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The Accuracy of Endodontic Length Measurement Using Cone-Beam Computed Tomography in Comparison with Electronic Apex Locators

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ABSTRACT

Introduction: The aim of this *in vitro* study was to evaluate the accuracy of cone-beam computed tomography (CBCT) and two electronic apex locators (EALs) when measuring the actual length of root canals. **Methods and Materials:** One hundred and eighty four root canals in 135 extracted anterior and posterior permanent teeth were studied. Root canal curvatures were analyzed on CBCT images, and root canals with curvatures less than 70° were chosen. Root canal length measurements were performed using CBCT, ProPex Pixi, E-Pex Pro, and the actual length (AL). The percentages of the measurements in the range of ±0.5 mm to the AL were compared using Fisher's Exact test. The ICC indices and Bland-Altman plots were used to display the agreement of three devices with the AL measurements. The statistical significance was set at $P<0.05$. **Results:** The accuracies of E-Pex Pro and ProPex Pixi (87.5% and 82.6%, respectively) were better than that of CBCT (71.7%) ($P<0.05$). **Conclusion:** This *in vitro* study showed that although the accuracies of the two EALs were at high level, there was no device that had an agreement with the actual root canal length measurement

Keywords: Cone-beam Computed Tomography; Electronic Apex Locator; Endodontics; Root Canal Length; Root Canal Therapy

Introduction

The preparation phase of root canals, that is principally based on the working length (WL) determination, is one of the most important stages in endodontic therapy [1]. An exact WL is essential in confining the root canal preparation inside the radicular space; preventing apical extrusion of the root canal content, and obtaining good apical obturation. Therefore, the determination of root canal WL is one of the most important variables in root canal preparation and can affect the success of the endodontic therapy. If the WL is not exactly determined, the root canal space cannot be shaped and cleaned appropriately [2].

There are two main methods for the determination of the root canal WL; periapical (PA) radiograph and electronic apex locator (EAL). However, there are other techniques which can give additional information; such as digital tactile sense, apical periodontal sensitivity, and paper cone [3]. Digital tactile sense and apical periodontal sensitivity are considered as unreliable methods [3, 4]. In addition, paper cone utilisation is not a precise way of determining the root canal WL because of the piston-like effect of the paper cone [5].

PA radiography is commonly used in endodontics for the estimation of the root canal WL; however, it has shown disadvantages. PA radiographs only display the two-dimensional image of a three-dimensional object [6]. Furthermore, and in many circumstances, the apex of the root cannot be detected on the radiograph due to the overlapped anatomic structures [7]. Distortion of the image is also a frequently encountered problem of PA radiography [8]. Moreover, an overestimated radiographic WL is a common result of this method of radiography [9, 10].

Figure 1. Schneider angle measurement on CBCT image

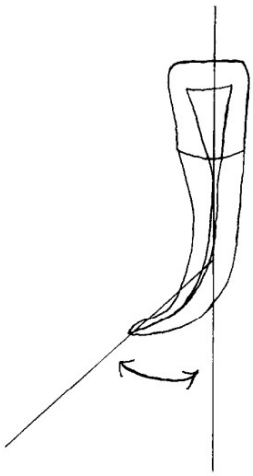

Figure 2. The original Schneider angle

Cone-beam computed tomography (CBCT) can create an exact three-dimensional image of the tooth and surrounding structures [11]. CBCT can also be useful in the detection of periapical lesions, root cracks, internal and external resorption, with a higher sensitivity when compared to conventional radiographs [11]. Although CBCT has many advantages, it is still not an appropriate replacement for conventional radiography in routine endodontics because of its high exposure dose and low resolution [12, 13]. However, for patients who have had previous CBCT due to unrelated endodontic reasons CBCT is a valuable modality for root canal therapy; especially in the determination of working length. To the best of our knowledge, there seems to be no similar results with regard to the degree of accuracy of CBCT for determining the endodontic working length from previous studies [14, 15].

Electronic apex locators (EAL)s are used to measure the length of root canals to the apical foramen and seem to be more exact than periapical radiography [16]. ProPex Pixi (Dentsply, Maillefer, Ballaigues, Switzerland) is one of the most reliable devices for the electronic determination of the root canal length [17]. A new EAL, E-Pex Pro (Changzhou Eighteeth Medical Technology Co., China), has been introduced in China. It is a member of the fifth generation of EALs for electronic measurement of root canal length.

The aim of this study was to evaluate the degree of accuracy of CBCT and two EALs when measuring the actual length of root canals.

Materials and Methods

The present study was approved by the Research Ethics Committee of the University of Medicine and Pharmacy at Ho Chi Minh City, Vietnam.

150 human extracted sound permanent anterior and posterior teeth due to periodontal and/or orthodontic reasons_ were used for this *in vitro* study. The extracted teeth were ultrasonically cleaned and stored in a 0.9% NaCl solution until utilisation.

Access cavities were prepared using Martin and Endo-Z burs (Dentsply, Maillefer, Ballaigues, Switzerland) in a high-speed handpiece. Then, pulpal tissues were removed with barbed broaches, and canals were irrigated using 3% NaOCl (Hyposol, Prevest DenPro, Jammu, India) and 27G endodontic irrigator tips (Endo-Eze, Ultradent Products Inc, South Jordan, Utah, USA). Canals were negotiated to the apex using a K-file #10 (Dentsply, Maillefer, Ballaigues, Switzerland). Incisal edges and/or occlusal surfaces were ground flat so that they could be used as reference points/planes for the measurement of root canal length. Afterwards, the teeth were inserted into alginate-containing (Hydrogum, Zhermack, Italy) working plastic trays, which had already been placed on an adjustable tripod. Then, they were prepared to be scanned by CBCT (Sirona Galileos, Dentsply-Sirona, York, Pennsylvania, USA) with a voxel size of 0.3 mm and a field of view (FOV) of 15 cm×15 cm.

All images were analysed using Galileos Viewer (Sirona Galileos, Dentsply-Sirona, York, Pennsylvania, USA). Sagittal view images of anterior teeth and coronal view images of posterior teeth were chosen so that the images of root canals were clearest on the screen. The root canal curvatures were measured on these images using Schneider method [18]. An angle tool was chosen, and two lines were drawn on the image. The first line was over the canal orifice, parallel to the main axis of the coronal root canal. The second line connected the apex and the point where the root canal left the main axis. The angle created by the two described lines was recorded as Schneider angle (Figures 1 and 2) [18]. Teeth with root canal curvatures below 70° were chosen for the study.

184 root canals in 135 teeth were chosen and divided into three groups: straight canals (0–5°), mildly curved canals (5-20°) and severely curved canals (20-70°) [18]. All root canals were measured in three ways; *a)* Digital imaging lengths using CBCT images, *b)* Actual lengths and *c)* Electronic lengths using EALs (ProPex Pixi and E-Pex Pro). CBCT images, used for Schneider curvature measurement, were chosen for the determination of root canal length; using the length measurement tool of the software. For anterior teeth, the measurement of root canal length was performed between two points: the mid-point of the incisal edge, and apical foramen. For posterior teeth, the measurement of root canal length was the length of the lines drawn following the canal curvature; from the apical foramen to the intersection between the main axis of the coronal root canal and the line across the flat, ground occlusal plane.

Then, the teeth were removed from the plastic trays and the actual lengths of the root canals were measured. A standard K-file #15 was inserted into the root canal from the orifice until the tip of the file was seen at the apical foramen. Then, the file was withdrawn until the tip of the file was seen at the most coronal border of the foramen under a stereomicroscope (Olympus SZX16, Olympus Corp., Tokyo, Japan) at a magnification of 10×. The rubber stop at the shank of the file was set at the reference point on the incisal edge or the occlusal plane. The distance from the rubber stop to the tip of the file was the actual length of the root canal and was measured using the mechanical Mitutoyo caliper at the 0.02 mm exact level (Mitutoyo Corp, Kawasaki, Japan).

The teeth were then inserted into the holes of a plastic model containing the saline solution to simulate teeth inside the jaw. Electronic root canal lengths were measured, using two EALs, following the method of a previous study [19]. In the previous study, teeth were inserted into a similar plastic jaw model in which a cavity was created and filled with saline solution. In that model, the apices of the roots were in contact with the saline solution. In addition, in that study, one metal wire was inserted into the base of the model in a way that the wire was also in contact with the saline solution. One pole of the EAL was connected to the metal wire at the base of the model. A K-file #15, connected to the other pole of the EAL, was inserted into the root canal until the tip went beyond the foramen. Then, the K-file was withdrawn and re-inserted to reach the apical foramen. All measurements were performed when either EALs displayed 00 (E-Pex Pro) or the yellow lamp lighted up constantly at the 0.0 level (ProPex Pixi) on the screens of the devices for longer than five seconds. The K-file length from the rubber stop to the tip of the file was measured using a Mitutoyo caliper.

Data was collected and analysed with One-sample t-test, Fisher's exact test, ICC indices and Bland-Altman plots using SPSS version 22.0 (IBM, Armonk, NY, USA).

Results

The mean differences of CBCT and two EALs to the actual lengths in millimeters are displayed in Table 1. There were significant differences amongst the three groups in the mean differences ($P<0.05$). There were significant differences for each pair of groups ($P<0.05$). All *P*-values in the one-sample t-test with a test value of 0 were much lower than 0.05 for the mean differences between CBCT and the two EALs with the actual root canal lengths. Therefore, there was no device compatible with the actual root canal length measurement (Table 1).

The proportion (%) of differences between the actual length and the length measurement using CBCT and the two EALs is displayed in Table 2. When using CBCT, ProPex Pixi, and E-Pex Pro, the proportion of differences, in the range of 0.5 mm, was 71.7%, 82.6%, and 87.5%, respectively. The Fisher's exact test showed that there were significant differences between the two values in the three groups ($P<0.05$).

Table 1. Mean differences between CBCT and two EALs with the actual lengths of root canals (mm), and the *P*-values of the One-Sample t-test with the test value of 0 for the mean differences

Groups (N)	Mean (SD)	Test Value=0	
		t	*P*-values
CBCT-AL (184)	0.36 (0.31)[a]	15.063	< 0.001*
ProPex Pixi-AL (184)	0.27 (0.25)[b]	14.289	< 0.001*
E-Pex Pro_AL (184)	0.11 (0.30)[c]	4.797	< 0.001*

[a, b, c] *Significant differences among each pair of groups, LSD Post Hoc test, P<0.05; *P<0.05, One-Sample t-test with test value of 0*

Table 2. The incidence (%) of differences between the actual length and length measurement using CBCT and two EALs

Groups	Shorter than AL N(%)		Equal to AL N(%)	Longer than AL N(%)		*P*-values
	>0.5 mm	≤0.5 mm		≤0.5 mm	>0.5 mm	
CBCT-AL	51 (27.7%)	113 (61.4%)	2 (1.1%)	17 (9.2%)	1 (0.5%)	0.001*
ProPex Pixi-AL	31 (16.8%)	129 (70.1%)	0 (0.0%)	23 (12.5%)	1 (0.5%)	0.001*
E-Pex Pro-AL	17 (9.2%)	110 (59.8%)	1 (0.5%)	50 (27.2%)	6 (3.3%)	0.001*

**P<0.05, Fisher's exact test*

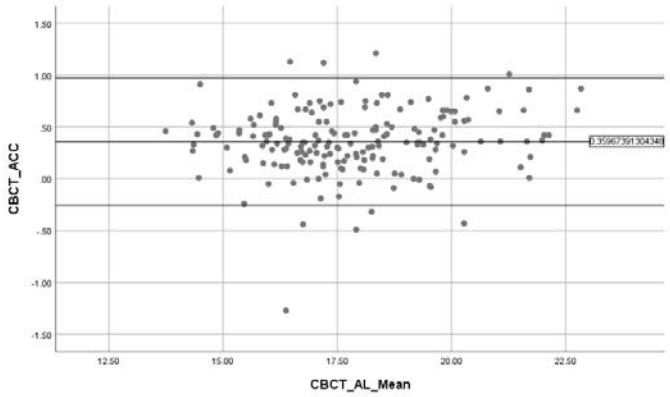

Figure 3. Bland-Altman plot for the agreement of CBCT and actual length measurements

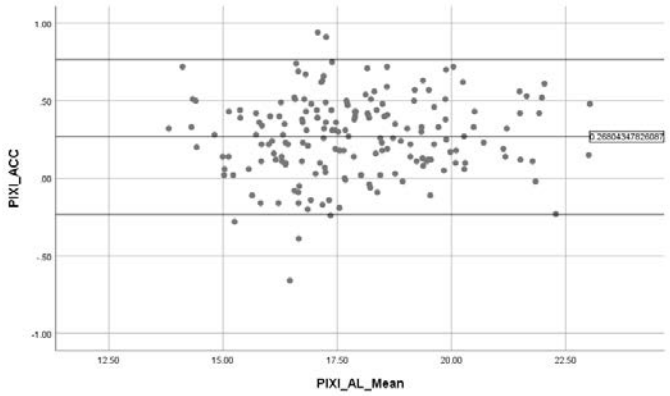

Figure 4. The Bland-Altman plot for the agreement of ProPex Pixi and actual length measurement

The Intraclass Correlation Coefficient indices were 0.969, 0.981, and 0.986 for CBCT, ProPex Pixi, and E-Pex Pro *vs* actual length, respectively.

The Bland-Altman plots are displayed in Figures 3 to 5. Figures show that the points were scattered from the mean lines, and that there were many points out of the upper and lower limits of the plots. This result revealed that, the measurements of all three devices did not agree with the actual lengths.

Discussion

The present study showed that there was no device (CBCT or EALs) compatible with the measurement of the actual length of root canals. Our investigation revealed that in the range of 0.5 mm from the actual length of the root canal, it seemed that E-Pex Pro was the most precise electronic apex locator in the experimental equipments. The results also showed that, the

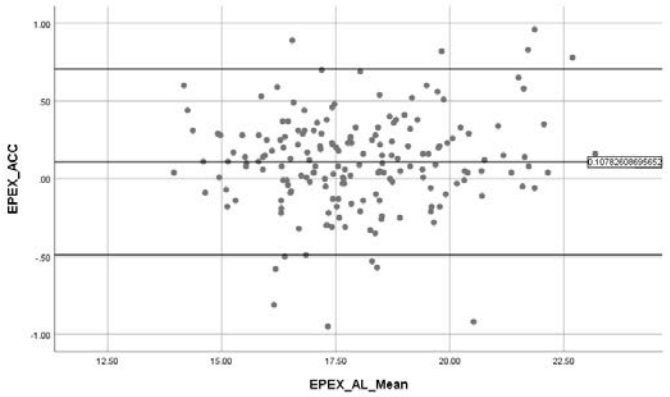

Figure 5. The Bland-Altman plot for the agreement of E-Pex Pro and actual length measurement

experimental CBCT was not the best choice in the determination of WL for endodontic therapy.A few studies used single-rooted and multi-rooted teeth for the measurement of root canal lengths [14, 20]. Cusp tips were used as a reference point in a study [14] while in other investigations, crowns were cut at the cemento-enamel junction (CEJ) to make a reference plane for the measurement of length [20]. In the present study, the occlusal surface was ground flat to make a reference plane so as to increase the accuracy of the root canal length measurement. Moreover, in our study, the position of the file tip when measuring the length of root canals was not the same as that in other studies. Sometimes, the tip of the file was flush with the apical foramen [14], or it was at the most coronal margin of the apical foramen as in this present study and a previous study [20]. In case the tip was at the end of the canal, the overall length was subtracted by 0.5 mm to gain the WL [21].

The results of the present study showed that although the mean of actual root canal lengths was larger than the measurement of length using other methods, there was no significant difference between the four groups regarding the measurements. However, the mean difference between CBCT measurements and the actual root canal lengths was the largest significant value in the three experimental groups. Therefore, the accuracy of CBCT was lower than that of EALs. This result was similar to the results of previous studies [20, 22].

Although the mean differences between measurements using CBCT and the two EALs even that of E-Pex Pro with the measurements of actual root canal length were low, the smallest difference was 0.11 mm. Thus, there was no device agreement with the actual root canal length because the *P*-values of one-sample t-tests were lower than 0.05. The range of

± 0.5 mm from the actual root canal length for WL was at an acceptable level in clinical endodontic therapy [23]. In the present study, in the range of ± 0.5 mm, the accuracy of CBCT measurements was greater than that of the study by Lucena *et al*. [20] and was similar to that of other previous studies [14, 15]. However, the accuracy of CBCT measurements was higher than that of EALs in the study by Yildirim *et al*. [15].

In addition, in our study, the accuracy of ProPex Pixi was up to 82.6%, in the range of ±0.5 mm, when compared with the actual root canal length. This result agreed with that of the study by Gehlot *et al*. [24] and did not agree with the results of some other studies [17, 25]. In another previous study, which used an alginate model and lower premolars with different protocols in determining the electronic root canal lengths, the accuracy of ProPex Pixi was up to 93% in the range of ±0.5 mm [17].Another study used a scanning electronic microscope for the determination of the distance from the file tip to the canal-dentinal-cement junction. In measuring the accuracy of ProPex Pixi, the incidence of the mean difference in the range of ±0.5 mm was up to 88% [25]. The incidence of accuracy in the range of ±0.5 mm of E-Pex Pro was highest in the three experimental devices, up to 87.5% in the present study. This result was similar to that of the study by Jafarzadeh *et al*. [26], in which EALs were more accurate than conventional radiography in the determination of WL in C-shaped canals. Although the accuracies of EALs were relatively high, unintentional over instrumentation was commonly encountered in root canal preparation even when EALs were used [27].

In the present study, anterior and posterior teeth were studied in an *in vitro* situation, therefore, there were certain limitations in the interpretation of results for clinical use. Further research should be conducted on other conditions such as artificial periapical lesions, open apices and so forth. Clinical studies, in particular, should be investigated since they can provide noble information for the exact values of devices in the precise measurement of root canal length for endodontic therapy.

Conclusion

CBCT is a useful modality in the determination of the length of root canals in endodontic treatments. However, and in this study, CBCT was not the most accurate method in measuring the length of the root canals. Although the accuracies of the two EALs were at high level, there was no device that had an agreement with the actual root canal length measurement.

Conflict of Interest: 'None declared'.

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