

Accuracy of Small Field of View CBCT in Determining Endodontic Working Length

N. L. S. Ahmad, Y. L. Thong, P. Nambiar

Abstract—An *in vitro* study was carried out to evaluate the feasibility of small field of view (FOV) cone beam computed tomography (CBCT) in determining endodontic working length. The objectives were to determine the accuracy of CBCT in measuring the estimated preoperative working lengths (EPWL), endodontic working lengths (EWL) and file lengths. Access cavities were prepared in 27 molars. For each root canal, the baseline electronic working length was determined using an EAL (Raypex 5). The teeth were then divided into overextended, non-modified and underextended groups and the lengths were adjusted accordingly. Imaging and measurements were made using the respective software of the RVG (Kodak RVG 6100) and CBCT units (Kodak 9000 3D). Root apices were then shaved and the apical constrictions viewed under magnification to measure the control working lengths. The paired t-test showed a statistically significant difference between CBCT EPWL and control length but the difference was too small to be clinically significant. From the Bland Altman analysis, the CBCT method had the widest range of 95% limits of agreement, reflecting its greater potential of error. In measuring file lengths, RVG had a bigger window of 95% limits of agreement compared to CBCT. Conclusions: (1) The clinically insignificant underestimation of the preoperative working length using small FOV CBCT showed that it is acceptable for use in the estimation of preoperative working length. (2) Small FOV CBCT may be used in working length determination but it is not as accurate as the currently practiced method of using the EAL. (3) It is also more accurate than RVG in measuring file lengths.

Keywords—Accuracy, CBCT, endodontic, measurement.

I. INTRODUCTION

ROOT canal systems may be complex and variable [1]. One of the important aspects of root canal treatment is accurate determination of the working length, which is necessary if damage to the root apices and periapical tissues is to be avoided due to overinstrumentation [2]. Intraoral imaging is the most commonly used method for working length determination. Along the course of a root canal treatment, five radiographs are usually taken at different stages. However, errors may occur due to image distortion and poor visualization of the apical foramen [3].

According to [4], in most parts of the world, conventional film radiography has been replaced by digital imaging. Digital radiography eliminates chemical processing, thereby being environmentally acceptable. The digital intraoral receptors

also require less radiation than film, thus lowering patient's X-ray exposure. Comparison of canal length estimation between direct digital imaging and conventional radiography in curved canals resulted in canal lengths that were significantly different from the true canal length. This was thought to be inherently caused by the magnification error [2].

Working length determination with the electronic apex locator has become important and is advocated prior to confirmation by radiographic determination [5]. In absence of root resorption, *in vitro* studies have shown high level of accuracy ranging from 85 to 95% [5]-[11].

Cone-beam computed tomography (CBCT) captures images in 3D. It comes with software that provides a number of tools for image analysis. It enables us to view the images in axial, sagittal and coronal slices and make the necessary measurements. CBCT systems can be classified into two categories, limited or full [12]. The field of view (FOV) of limited CBCT ranges in diameter from 40-100mm which is suitable for endodontic applications [12]. These include diagnosis of endodontic pathosis, canal length and morphology, assessment of pathosis of non-endodontic origin, evaluation of root fractures, analysis of external and internal root resorption, invasive cervical resorption and presurgical planning [12]-[14].

A study was undertaken to ascertain the accurateness of CBCT in measuring the estimated preoperative working lengths (EPWL), endodontic working lengths (EWL) and file lengths. This is necessary as the CBCT machines is a recent development and can be placed in the dental operator, has quick scanning time and provides exact size of images of the teeth.

II. MATERIALS AND METHODS

A sample of 27 extracted maxillary first permanent molars with intact roots were selected. For intraoral imaging, Radiovisionography (RVG) imaging machine was employed (Carestream Health Inc, New York, USA). An index was then custom made for each tooth using impression compound (Hoffman Dental Manufaktur GmbH, Berlin, Germany) to obtain buccal and mesiobuccal impressions side by side. Another index was also made for each tooth to stand vertically (to be used during CBCT scanning). Each tooth that was mounted vertically on its compound index was placed into a container filled with water to simulate the soft tissue X-ray attenuation. Scanning of the teeth was performed employing the Kodak 9000 3D CBCT extraoral imaging system (Carestream Health, Inc.) at the Oral and Maxillofacial Imaging Division, Faculty of Dentistry, University of Malaya.

N. L. S. Ahmad is a Restorative Dental Specialist, Ministry of Health, Restorative Dental Specialist Unit, Seremban Dental Specialist Centre, 70100 Seremban, Negeri Sembilan, Malaysia (corresponding author, phone: 06-7629218; fax: 06-7620229; email: dr.lailasofia@moh.gov.my).

Y. L. Thong, P. Nambiar are with the Department of Restorative Dentistry, Faculty of Dentistry, Universiti of Malaya, 50603 Kuala Lumpur Federal Territory, Malaysia (e-mail: thongyl@um.edu.my, phrabha@um.edu.my).

This machine recorded the scanned volume at a field-of-view (FOV) size of 5×3.8 cm. Appropriate protocol (voxel size $76\mu\text{m}$ as recommended for endodontics) with a fixed Kv, Ma value and 14 Bits grey scale resolution according to the child parameter was used. The region of interest was selected as posterior maxillary region (Kodak 9000 3D User's guide, 2008) and the system file number recorded.

The occlusal table was then flattened by using a tapered fissure diamond instrument (Maillefer, Ballaigues, Switzerland) and a CBCT scan was again taken following the protocol described earlier. An access cavity was made on the occlusal surface and the remnant radicular pulp tissue was removed with barbed broach (Maillefer, Ballaigues, Switzerland). Only three canals (mesiobuccal, distobuccal and palatal) in each tooth were selected for preparation and working length determination. Patency was confirmed by instrumenting through the canal with a size 10 K-file (Maillefer, Ballaigues, Switzerland) until the file tip was visible through the foramen.

The root of each tooth was completely embedded in the alginate mixture placed in a plastic container, while the lip clip of the electronic apex locator (Raypex 5, VDW, Munich, Germany) was inserted into the alginate. The canals were then filled with 5.25% sodium hypochlorite solution. A size 10 K-file or any larger size that fitted snugly (for bigger canals) was connected to the other electrode of the Raypex 5 apex locator for electronic measurement. When the apex locator indicator reached the last green bar as recommended by the manufacturer, the rubber stop on the file was adjusted to the level of the prepared occlusal table. The location of the reference point on the occlusal table was marked using a fine tip black marker pen. The file then measured using a stainless steel ruler to the nearest 0.5 mm from the tip of the file to the lower border of the rubber stop and recorded into Microsoft Excel spreadsheet. Fine canals were enlarged with K-files (Maillefer, Ballaigues, Switzerland) up to size 15 for radiographic evaluation. Steps were repeated for all the canals in the same tooth.

All 27 samples were divided evenly (9 each) into three groups; a) overextended, b) underextended, c) non-modified. For the underextended group, the length of the electronically measured file was deducted by 1.0 mm and the file with modified measurement was placed into the respective canals. For the overextended group, the apex locator was used to confirm the overextended reading, i.e. when the apex locator indicator reached the final red bar, 0.5 mm increments were added to the original length, until the tip of the file was just beyond the apical foramen.

For the non-modified group, the file was placed to the indicated correct electronic working length. Each group was marked and labeled. A file that fitted closely at the assumed length was selected, measured using a metal ruler and placed back into the canal. The access cavity was filled with clear self-polymerizing resin (Satex, Metrodent Limited, Paddock, UK) to immobilize the files in the access cavity. The resin was then left to set completely before being mounted again on its respective compound index for imaging with RVG followed

by CBCT imaging.

A calibration tool, a size 20 K-file of 15.0 mm length was prepared by grinding one end of the file with a Transmetal bur (Maillefer, Ballaigues, Switzerland) until the desired length was reached. This length (15.0 mm) was confirmed with Absolute Digimax digital caliper (Mitutoyo, Tokyo, Japan).

The image sensor size 1 (Kodak RVG 6100, Carestream Health Inc, New York, USA) was first fixed to a flat surface using plasticine. A plastic cone was used to provide a consistent and reproducible alignment of the tooth, X-ray beam and image receptor. Preva DC, Progeny Dental Intraoral X-ray unit was used to deliver the X-ray beam.

A RVG image (mesiobuccal view) was taken of each tooth, together with the calibration tool, which was placed on the image sensor, beneath the compound index. The calibration tool and tooth sample were confirmed to be side by side to avoid superimposition and the image saved according to the previously described protocol.

The digital images were saved in Trophy Dicom format for evaluation. All the images were saved according to the sample number. The tooth was then scanned with Kodak 9000 3D CBCT unit (Carestream Health Inc, New York, USA) following the protocol described previously. The RVG images (mesiobuccal view) were viewed to (a) measured the file length and (b) determined the perceived ideal working length. Measurements were done at three different times (one week intervals) and the average recorded.

The images were then analyzed using the orthogonal slices. The images were magnified by 5x using the magnification tools. The measurement tool was selected followed by the multiple measurement icons. The cursor was brought to the measurement point and the mouse was clicked at a selected length while scrolling the image following the curvature of the files. Using the measurement tools, the chief investigator, a) measured the estimated preoperative working length, b) measured the file length, and c) determined the perceived ideal working length. Measurements were done at three different times (one week intervals) and the average recorded.

Methylene blue dye (Labchem Sdn. Bhd., Kuala Lumpur, Malaysia) was painted on the root apices and rinsed under running water after 1 minute. The tooth was dabbed dry. The shafts of the files were then cut using a wire cutter to facilitate positioning of the tooth on the viewing platform of the stereomicroscope later. Each root apex was viewed using the binocular dental loupes of 3.5x magnification (Medlite Dental, Ohio, USA) to locate the major foramen. The lateral surface of the root apex was then shaved longitudinally using a tapered tungsten carbide bur, using the stained apical foramen and stained canal as a guide. As the root canal became visible, the thin residual dentine layer was scraped using Hedstroem file size 15 (Maillefer, Ballaigues, Switzerland).

The tooth sample was placed on the viewer platform, adjusted and fixed in position with plasticine. Each canal was viewed with the SZX7 stereomicroscope (Olympus, Pennsylvania, USA) under 12.5x magnification. The image was captured using DigiAcquis TWAIN camera (Olympus, Pennsylvania, USA) connected to the stereomicroscope. The

conditions and points of measurements were observed and measurements were made accordingly.

The working length measurement point was taken as the most coronal part of the major foramen. Distance from file tip to the measurement point was measured using the cell D Life Science Documentation software (Olympus, Pennsylvania, USA). In case of apical delta, the canal most likely to be penetrated by the K-file was taken as the main canal.

From the study, Kappa score for categorical data was assessed and the value was 1.0, suggesting perfect agreement. Intra examiner reliability was assessed using coefficient of reliability. Data for all methods were then entered into Microsoft Excel 2007 spreadsheet. All measurements were done three times (one week intervals) and averaged. All measurements were rounded off to the nearest 0.5 mm. All data were recorded and entered into SPSS (statistical package for the social science) for Windows version 12.0. For all the statistical tests, the confidence level was set at 95% and the level of significance was set at $p < 0.05$.

III. RESULTS

A. Accuracy of the CBCT Estimated Pre-Operative Working Length Compared to the Control Working Length Observed under Direct Magnification

Paired t-test analysis showed significant difference between estimated pre-operative working length and control length observed under direct magnification, as illustrated in Table I. The mean CBCT estimated preoperative working length was shorter than control length.

B. Endodontic Working Length Using Small FOV CBCT, RVG and Electronic Methods Compared to Control Working Length

Each set of observations was repeated twice and the means were taken to calculate the difference between the individual method and control length (paired observations). The mean differences were then calculated and presented separately for each variable. The limits of agreement for each variable were then computed to assess the level of agreement between the paired observations. The results of paired differences were presented separately for each method. The differences between each method and the control were tabulated together to allow comparison.

The range and mean of these differences, the standard deviation (SD) and limits of agreement are presented in Table II. The upper limit of agreement represents underextended working length while the lower limit represents overextended working length.

Results from the differences in measurements of endodontic working length can be summarized as follows:

1. For the electronic method, on 95% of occasions, the differences (potential error) in the measurements from this method are between 1.04 mm underextended and 0.69 mm overextended. For the RVG method, corresponding differences are between 1.03 mm underextended and 0.87 overextended. For the CBCT method, the differences are between 1.30 mm underextended and 0.78 mm

overextended.

2. The range (from the minimum and maximum value) of the 95% limits of agreement is 2.24 mm for electronic, 2.61 mm for RVG and 2.84 mm for CBCT methods.

C. Endodontic File Lengths Using Small FOV CBCT and RVG Compared to Actual File Length

Each set of observations was repeated three times and the means were taken to calculate the difference between the individual method (RVG & CBCT) and actual file length (paired observations). The mean differences were then calculated and presented separately for each variable. The limits of agreement for each variable were then computed to assess the level of agreement between the paired observations. The results of paired differences were presented separately for each method. The differences between each method and the control were tabulated together to facilitate comparison.

TABLE I
PAIRED T-TEST ANALYSIS FOR ESTIMATED PRE-OPERATIVE WORKING LENGTH COMPARED TO THE CONTROL WORKING LENGTH

Variables	Control length Mean (SD)	CBCT estimated preoperative working length Mean (SD)	Mean diff. (95% CI)	t-statistic (df)	p value
Working length	17.49 (1.72)	17.17 (1.67)	0.32 (0.21, 0.43)	5.93 (80) ^a	0.000 ^a

^a Paired t test was used, level of significance was set at 0.05

The range and mean of these differences between each method and the control length, the standard deviation (SD) and limits of agreement are presented in Table III. The upper limit of agreement represents underextended working length while the lower limit represents overextended working length.

Results from the differences in measurements of endodontic file length can be summarized as follows:

1. For the RVG method, on 95% of occasions, the differences (potential error) in the measurements from RVG method are between 1.12 mm underextended and 0.92 mm overextended. For the CBCT method, corresponding differences are between 0.80 mm underextended and 0.47 mm overextended.
2. The range of the 95% limits of agreement is 3.50 mm for RVG and 2.00 mm for CBCT method.

D. Repeatability of Measurements

The coefficient of repeatability was used to determine the repeatability of the measurements (Table IV). In other words, it reflects the potential error in the measurements. To gauge the repeatability of the measurements for all variables in Objectives 2 and 3, the differences between two repeated sets of measurements were computed for each method. The coefficients of repeatability are all small (<0.5 mm). A small CR value indicates good repeatability and intra-operator error will have little influence in inferences made from the experimental results.

TABLE II
DIFFERENCES IN WORKING LENGTH DETERMINATION BETWEEN EACH METHOD AND THE CONTROL

	Min	Max	Range	Mean diff	SD	Limits of agreement (mm)	
	mm	mm	mm	mm	mm	Upper	Lower
Electronic	-0.690	1.550	2.240	0.171	0.432	1.035	-0.692
RVG	-1.000	1.610	2.610	0.078	0.474	1.026	-0.869
CBCT	-1.020	1.820	2.840	0.257	0.521	1.300	-0.785

n = 81, SD = Standard Deviation of the differences

TABLE III
DIFFERENCES IN FILE LENGTH MEASUREMENTS BETWEEN EACH METHOD AND THE ACTUAL LENGTH

	Min	Max	Range	Mean diff	SD	Limits of agreement (mm)	
	(mm)	(mm)	(mm)	(mm)	(mm)	Upper	Lower
RVG	-1.500	2.000	3.500	0.988	0.509	1.116	-0.919
CBCT	-0.500	1.500	2.000	0.167	0.316	0.799	-0.466

n = 81, SD = Standard Deviation of the differences

TABLE IV
COEFFICIENTS OF REPEATABILITY (DIFFERENCES BETWEEN TWO SETS OF MEASUREMENTS)

	Magnif (mm)	Electronic (mm)	CBCT (mm)	RVG (mm)
Mean	0.0370	0.0185	0.0000	-0.0062
SD	0.1317	0.1845	0.2236	0.0555
Coefficient of repeatability	0.2634	0.3690	0.4472	0.1110

Magnif = direct magnification method, Electronic = electronic method, CBCT = CBCT method, RVG = RVG method

IV. DISCUSSION

In endodontic working length determination, the present study showed that the electronic method had the smallest range in 95% limits of agreement and thus the most accurate of the three methods. With 77 of 81 scores within the 95% limits of agreement and only 4 discrepancies of 81 scores in all three methods, it could be concluded that all three methods are safe to be used in endodontic working length measurement. However, CBCT method would cause under instrumentation of up to 1.30 mm, and both RVG and CBCT methods would cause over instrumentation of up to approximately 1.0 mm.

This is related to the selection of measuring point as the most coronal part of the major foramen which in this study, coincides with the maximum point of the apical constriction. As [15] had reported, the mean distance between the major and minor apical diameters is 0.5mm in a young person and 0.67mm in an older individual because of the cementum build up in older individuals. This would suggest that a limit of approximately 0.70 mm beyond the apical constriction is still acceptable as it still would not be beyond the apical foramen. In the other extreme, if the acceptable apical limit is 1.0 to 2.0 mm short of the apical foramen to confine the instruments, irrigants and obturating materials to the canal space as suggested by [16] and patency filing is employed, all the three methods (electronic, RVG and CBCT) are clinically acceptable as they all had a maximum underextended reading at 1.0 mm, 1.0 mm and 1.3 mm respectively.

In measurement of file lengths, positive difference indicated shorter than actual file length, while negative difference

indicated longer than actual file length. The present study showed that CBCT method had the smaller limit of agreement in file length measurement differences from 0.79 mm to -0.46 mm (Table III). The RVG method showed higher upper and lower limit of agreement of 1.11 mm and -0.91 mm respectively. This would imply that measurements of endodontic files are more accurate with the CBCT method. Bigger window of 95% limits of agreement in RVG method (range: 3.5 mm) means it has greater potential of error. This would be expected as reported by Kim-Park and co-workers [17] that curvatures present in palatal canals for example, would appear shortened in the two-dimensional radiographic image. The difference is lower in the CBCT method as it is three dimensional, but presence of an almost acute curvature still poses difficulty in measurements. There were no other studies utilizing CBCT in measuring file lengths. The closest is the accuracy of known wire dimension using CBCT's three dimensional measuring tool in the study by [18] which was comparable to the accuracy reported by [19]. ([18]: mean 0.29mm, SD 0.20mm; [19]: mean 0.13mm, SD 0.09mm.) The results obtained from the present study cannot be directly compared with the others as they had used a different statistical analysis. However, all other studies showed that CBCT is excellent in linear and angular measurements [20], [21].

The results suggest that CBCT is a safe tool to be used in endodontics, although not to the extent of replacing the currently recommended methods of first using an electronic apex locator and later to confirm with a radiograph. This is because the difficulties encountered in conventional radiographic measurements are not present in CBCT images, although the operator's experience in making measurements may well affect the intra observer variability. A less experienced observer would have a greater variability in measurements.

The study design did not simulate the actual clinical situation, especially in the imaging of tooth samples using the RVG. All were imaged at a fixed position of the tooth on the compound index, whereas, in the clinical scenario, the tooth might be at a certain angulation which will definitely affect the measurements derived from it. This is not a problem with CBCT.

V. CONCLUSION

Underestimations of the preoperative working length by the small FOV CBCT is clinically insignificant. It is safe to be used in the estimation of endodontic preoperative working length. Small FOV CBCT may be used in working length determination however the currently practiced method of using the EAL proved to be more accurate. A preoperative estimation of endodontic working length can be done if there is an available preoperative CBCT of the tooth of interest. Taking an additional preoperative 2D radiograph is then unnecessary. CBCT can be used for EWL determination if there is a concurrent need for the imaging while performing root canal treatment but it is not to be used routinely or to replace the current recommended method. In measuring

lengths, CBCT is the more accurate method compared to RVG.

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