Original Article

Endodontic Length Measurements Using Different Modalities: An *In Vitro* Study

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Abstract

Introduction: The aim of this study was to investigate and compare the accuracy of the 3D Endo software, conventional CBCT software Romexis Viewer, and the EAL E-Pex Pro in WL determination. **Materials and Methods:** Three hundred and two root canals in 110 intact human extracted molars were accessed. The actual lengths (ALs) were measured. Root canal lengths were measured using 3D Endo with proposed length (3D-PL) by software, correct length (3D-CL), Romexis Viewer, and the E-Pex Pro. The percentages of the measurements in the range of ±0.5 mm to the AL were compared using the Fisher's exact test. The paired *t* test and Bland–Altman plots were calculated to detect the agreement of the four methods with the AL measurements. The statistical significance was set at $P<0.05$. **Results:** The accuracies in the range of ±0.5 mm to the AL were 83.8%, 86.7%, 48.3%, and 99.7% for 3D-PL, 3D-CL, Romexis Viewer, and E-PexPro, respectively. There were agreements between 3D-PL and Romexis Viewer with the AL measurements. **Conclusion:** The CBCT measurements using 3D Endo with the proposed length by the software and Romexis Viewer with the voxel size of 0.15 mm agreed with the AL measurements of the root canals.

Keywords: *3D Endo, cone-beam computed tomography, electronic apex locator, endodontics, root canal length*

Introduction

Endodontic treatment requires not only knowledge of and familiarity with root anatomy, root canal morphology, and their alterations, but also the lengths of these root canals to ensure the optimally removal of canal components in the root canal preparation phase.[1] An appropriate working length (WL) is important in confining the instrumentation inside the radicular space, restricting extrusion of debris, and ensuring proper obturation.[1] The end point of root canal procedure is apical constriction, an inconstantly anatomic landmark. Regardless of this inconsistent feature, an effort should be incessantly performed to enclose root canal treatment inside the canal space. The mission in locating the endpoint of endodontic treatment has usually required the combination among many contemporary modalities and operator skills.

Traditionally periapical (PA) radiograph has been tough in many dental schools for WL determination, besides being utilization as a diagnostic method. However, this has certain shortcomings. This analog or digital radiograph presents a two-dimensional plenary projection of a three-dimensional structure, leading to misinterpret actual condition, identify root apex incorrectly, overestimate WL, and manage endodontic therapy hardly.[1]

With the coming out of "multiple frequencies" or "ratio method" mechanisms, the following generations

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of electronic apex locator (EAL) overbalance the early generations, which base on the far simpler mechanisms.[2] Although the reliability and accuracy of the EAL are better than that of traditional radiograph, the performance of the EAL might be falsified by certain situations such as obstruction of canal, or complexities in anatomical features.[3]

Cone-beam computed tomographic (CBCT) scan is a contemporary radiographic imaging system and has been advocated that can overcome shortcomings in conventional radiographic methods.[4] Data available from the preexisting CBCT scan allows for precise diagnosis, proper treatment planning, and predictable canal instrumentation.[4] CBCT is also an accepted modality to evaluate and visualize the complicated morphology of an individual tooth.[5]

Geometrically precise measurement scan be extracted from the CBCT, helping in exact computation of intra- and inter-canal distances and determination of root canal length.[6]

However, reports from several studies in the literature regarding the precision of CBCT measurements compared with that of other modalities reach no concurrence.[1,7,8]

The AAE and AAOMR Joint Position Committee (2015) show that in certain complex morphological cases, the limited field of view CBCT should be considered, however, the committee has previously confirmed that intraoral radiographs should be considered the imaging modality of choice in the evaluation of the endodontic patient.[9] Thus, CBCT should not be used for routine endodontic diagnostic.

Recently, 3D Endo software (Dentsply Sirona, Johnson City, Tennessee) has been developed for endodontic treatment planning with high complex situations.[10] The requirements of minimum resolution of 200 µm and standard DICOM are compatible for the 3D Endo software with an intuitive, lively, attractive interface for analysis. The 3D Endo software has separate steps with straightforward instructions for operator from the beginning through the end of the endodontic procedure. Capability of producing a canal pathway semi-automatically with the landmarks defined by operator is one of the most creative features of the software. With this guidance, the WL of the root canal will be displayed first as the suggested length and second, by the operator once not satisfied determination.

The aim of this study was to investigate and comparison of the accuracy of the 3D Endo software, conventional CBCT software (Romexis Viewer, Planmeca Oy, Helsinki, Finland), and the EAL E-Pex Pro (Changzhou Eighteeth Medical Technology Co., China) in WL determination.

Materials and Methods

This study was approved by the Research Ethics Committee of the University of Medicine and Pharmacy at Ho Chi Minh City, Vietnam. The study acquired the intact human extracted molars obtained from many hospitals for many reasons. Using the data from the previous study,[1] and the sample size calculation in Bland–Altman plot submenu of the MedCalc Statistical Software version 19 (MedCalc Software, Ostend, Belgium), the appropriate size was 302 root canals. Therefore, 111 extracted molars were chosen for this study.

Teeth were stored in sterile saline and then cleaned with the ultrasonic scaler Cavitron (Dentsply Sirona, Switzerland), immersed into the 10% formalin solution. Teeth were observed thoroughly under a stereomicroscope to exclude immature apical, cracked, external resorption roots (at a magnification of 10). After being coded with numbers on the crowns, teeth were then ready for cavity access preparation. Cavity access was prepared with the straightline access concept using the Martin and Endo-Z burs (Dentsply Sirona, Ballaigues, Switzerland). After exposure of all canal orifices was completed, the #10 ISO K-file was introduced into all canals until the tip of the file was visible at the most coronal border of the AF opening under the stereomicroscope (Olympus SZX16, Olympus Corp, Tokyo, Japan). The rubber stop was adjusted to the occlusal reference point, the file was removed from canal and the length from tip to rubber stop of the file was measured using a digital caliper Mitutoyo (Mitutoyo Corp, Kawasaki, Japan) and recorded as the actual canal length (AL). The teeth were then immersed into the freshly mixed alginate tray to prepare for electronic measurements. The root canal lengths were measured using the electronic apex locator E-Pex Pro. The #10 ISO K-file was inserted into the canal until the 00-mark lighted up and remained stable for 5 s on the EAL's screen. The rubber stop was adjusted to the occlusal reference point, the file was withdrawn from the canal and the length was measured as mentioned above. This length was recorded as the electronic length (EL).

Afterward, all teeth were arranged and immersed into the plastic molds. The 3 mm thick floor of the mold was made by wax and the remaining part was light impression silicone that reached to the cemento-enamel junctions of teeth. Molds with teeth were then put on the customized shelf and scanned using the cone-beam computed tomography (CBCT) (Planmeca ProMax, Planmeca Oy, Helsinki, Finland) with endo mode, 90 kV, 10 mA, field of view (FOV) 50 mm x 50 mm, pixel of 0.15 mm.

In the first section, the CBCT images were observed and analyzed using the Romexis Viewer software from CBCT manufacturer. The slices of the tooth were scanned and observed until the best image of entire length of the canal in bucco-lingual view at the greatest curved angle was selected. The measuring line was drawn from the occlusal reference to the apical foramen (AF), accompanying any deviations from the course of the canal, and was measured in millimeters. Root canal lengths were measured using the tools of Romexis Viewer and recorded as the conventional CBCT length (CL).The conventional CBCT measurements were performed twice with an interval of two weeks to check the intra-examiner reliability.

In the second section, the CBCT data were displayed on the 3D Endo software (Dentsply Sirona, Salzburg, Austria) to analyze using its own tools. Tooth's 3-D image was first isolated with the surrounding structure using the proper tools of the software. The operator confirmed the canal orifice and the apex foramen for each canal of each tooth. Once these two landmarks were defined, the automatic line would be drawn immediately by software to connect these two points. The canal pathway was defined by selecting and adjusting the positions of as many points as possible on this line in horizontal and vertical planes from the orifice to apex. This step was performed by operator. The 3D Endo software reconstructed automatically the 3-D image and inside canal system and inserted a virtual K-file reaching to the apex. After adjusting the coronal angulation of the file following the straight-line access concept, the operator pressed the Suggest button to automatically produce the proposed length (3D-PL). This length was recorded as 3D-PL. Normally, the position of the rubber stop on the occlusal surface at the proposed length (PL) did not satisfy the operator, therefore, adjustment of the rubber stop position was conducted by operator for the best suitable location and this length was recorded as corrected length (3D-CL). The 3D Endo measurements were performed twice with an interval of two weeks to check the intra-examiner reliability.

All measuring data were stored and analyzed using MedCalc Statistical Software version 19 (MedCalc Software, Ostend, Belgium). The data were first screened for normality of distribution using the Shapiro–Wilk test. The intra-examiner reliability was checked using intraclass correlation (ICC) index. Fisher's exact test, Paired *t* test, ICC indices, and Bland–Altman plots were used for analyzing the data.

Results

The IntraClass Correlation indices were 0.982, 0.984, 0.940, and 0.997 for 3D-PL, 3D-CL, Romexis Viewer, and E-Pex Pro versus actual length (AL) measurements, respectively.

The proportion (%) of differences between the AL and the length measurements using CBCTs and the EAL is displayed in Table 1. When using 3D Endo PL, 3D Endo CL, CBCTRomexis Viewer, and E-Pex Pro, the proportion of differences, in the range of ±0.5 mm, was 83.8%, 86.7%, 48.3%, and 99.7% respectively. The Fisher's exact test showed that there were significant differences among the four groups ($P < 0.05$).

The mean biases, standard deviations, confidence intervals, *P* values in the paired *t* test and linear regression analysis, fixed or proportional biases for different methods' measurements are displayed in Table 2. Using the analysis method of the previous studies,[11,12] there were two fixed biases and no proportional biases for this study. There were not significant differences in the mean differences between 3D-PL, Romexis Viewer, and AL measurements ($P > 0.05$); therefore, the 3D Endo proposed length and CBCT Romexis Viewer WL measurements agreed with the AL. Because of the *P* values for the paired *t* tests in groups using 3D-CL and EAL were lower 0.05, these two modalities did not agree with the AL. Figures 1–4 display the Bland–Altman plots for the agreements of the four modalities with AL.

Table 1: Incidence (%) of differences between the actual length and length measurements using CBCTs and the EAL

Groups	Shorter than AL *N*(%)		Equal to AL *N*(%)	Longer than AL *N*(%)		
	>0.5 mm	≤0.5 mm		≤0.5 mm	>0.5 mm	±0.5 mm(%)
3D-PL – AL	27(8.9)	105(34.8)	18(6)	130(43)	22(7.3)	83.8[a]
3D-CL – AL	28(9.3)	140(46.4)	9(3)	113(37.4)	12(4)	86.7[a]
Romexis – AL	76(25.2)	65(21.5)	0(0)	81(26.8)	80(26.5)	48.3[b]
E-Pex Pro – AL	0(0)	213(70.5)	62(20.5)	26(8.6)	1(0.3)	99.7[c]

Superscript different letters indicated the significant differences at $P < 0.001$

Table 2: Mean biases, standard deviations, confidence intervals, *P* values in two statistical tests, fixed or proportional biases for different methods' measurements

Groups	Paired *t* test			Linear regression	Fixed bias	Proportional bias
	Mean bias	95% CI	*P*	*P*		
3D-PL – AL	0.01586	−0.02602 to 0.05774	0.4567	0.9953	No	No
3D-CL – AL	−0.05844	−0.09608 to −0.02080	0.0024*	0.0505	Yes	No
Romexis – AL	0.03579	−0.04090 to 0.1125	0.3591	0.5378	No	No
E-Pex Pro – AL	−0.03937	−0.05350 to −0.02524	<0.0001*	0.8515	Yes	No

* Differences at significant level of 0.05

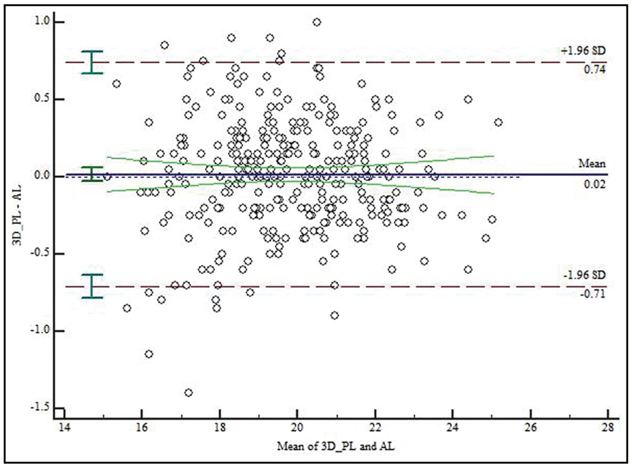

Figure 1: Bland–Altman plot for the agreement of 3D-PL and AL measurements

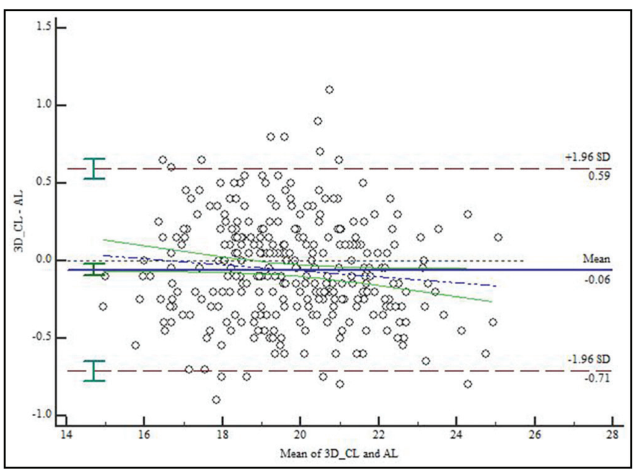

Figure 2: Bland–Altman plot for the agreement of 3D-CL and AL measurements

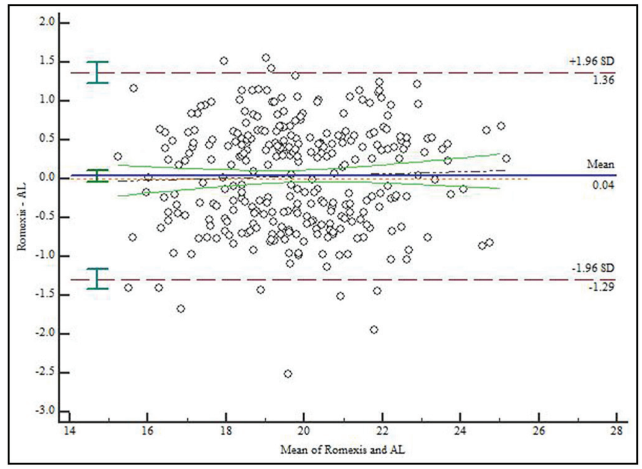

Figure 3: Bland–Altman plot for the agreement of Romexis viewer and AL measurements

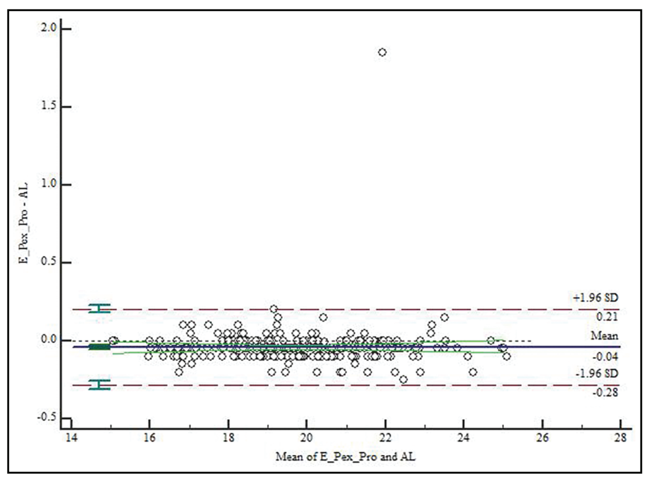

Figure 4: Bland–Altman plot for the agreement of E-Pex Pro and AL measurements

Discussion

The results of this study showed that, in the range of ±0.5 mm from the apical foramen, the EAL E-Pex Pro was the best accurate modality among the experimental ones. The mean differences were lowest in the 3D-PL measurements, using the 3D Endo software that was proposed semi-automatically by the program after determination of the apex foramen by the operator. The 3D-PL and Romexis Viewer measurements agreed with the AL of the root canals.

The important role of the WL determination had never diminished especially in the existing of more and more modern effective instruments for preparation,[13,14] the complexity of the root canal system,[15] and the demand for restoration of endodontically treated teeth.[16] The WL obtained by the E-Pex Pro in this study did not differ from that of the previous study, with the highest accuracy in the range of ±0.5 mm and disagreement with the AL.[1] There was fixed bias between the E-Pex Pro and the AL measurements with the means of the EAL measurements were constantly lower than the latter, across the entire range of measurements.

Demands for dental CBCT imaging in several applications continuously increase, leading to the increase of endodontic cases with pre-existing CBCT owing to other requirements. These cases are normally incidental findings and have considerable advantages in endodontic decision making and treatment planning.

3D Endo software is introduced and dedicated for complex endodontic cases in the clinical situation. This software, with intuitive, friendly interface and clear instructions step-by-step throughout procedure, completely satisfies all requirements for all cases, especially in the simulated endodontic education.

WL determination with the canal pathway is one of the most creative characteristics of the 3D Endo software. The function of manual adjustment of length whenever the suggested length is not satisfied is also a valuable feature of the software. This feature is developed in the effort of maximum reduction of operator's errors in WL determination. Depending on the curvature levels of the canal after adjusting the canal pathway, the operator can estimate proper length of instrumented canal to correct the WL for the following steps. The virtual canal pathway displayed on the screen of the computer assists the operator in effective visualization and management of the root canal instrumentation.

The results showed that the 3D-CL measurements disagreed with the AL. There was fixed bias without proportional bias, like that of the EAL measurements. The 3D-CL measurements were the WL after correcting the proposed lengths by the operator. The virtual rubber stop on the file was corrected using the anatomic landmarks on the occlusal surface by the operator in the effort of reaching to the most accurate length. There could be because of the occlusal missing structure from the access cavity or leak of the skill in adjusting, leading to the incorrect measurements. One of the more important reason could result from the voxel size of the parameters, in this case, was 0.15 mm. However, the 3D-PL measurements agreed with the AL without fixed or proportional biases. The semi-automatically correct by the software reached to the best results with the lowest mean differences in this study. This result showed that the reliable and accurate measurements could be obtained using the 3D Endo software at the voxel size of 0.15 mm.

Studies on determination of WL with CBCT commonly used human extracted teeth in dry mandible or in jaw model.[17-19] The setting with the dry human mandible is better than other contexts in controlling of some clinical variations such as artifacts caused from position or motion of patient, beam hardening from other surroundings, or noise from other anatomic structures.[17,19] The arrangement of teeth in the impression tray of this study does not eliminate completely artifacts from the neighboring teeth in the tray. However, CBCT images are clear and anatomic landmarks are defined easily and exactly owing to of high resolution. The Romexis Viewer measurements agreed with the AL with good mean differences, just higher than that of the best method in this study. At the present resolution of the image, the Romexis Viewer measurement was reliable and accurate modality for WL determination. This result differed from the other previous studies.[1,7,19]

Although the human extracted teeth seem appropriately for evaluation the accuracy of CBCT WL determination, the artificial endodontic training tooth still completely satisfies requirements of this purpose[20]. Authors just select the actual root canal length of the artificial tooth as the gold standard in evaluation of the accuracy of the CBCT WL.[20] The 3D Endo software can improve accurate 3D root canal length determination, however, the operator should check, control, and maintain continuously the WL during the preparation phase to detect changes especially in the severe curved canal.[20]

One important shortcoming with CBCTin endodontic WL determination on the heavily metallic restored tooth is the significant artifact.[6] More artifact means a greater approximate range of length, and in these cases, CBCT provides only an estimate of the length.[6]

Proper knowledge of root canal anatomy and morphology is indispensable for every clinician in endodontics for locating the root canal orifices. CBCT imaging has supplied an exact, noninvasive approach for clinical chairside assessment of root canal anatomy.[4] The 3D Endo softwareis an effective, quick, and easy modality for identification and visualization of canal trajectories in three dimensions. This software reveals promise in supporting operator for quantifying anatomical complexities preoperatively.[21]

Endodontics can be performed at a high level without CBCT imaging, but it cannot be practiced at the highest level.[6] Image-guided endodontics with minimally invasive access and instrumentation is recently recommended by authors for better in preservation as much tooth structure as possible.[6] Combination between CBCT and optical scans using dedicated endodontic software can produce the exact guide tray to create a drill line in accessing the root canal apical third safely and effectively.[22] These tools are helpful for obliterated canals in negotiating and preparing such endodontic cases.

The radiation exposure for dental CBCT has been a dramatic reduction as compared with the conventional medical CT. However, this is not the major key to use for the routine examination in dentistry, especially in endodontics. The benefits from the examination far outweigh the risks related to ionizing radiation exposure should be carefully considered.[6] Although the radiation exposure for each dental examination is less than dose of radiation from other sources, the time patient experiences is so short, leading to the augmentation of damage. Diagnostic examinations should be performed at the lowest dose of radiation, following the ALARA principle: as low as reasonably achievable.[23] The American Association of Endodontists statement suggests that the risk-benefit ratio is too high for CBCT to be used as a routine screening tool, even though the radiation levels are quite low with focused-field imagers.[9] Therefore, CBCT scans cannot be used as a routine procedure for endodontic diagnostic and application of CBCT only for root canal length measurement is not advocated.[20] In cases with the pre-existing CBCT because of other reasons, the 3D Endo software is an invaluable tool in root canal morphological evaluation, treatment planning, and especially in WL determination.[20]

Conclusion

The CBCT measurements using 3D Endo with the proposed length by the software and Romexis Viewer with the voxel size of 0.15 mm agreed with the AL measurements of the root canals. Other methods using the corrected length with 3D Endo by the operator and EAL had fixed biases.

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Conflicts of interest

There are no conflicts of interest.

Authors contributions

PNN designed, carried out the study, collected, and analysed the data. KVP conceived, wrote, reviewed, and edited the manuscript.

Ethical policy and institutional review board statement

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

Patient declaration of consent

Not applicable.

Data availability statement

Not applicable.

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