II and 0.993/0.995/0.992, respectively, for the three measurements with Wirele-X.

The average distance between ACL and EAL measurements was −0.11 mm (±0.16) and −0.07 mm (±0.21) for the Root ZX II and Wirele-X systems, respectively. There was no statistical difference between the two EAL measurements ($p > 0.05$). The file tip was located within ±0.5 mm from the ACL in 100% of the Root ZX II measurements and in 96.8% of the Wirele-X measurements (Table 2).

EAL measurements greater than the ACL were found for both apex locators, 22.6% for the Root ZX II and 29.0% for the Wirele-X (Figure 1; Table 2). These differences were not statistically significant ($p = 0.56$).

DISCUSSION

The present in vitro study evaluated the accuracy of the Root ZX II and the Wirele-X in determining the ACL. An alginate model was chosen because previous studies have shown that in vitro EAL measurements in alginate are comparable to in vivo EAL measurements and more accurate than other in vitro embedding media such as electroconductive gel [19]. Measurements were obtained within 30 minutes to minimise changes in electroconductivity of the alginate due to desiccation. Decoronation with a diamond disc resulted in a flat, reproducible reference point that allowed accurate stopper placement. In this study, #10 K-files were used for experimental measurements because small hand files are often used for initial canal length and WL determinations, and it has been shown that the size of hand files does not affect EAL measurements [20, 21]. Patency was confirmed prior to EAL length determination since canal blockage has been shown to negatively influence in vitro EAL accuracy [22].

The silicone stoppers on each experimental hand file were fixed in place with cyanoacrylate during ACL and EAL measurements. This was done to prevent the stopper from moving while measuring with a precision calliper. Some minor stopper movement may have occurred, but this may also occur during clinical use. The measurements in this study were to the nearest 0.01 mm which is not feasible clinically.

The use of both EALs resulted in measurements short of the apex most often, but 22.6% and 29% of the time measurements were long with the Root ZX II and the Wirele-X, respectively. Clinically long measurements can result in damage to the apical constriction and apical tissues. The largest measurement beyond the ACL was 0.26 mm. The subtraction of 0.5 mm from the EAL-determined measurement at the root apex, as suggested in the Root ZX II's directions for use (DFU), to determine WL would result in WL values coronal to the ACL for all specimens in this study. One measurement from the Wirele-X was short of

TABLE 2 Difference between actual canal length (ACL) and electronic length of root ZX II and Wirele-X (mm)[a]

Distance from ACL (mm)[a]	Root ZX II		Wirele-X	
	n = 31	%	*n* = 31	%
−1.0 to −0.51	-	-	1	3.2
−0.5 to 0.0	24	77.4	21	67.8
+0.01 to 0.5	7	22.6	9	29.0
+0.51 to 1.0	-	-	-	-

[a]Negative value indicates measurement short of the ACL. Positive value indicates measurement exceeding the ACL.

TABLE 1 Descriptive statistics regarding difference between actual canal length (ACL) and electronic length of root ZX II and Wirele-X (mm)[a]

Electronic apex locator measurements	Minimum	Maximum	Average	Standard deviation
Root ZX II	−0.42	0.19	−0.11	0.16
Wirele-X	−0.82	0.26	−0.07	0.21

[a]Negative value indicates measurement short of the ACL. Positive value indicates measurement exceeding the ACL.

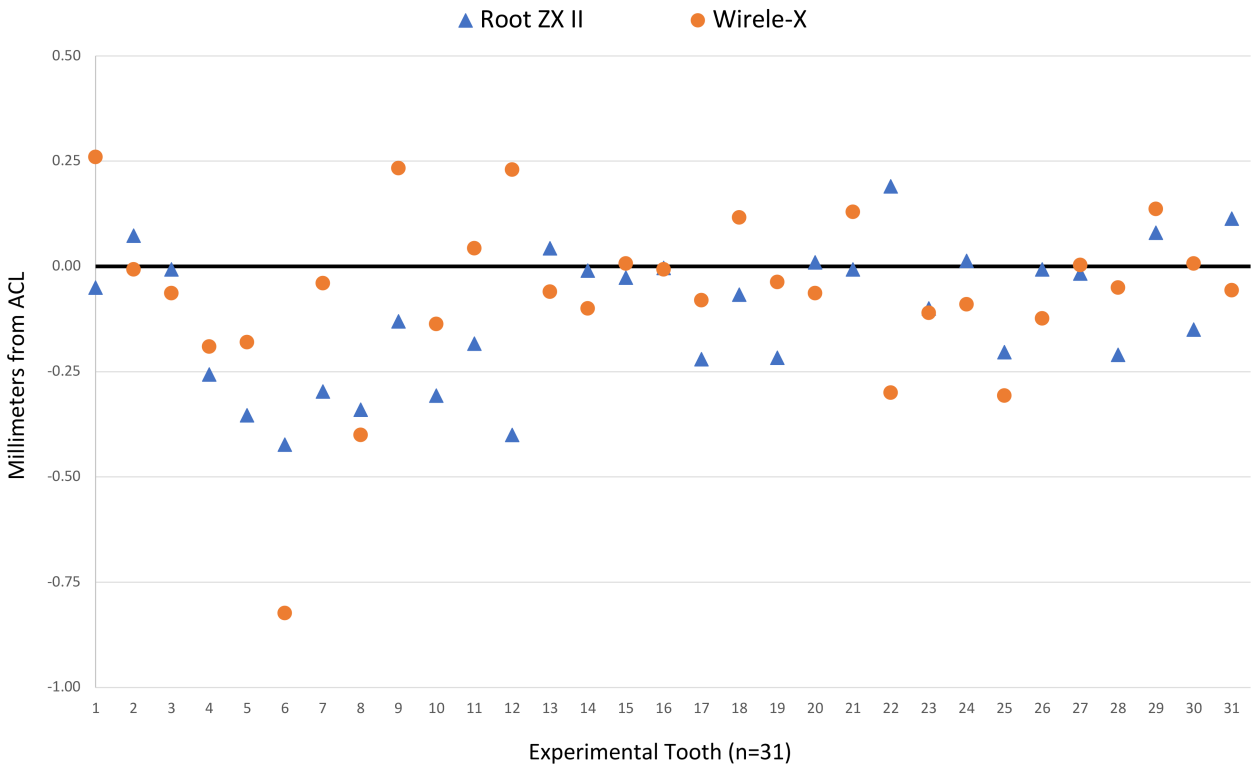

FIGURE 1 Comparison of measurements from the root ZX II and the Wirele-X apex locators

the ACL by more than 0.5 mm. These results support the use of PA radiographs in conjunction with EALs to determine WL [23, 24, 25].

The Wirele-X Bluetooth connection eliminates cords traversing the operative field, which the manufacturer claims is both safer and more convenient. Some patients may be concerned with radio frequency radiation emitted from the Wirele-X EAL [26, 27]. For those patients, the Wirele-X can be used with a cord like most EALs. The Wirele-X DFU recommends that the Wirele-X not be used on patients who have a pacemaker or other implantable electrical device [28]. Until the Wirele-X is proven to be safe for use with pacemakers or other implantable devices, this recommendation should be followed. Many dental devices and equipment, with the exception of electrosurgery, produce only minimal electromagnetic interference (EMI); but care should be exercised to keep potential sources of EMI as far away as possible from cardiovascular implantable electronic devices such as pacemakers and implantable cardioverter-defibrillators [29, 30]. Cellular wireless communications equipment such as wireless network devices and mobile phones can affect the Wirele-X and should be kept at least 30 cm from any part of the device [28].

In this study, the accuracy the Root ZX II and the Wirele-X EALs were compared with ACL using an alginate model in vitro. Both devices provided a high level of accuracy and reliability. There were no statistically significant differences between the two devices, so the null hypothesis is accepted. Additional in vitro and in vivo testing of the Wirele-X EAL is recommended to further evaluate its performance.

AUTHOR CONTRIBUTIONS

L.B. and C.D. designed and performed the research. A.A. analysed the data. O.P. approved the final manuscript. All authors have approved the final manuscript.

ACKNOWLEDGEMENT

Special thanks to Forum Tec for providing the Wirele-X electronic apex locator for this research project and to Drs. Mia Tittle and Suzanne Carpenter for their assistance in the experimental procedures.

FUNDING INFORMATION

Partial funding was supplied by a grant from the American Association of Endodontists Foundation.

CONFLICT OF INTEREST

Dr. Peters serves as a consultant for Dentsply Sirona. The remaining authors deny any conflicts of interest related to this study.

ORCID

Craig A. Dunlap https://orcid.org/0000-0002-4322-3437

Anna Arias https://orcid.org/0000-0003-2270-8096
Ove Peters https://orcid.org/0000-0001-5222-8718

REFERENCES

1. McClanahan S, Crepps JT, Maranga MC, Worrell DE, Behnia A. Glossary of endodontic terms, tenth edition. Chicago, IL: American Association of Endodontists; 2020.
2. Sjogren U, Hagglund B, Sundqvist G, Wing K. Factors affecting the long-term results of endodontic treatment. J Endod. 1990;16:498–504.
3. Ricucci D, Langeland K. Apical limit of root canal instrumentation and obturation, part 2. A histological study. Int Endod J. 1998;31:394–409.
4. Ng YL, Mann V, Rahbaran S, Lewsey J, Gulabivala K. Outcome of primary root canal treatment: systematic review of the literature -- part 2. Influence of clinical factors. Int Endod J. 2008;41:6–31.
5. McDonald NJ. The electronic determination of working length. Dent Clin N Am. 1992;36:293–307.
6. Kuttler Y. Microscopic investigation of root apexes. J Am Dent Assoc. 1955;50:544–52.
7. Goldman M, Pearson AH, Darzenta N. Endodontic success--who's reading the radiograph? Oral Surg Oral Med Oral Pathol. 1972;33:432–7.
8. Rosenberg DB. The paper point technique, Part 2. Dent Today. 2003;22:62–4. 66-7.
9. Marcos-Arenal JL, Rivera EM, Caplan DJ, Trope M. Evaluating the paper point technique for locating the apical foramen after canal preparation. Oral Surg Oral Med Oral Pathol Oral Radiol Endod. 2009;108:e101–5.
10. Seidberg BH, Alibrandi BV, Fine H, Logue B. Clinical investigation of measuring working lengths of root canals with an electronic device and with digital-tactile sense. J Am Dent Assoc. 1975;90:379–87.
11. Amin J, Lines J, Milosevic MP, Park A, Sholapurkar A. Comparison of accuracy and reliability of working length determination using cone beam computed tomography and electronic apex locator: a systematic review. J Contemp Dent Pract. 2019;20:1118–23.
12. Suzuki K. Experimental study on iontophoresis. J Jap Stoma. 1942;16:411–7.
13. Sunada I. New method for measuring the length of the root canal. J Dent Res. 1962;41:375–87.
14. McDonald NJ, Hovland EJ. An evaluation of the apex locator Endocater. J Endod. 1990;16:5–8.
15. Kobayashi C, Suda H. New electronic canal measuring device based on the ratio method. J Endod. 1994;20:111–4.
16. Dunlap CA, Remeikis NA, BeGole EA, Rauschenberger 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.
17. Gordon MP, Chandler NP. Electronic apex locators. Int Endod J. 2004;37:425–37.
18. Lipski M, Trabska-Swistelnicka M, Wozniak K, Dembowska E, Drozdzik A. Evaluation of alginate as a substitute for root-surrounding tissues in electronic root canal measurements. Aust Endod J. 2013;39:155–8.
19. Iparraguirre Nunovero MF, Piasecki L, Segato AVK, Westphalen VPD, Silva Neto UX, Carneiro. A laboratory study of the accuracy of three electronic apex locators: influence of embedding media and radiographic assessment of the electronic apical limit. Int Endod J. 2021;54:1200–6.
20. Nguyen HQ, Kaufman AY, Komorowski RC, Friedman S. Electronic length measurement using small and large files in enlarged canals. Int Endod J. 1996;29:359–64.
21. Orosco FA, da Silva GF, Weckwerth PH, Lopes MTM, Garcia AMR, Duarte MAH, et al. Influence of different sized files on the accuracy of two electronic apex locators. Aust Endod J. 2018;44:251–4.
22. Abdelsalam N, Hashem N. Impact of apical patency on accuracy of electronic apex locators: in vitro study. J Endod. 2020;46:509–14.
23. Gutmann JL, Leonard JE. Problem solving in endodontic working-length determination. Compend Contin Educ Dent. 1995;16:288, 290, 293-284 passim; quiz 304.
24. Fouad AF, Reid LC. Effect of using electronic apex locators on selected endodontic treatment parameters. J Endod. 2020;26:364–7.
25. Martins JN, Marques D, Mata A, Carames J. Clinical efficacy of electronic apex locators: systematic review. J Endod. 2014;40:759–77.
26. Myung SK, Ju W, McDonnell DD, et al. Mobile phone use and risk of tumors: a meta-analysis. J Clin Oncol. 2009;27:5565–72.
27. Choi YJ, Moskowitz JM, Myung SK, Lee YR, Hong YC. Cellular phone use and risk of tumors: systematic review and meta-analysis. Int J Environ Res Public Health. 2020;17:8079.
28. ForumTec W-X. Smart wireless apex locator: User manual. Ashkelon, Israel: Forum Engineering Technologies Ltd; 2020.
29. Idzahi K, de Cock CC, Shemesh H, Brand HS. Interference of electronic apex locators with implantable cardioverter defibrillators. J Endod. 2014;40:277–80.
30. Tom J. Management of Patients with Cardiovascular Implantable Electronic Devices in dental, Oral, and maxillofacial surgery. Anesth Prog. 2016;63:95–104.

How to cite this article: Brand L, Dunlap CA, Scott R, Arias A, Peters O. An in vitro evaluation of the WIRELE-x electronic apex locator. Aust Endod J. 2022;00:1–5. https://doi.org/10.1111/aej.12688