Original Article

An Effective Artificial Testing Model to Reliability Experiments for Electronic Apex Locator Devices Used in Endodontic Practice

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Abstract

Background and Aim: This experimental study aimed to investigate the reliability of using electronic apex locator devices to determine the working length of artificial root canals. **Materials and Methods:** The experiments were performed using resin endoblocks and mandibular canine teeth (n = 20/group). After the same working length of root canal samples was provided, the teeth and artificial root canals were embedded in an alginate mold. The measurements with Root ZX® and Propex Pixi® apex locators were performed and recorded. The data were analyzed using SPSS software (SPSS V23; IBM Corp., Armonk, New York, USA) and the variance was set at $P < 0.05$. **Results:** There was no significant difference between the groups; mean distance from the actual working length using different apex locators (P = 0.633, P = 0.474), and endpoint positioning distributions (P = 0.591). **Conclusion:** The results indicate that the artificial model could be a laboratory method of determining the accuracy of apex locators and efficient calibration of devices before their clinical use.

Keywords: *Artificial test method, artificial tooth, electronic apex locator, working length determination*

Introduction

Successful prognosis of root canal treatment depends on various steps. These stages include: shaping, disinfection, and three-dimensional obturation of the correct working length of the root canal space.[1,2] The root canal treatment working length (WL) of a root canal has been described as the distance from the coronal reference point to the apical constriction of the root canal.[2,3] The minor anatomical diameter of the apical foramen, defined as apical constriction (AC) or cementum–dentine junction, is the narrowest part of the root canal with the smallest diameter of blood supply. This feature confines it to the smallest wound area, and thus provides the best healing condition.[2,3] Therefore, AC, the minor transition point from the root canal to the periodontal tissues, should be the endpoint of the WL.[2,4] Several techniques have been used to determine the WL; however, electronic location of the root canal endpoint is the most accepted and reliable technique considering the disadvantages of radiographic determination.[5,6]

With the technological developments, the manufacturers have put many electronic apex locator devices (EALs) on the market; however, Root ZX® (J. Morita, Tokyo, Japan) and Root ZX® Mini apex locators with the same working principle are considered the gold standard devices. Their reliabilities have been proven in many studies.[6-9] Furthermore, Propex Pixi® (Dentsply Maillefer, Ballaigues, Switzerland) is also a reliable device with similar success rates to Root ZX.[6,10]

The EALs can determine the zero point of the apex, which corresponds to the major transition to the periapical tissues; however, this level does not indicate the AC. Establishing the exact location of the AC is a clinical challenge.[9] It was reported that the position is usually 0.5–1.0 mm short of the zero point determined by EALs; however, the actual distance between the

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AC and the major apical foramen varied from 0.3 to 3.80 mm.[11-13] Studies have shown differences in the accuracy of EALs because of the variation of complex apical anatomy of the tooth; besides, the clinical and ex vivo studies have limitations to standardization.[9,10,13-15] Therefore, there is a need for suitable and effective calibration techniques for these tools.

The resin endoblocks, which correspond to the simulation of the root canal, have the unique characteristics to standardize the research method and exclude parameters that could influence the anatomical and clinical variations by providing similar root canal length, shape, and diameter.[16,17] Previous reports of endodontic researches presented that artificial root canals could be used in different endodontic approaches for a standardized test model.[16-20] However, to the best of our knowledge, no study has been evaluated or compared the artificial canals for reliability experiments for electronically locating the root canal endpoint. In this context, this study aimed to investigate the usability of simulated artificial root canals as an effective technique in a comparative manner for the reliability of the EALs experiments before clinical use.

Materials and Methods

The evaluation was accomplished in full accordance with ethical principles, according to the World Medical Association Declaration of Helsinki and standing orders of the ethics committee (Non-interventional Clinical Studies Protocol Number: 2021/11-09.06.2021). The methodology was conducted similar to preceding EALs reliability studies.[5,9,10,21] All the measurements were performed by a single experienced operator previously trained in the use of selected EALs. To set a standardized experimental model and exclude variations in comparison, two different reliability-tested apex locators were used on the same samples of which actual lengths were set and determined.

Sample Selection and Actual Working Length Determination

Twenty fabricated standard resin endoblocks (1 × 1 × 3 cm; taper 0.02; canal length 16 mm, Dentsply Maillefer, Ballaigues, Switzerland) were selected. The blocks were sequentially numbered from 1 to 20 and controlled for apical patency with a #10 K-file (Dentsply Maillefer, Ballaigues, Switzerland). The #10 K-file was inserted into the artificial canal until it reached the apex under ×3.5 magnification. The rubber stopper of the file was fixed, and the length was measured using 0.01-mm precision digital calipers. Each sample was determined and recorded at 16 mm. Measured artificial canals with different values were excluded from the study.

Twenty mandibular canines which had completely formed apices with similar shapes and lengths were selected. The tissue remnants and calculus were removed mechanically. Teeth with complicated root canal anatomy, immature root formation, internal or external root resorption, and previous root canal treatment were excluded. The presence of a single apical foramen for each canal was determined under a dental operational microscope (Leica Microsystems, Wetzlar, Germany). Radicular access and pulp tissue removal were accomplished in a standard manner. The teeth samples were sequentially numbered from 1 to 20, and controlled for apical patency with a #10 K file (Dentsply Maillefer, Ballaigues, Switzerland). The WL of each canal was determined as the file was seen from the apex under × 3.5 magnification. After sectioning the crowns with a diamond disk to achieve 16-mm canal length using 0.01-mm precision digital calipers, the standard root canal samples of the same length were provided.

Experimental Setup and Electronic Working Length Determination

The experimental model is presented in Figure 1. The teeth and resin artificial blocks were embedded in an alginate mold that was kept moist with a saline solution, and the measurements of root canal length with selected EALs (Root ZX®, J. Morita, Tokyo, Japan; Propex Pixi®, Dentsply Maillefer, Ballaigues, Switzerland) using #15 K file (Dentsply Maillefer, Ballaigues, Switzerland) were performed to determine the zero point of the apex which is the major transition to the simulated periapical tissues. For a stable measurement, the rubber stopper was fixed when the electronic bar of the EALs steadily progressed to the zero point sign for at least five seconds. For unstable measurements, the file was removed, and the approach was repeated as mentioned above. The determined length was measured using 0.01-mm precision digital calipers and recorded for both artificial and natural teeth.

Statistical analysis

Statistical analysis was performed with SPSS software (SPSS V23; IBM Corp., Armonk, New York, USA). The data were subjected to the Shapiro–Wilk normality test for determination of distribution. Generalized linear models were used to examine the main effects of the tooth groups and EALs. The Chi-square test was used to compare the distribution of the determined distance from the actual WL of EALs according to groups. The data were statistically analyzed at a variance of $P < 0.05$.

Results

Tables 1 and 2 present the comprehensive comparison of EALs measurements using different tooth structures. No significant difference was found for the WL measurement

Table 1: Descriptive statistics of the WL determination and mean distance from the actual working length by group and device (P<0.05)

	Artificial	SD (±)	Natural	SD (±)	Total	SD (±)
RootZXmini	0.054	0.279	−0.065	0.361	−0.006	0.320
Propex Pixi	−0.007	0.218	0.010	0.381	0.002	0.302
Mean±SD	0.024	0.245	−0.028	0.363	−0.002	0.307
	Test statistics		**Degrees of freedom**		***P***	
WL						
Group	0.289		1		0.591	
Device	0.009		2		0.995	
Group*Device	0.915		2		0.633	
	Test statistics		**Degrees of freedom**		***P***	
WL/Actual WL						
Group	0.289		1		0.591	
Device	0.005		1		0.941	
Group*Device	0.514		1		0.474	

Negative values were used for results exceeding the apical foramen. No significant difference was found among the group and device main effects and interactions on WL determination

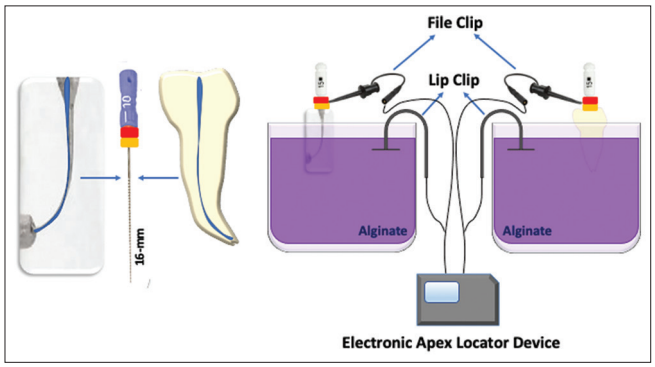

Figure 1: Representative experimental model

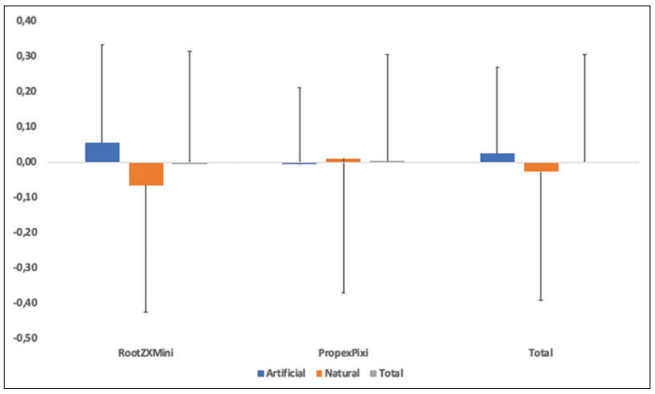

Figure 2: Mean distance to actual WL among the groups and devices with standard deviations

among the groups, devices, and group–device interactions on the determination (P = 0.591, P = 0.995, P = 0.633). There was no statistically significant mean distance from the actual working length of the groups, devices, and group–device interactions (P = 0.591, P = 0.491, P = 0.474). Also, no statistically significant differences were found between the WL endpoint positioning distributions according to the groups in Root ZX Mini, Propex Pixi EALs (P = 1.000, P = 0.574), and regardless of the device (P = 0.591) [Figure 2]. In the Root ZX Mini group, 50% of the artificial teeth were longer than the actual WL with the mean of 0.054 ± 0.279; 50% of the natural teeth were determined longer with the mean of −0.065 ± 0.361. In the Propex Pixi group, 50% of the artificial teeth were longer than the actual WL with the mean of −0.007 ± 0.218; 50% of the natural teeth were longer; and 40% were shorter with the mean of 0.010 ± 0.381. Regardless of the device, 50% of the artificial group were longer than the actual WL with a total mean of 0.024 ± 0.245; 50% of the natural group were determined longer with a total mean of −0.028 ± 0.363.

Discussion

Due to limitations in the standardization of extracted teeth in the preclinical EALs experiments, artificial root canals were evaluated in this study for various reasons, such as manufactured with standardized lengths, with known positions, and apical diameter parameters that may well affect the outcome of the measurement and reliability. Furthermore, evidence suggests that artificial canals are a valid substitute for the tooth in previous researches.[16-20]

The *in vitro* test model for EALs was first proposed by Czerw *et al*.[21] The comparative evaluation of *in vitro* and *in vivo* models concluded no statistically significant differences between the *in vivo* and the *in vitro* groups.[5] Accurate mimicry of periodontal tissues may explain the consistency of *in vitro* and *in vivo* study results. For clinical simulation of accuracy experiments, the alginate and sponge models have been used to mimic the periodontal tissues.[22,23] Natural and artificial teeth were placed into alginate mold to mimic periapical soft tissues as a conducting ambient for the electrical circuit

Table 2: Comparison to the distribution of the endpoint positioning from the actual WL of EALs according to groups

Device	Distance	Artificial	Natural	Total	*P**
RootZXmini	Shorter than WL	10 (50)	10 (50)	20 (50)	1.000
	Longer than WL	10 (50)	10 (50)	20 (50)	
Propex Pixi	Shorter than WL	10 (50)	8 (40)	18 (45)	0.574
	Longer than WL	10 (50)	10 (50)	20 (50)	
	Equal to WL	0 (0)	2 (10)	2 (5)	
Total	Shorter than WL	20 (50)	18 (45)	28 (47.5)	0.591
	Longer than WL	20 (50)	20 (50)	40 (50)	
	Equal to WL	0 (0)	2 (5)	2 (2.5)	

*Chi-square test, there was no statistically significant difference between the endpoint distributions of the WL

between the clip attached file inside the root canal. The lip clip mounted to the alginate was considered the ideal medium for laboratory evaluation of EALs.[23-25] The working principle of the EALs is based on closed-circuit electrical conductivity. In the absence of an insulator such as dentin, the electrical circuit is closed, and a "ZERO" reading is obtained.[22] The artificial resin canals also have an insulator structure like dentin.

The EALs have been reported to be reliable for determining WL by locating the major foramen.[5-10,14,15,26] However, it was suggested that the precise location of the minor foramen or AC cannot be determined, and it has been presented that the constriction might not always exist.[27] Therefore, even though the blocks have limited AC, because of being insulators, this study focused on the hypothesis that artificial resin canals might also be used for the accuracy of experiments or calibration of EALs.

Wrbas *et al.*[28] recommended that the same sample be measured to precisely compare the accuracy and variations in determining the WL among the types of EALs. Therefore, this study was conducted in the same samples in groups (artificial, natural) for measurements of actual WL and electronically locating the WL with different devices.

Various authors suggested that the WL could be calculated to be 0.5–1 mm shorter than the determined length by EALs.[2-4] However, the methodology of this study was arranged regardless of AC location calculation because of the reason mentioned above. The major apical foramen determination was the indicator for the comparison.

The previous EALs accuracy experiments were performed using a tolerance of ±0.5–1 mm that was assumed to be a reliable measurement range.[6,22,25] Since the present experimental model was an applicability evaluation, the accepted ±0.5–1-mm error tolerance for the EALs was not applied, and directly obtained data were compared. Nevertheless, in all groups, the measurements were in the acceptable range. In addition, the absolute mean of the determined distance from the actual WL values of the groups was numerically similar; however, the standard deviation of the artificial tooth was less than the natural group values. Thus, the results indicated that the artificial tooth presented more consistent determination in an acceptable range.

Root ZX® mini accurately determines the actual WL of 83.33–100% tolerance with ±0.5–1 mm, respectively.[6] The percentage of accurate measurements by Propex Pixi was reported to be 83.33–89.99% of the tolerance.[6] Root ZX® Mini and Propex Pixi® were used in this study, as studies reported were with similar accuracy.[6,9,10] This study presented consistent results with no statistical differences in selected EALs measurements in both groups.

Huang conducted an extensive study to understand better the working principles of EALs in vitro, as well as using an artificial apparatus.[29] The apparatus used to mimic the natural tooth was a glass tubule, and the saline solution mimicked the periodontium. Although the study results differed according to the change in tube diameter, some data obtained were in agreement with this study in terms of idea and results. For an inexpensive endodontic teaching model about WL determination using radiography and electronic apex locator, Tchorz *et al.*[30] first proposed for an artificial tooth model using fabricated resin (VDW, Munich, Germany) with multiple roots and colored root canals. However, the pilot observational study was focused on evaluating the students' preclinical training. Besides, Bernardo *et al.*[31] used only artificial teeth for the EALs experiment. However, the validity of using artificial teeth for the EALs experiment was unknown up to the present. As a result, the null hypothesis was accepted that artificial models could be used in reliability experiments.

Laboratory studies introduced the preliminary results to improve the clinical situations. However, all evaluation methods have limitations compared to each other. Therefore, it is crucial to calibrate laboratory studies to the clinical conditions and present standardized test models to evaluate the accuracy of EALs as regards endodontic treatment outcomes. Further studies are required to understand better the proposed test model and the clinical impact of the results.

In conclusion, the results in this study give a complete agreement between natural and artificial teeth to determine the apical transition to the simulated periodontal tissues from the major foramen. The results indicated that the artificial model could be a handy laboratory method for assessing the accuracy of electronic apex locator devices. It is considered that the artificial EALs test model proposed in this study could

be helpful for the efficient calibration of devices before their clinical use.

Declaration of patient consent

The authors certify that they have obtained all appropriate patient consent forms. In the form the patient(s) has/have given his/her/their consent for his/her/their images and other clinical information to be reported in the journal. The patients understand that their names and initials will not be published and due efforts will be made to conceal their identity, but anonymity cannot be guaranteed.

Artificial Method for Reliability of Apex Locator Devices.

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Conflicts of interest

There are no conflicts of interest.

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