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THE ACCURACY OF CONE BEAM COMPUTED TOMOGRAPHY IN ASSESSMENT OF TOOTH AND ROOT LENGTH MEASUREMENTS: IN-VITRO STUDY

Omniya Abu El-Dahab * *and* Iman Dakhli *

ABSTRACT

Aim: Assessment of the accuracy of cone beam computed tomography in tooth and root length measurements.

Methods: 50 human extracted teeth were used in the current study. The 50 premolars were divided into two groups: Group (1) consisted from 25 double rooted maxillary first premolars while Group (2) comprised 25 single rooted mandibular first premolars. Teeth and roots lengths were measured for each group with a manual caliper and from CBCT images. Physical and CBCT measurements were taken twice by two observers and the average values were used to avoid interobserver errors to compare between the manual caliper and the CBCT measurements and then the accuracy of CBCT was assessed.

Results: Intraclass correlation between CBCT vs. Physical Measurements ranged from (-0.04 to -0.759) which indicates a complete disagreement between the physical measurements and CBCT measurements for all tested groups.

Conclusion: Dental measurements taken on digital models are not as accurate as those taken manually. There is always underestimation of CBCT measurements compared to physical measurements.

INTRODUCTION

CBCT has sailed us beyond the capabilities of other imaging modalities in depicting the required data. This new technology is superb because of its great performance, low cost, and reduced radiation dose compared with conventional computed tomography. During our journey in the third dimension, we could easily and accurately detect, delineate and measure the true 3-dimensional anatomy of patients. At the same time getting rid of these intrinsic weaknesses of 2-dimensional imaging (distortion, superimposition). These remarkable immense advantages have led to a clearer definition of clinical applications of CBCT in various dental specialties. However, as with every new development, CBCT data should be validated

* Lecturer of Oral and Maxillofacial Radiology, Faculty of Oral and Dental Medicine, Cairo University, Egypt.

for their accuracy. Although the need to ascertain CBCT accuracy is not controversial, its accuracy has not been satisfactorily verified[1-7].

Tomogram based morphological measurements are influenced by some factors including identification of bony landmarks and experience of the examiner. Despite the importance of these factors to identify and minimize the measurement errors, it is unachievable because these factors are not separable in real life conditions. Therefore, measurement errors remain the major source of uncertainties in various applications such as the diagnosis, planning, and evaluation of treatment. Moreover, because these morphological measurements may be taken by the same or different clinicians of different experiences, and at different stages in the management of one patient, it is also imperative to determine if the measurements used are reliable both within (intrarater) and between clinicians (interrater), and between sessions (intersession)[8].

Methodology

In this study, 60 human extracted teeth were collected and only 50 were used after exclusion of any tooth with crown or root fracture or carious damage. Individual tooth surfaces were hand scaled to remove any remaining soft tissue. All teeth were stored in distilled water at -20°C.

The 50 premolars were divided into two groups:

Group (1): 25 double rooted maxillary first premolars.

Group (2): 25 single rooted mandibular first premolars.

Physical measurements

For randomization, each tooth was given a number for coding. Measurements were taken twice in the vertical plane by two radiologists (from the most superior identified point whether it is buccal or palatal for double rooted teeth to the most inferior identified point whether it is buccal or palatal for double rooted teeth, maintaining a perpendicular plane to the horizontal axis) with a manual caliper (VERNIER CALIPER) (150MM×0.02MM/6 "×1/1000") (made in China) accurate to within 0.01 mm. The actual root and tooth lengths were derived from measurement averages and were used as the gold standard of this study.

For Group (1): double rooted maxillary first premolar: measurements were taken with a manual caliper in the vertical plane from tip of the buccal cusp to the apex of the longest root (either buccal or palatal root) maintaining a perpendicular plane to the horizontal axis on each measurement.

- The length of the buccal and lingual roots was measured with the caliper in the vertical plane from the CEJ to the apex of the buccal and lingual roots

For Group (2): single rooted mandibular first premolar: the tooth length was measured with the manual caliper starting from the tip of the buccal cusp to the apex of the root

- The length of the root was also measured with the caliper from the CEJ to the apex of the root
- Some anatomic variations of the sample teeth: Some of the roots have curvature at the apex, but we didn't consider it in the measurements.

CBCT measurements

CBCT images were taken at the 3D Diagnostix DENTAL IMAGING CENTERS using (i-CAT) **Image Sciences International Hatfield, Pa USA**, The cross-sectional images were obtained with the following specifications using dental mode at (120) kV, (5) mA,(4) seconds. Images were obtained by volume data of cone type with a field size of (46) mm. The cross-sectional images were evaluated. The teeth were inserted in a mold made of dental modeling pink wax in bucco-lingual direction and were coded with numbers during the imaging sessions corresponding to those used during physical measurements (DENTAX EL-KODS) (Made in A.R.E) to be scanned with CBCT.

The measurements were taken from the (cross-sectional views) using the implant screen as follows: The images were oriented for each tooth in the correct plane using the rotation option in the reconstructed panoramic view to mesial, distal, labial, and lingual cement enamel junctions, buccal cusp tip, palatal cusp tip, buccal root apex and palatal root apex as reference points. Root and tooth lengths were derived from these points and then compared with actual measurements of the teeth made with manual calipers.

The length of each tooth and root were measured using the same reference points used in the measurements with the manual caliper for each group.

The following linear distances were measured for each tooth from CBCT images: (1) Maxillary premolars: distance from the facial cusp tip to the root apex of the buccal root (2) Mandibular premolars: distance from the facial cusp tip to the only root apex of the tooth. (3)Root length was measured from the most apical point of the root (RA) perpendicular to the line defined by the most mesial and distal CEJ. Root length was defined as the perpendicular distance from the line connecting MCEJ (Mesial cement-enamel junction) and DCEJ(Distal cement-enamel junction) to the RA (fig. 1).

All measurements were taken twice by two observers and the average values were used to avoid interobserver errors to compare between the manual caliper and the CBCT measurements and then the accuracy of CBCT was assessed.

Statistical analysis

Systematic differences between the 2 observations were described with mean absolute differences and standard errors (SE). Intraclass correlation and method error statistic = $\sqrt{[\sum \text{differences}2/2n]}$ were used to quantify reliability between the 2 observations and between method of measurement for both tooth length and root-length measurements. The 2 observations were averaged for all the same method to be used for assessment of the difference between methods. Paired t-test used to compare between the CBCT and Physical measurements. Statistical significance was set at $P < 0.05$.

Statistical analysis was performed with IBM® SPSS® (SPSS Inc., IBM Corporation, NY, USA) Statistics Version 22 for Windows.

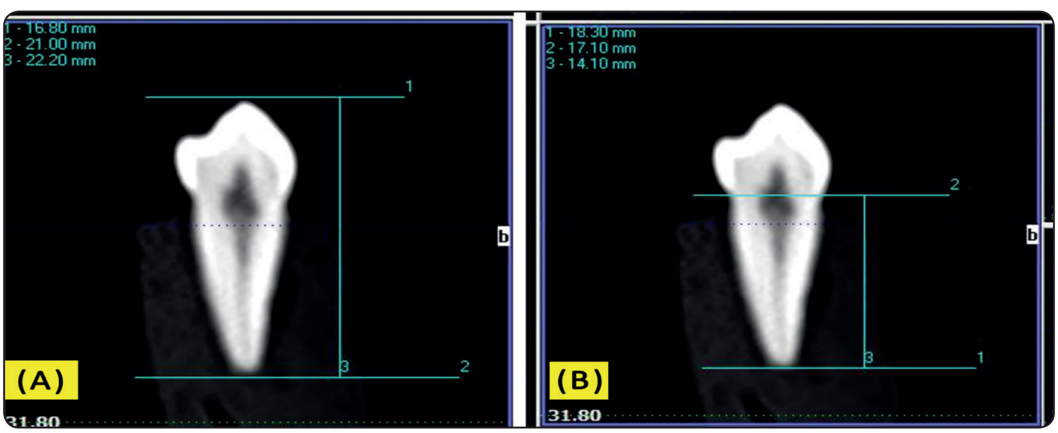

Fig (1): Cropped cross-sectional images of mandibular 1st premolar: a) the tooth length and b) the root length.

RESULTS

Method error between the 2 observers was greatest for the lower premolar tooth length (0.06 mm) for the CBCT while for the physical measurements the largest method error was in the upper premolar buccal root length (0.04 mm). The least method error between the observers was in the lower premolar root length for CBCT (0.01 mm) and upper premolar tooth length for physical measurements (0.01 mm).

Intraclass correlations for the CBCT measurements and physical measurements were high between replicates (Table 1) ranged from (0.926 to 0.974 for CBCT) and (0.945 to 0.998 for physical measurements) which indicates a high agreement between the two observers (Table. 1).

Between trials, the method error was greatest for the lower premolar tooth length (0.17 mm) followed by root length for lower premolar and tooth length for upper premolar (0.09 mm) with least method error for the upper premolar palatal root length (0.02 mm). Mean Difference between the CBCT and physical measurement ranged from (-0.17±0.53 mm to -1.23±0.49 mm) and it is only significant for tooth length for upper premolar (Table.2). These values indicate that the physical measurement was always higher in value compared to CBCT for all the tested measurements, so there was always underestimation of CBCT measurements compared to physical measurements.

Intraclass correlation between CBCT vs. Physical measurements ranged from (-0.04 to -0.759) which indicates a complete disagreement between the physical measurements and CBCT measurements for all tested groups(Table. 2).

TABLE (1): Systematic differences with standard errors (SE) and method errors (ME) and Intra class correlation (ICC) between the 2 observation for the physical and CBCT Measurements.

		CBCT				Physical Measurements			
		ICC	Mean Difference	SE	ME	ICC	Mean Difference	SE	ME
Upper Premolar	Tooth Length	0.974	0.35	0.13	0.05	0.998	0.04	0.03	0.01
	Buccal Root Length	0.956	0.31	0.17	0.04	0.949	0.27	0.15	0.04
	Palatal Root length	0.930	0.31	0.23	0.04	0.974	0.15	0.09	0.02
Lower Premolar	Tooth Length	0.956	0.40	0.14	0.06	0.998	0.04	0.03	0.01
	Root Length	0.926	0.08	0.17	0.01	0.945	0.24	0.11	0.03

TABLE (2): Systematic differences with standard errors (SE) and method errors (ME) and Intra-class correlation (ICC) between the physical and CBCT Measurements.

		CBCT VS. Physical Measurements				
		ICC	Mean Difference	SE	ME	P-value
Upper Premolar	Tooth Length	-0.119	-0.61	0.58	0.09	0.019*
	Buccal Root Length	-0.759	-0.36	0.61	0.05	0.093 NS
	Palatal Root length	-0.040	-0.17	0.53	0.02	0.301 NS
Lower Premolar	Tooth Length	-0.067	-1.23	0.49	0.17	0.561 NS
	Root Length	0.323	-0.63	0.36	0.09	0.756 NS

DISCUSSION

As technologies improve, dentists will continually have new tools to aid with diagnosis and treatment planning. As with any new method, accuracy must be assessed by comparison with a gold standard. In this study, manual caliper measurements on extracted teeth were used. One advantage of the present research is that we use a gold standard to compare the data obtained by the examiners, thereby achieving a more reliable comparison of the results. In the current study, to increase the sensitivity of the data, number of specimens was increased.

An alternative method used for simulation of soft-tissue attenuation is a water bath, but unfortunately, it may cause damage to the dry skulls and could influence measurement accuracy because of expansion of the bone due to absorption of water by the dry mandibles [(9-12)].

Many previous studies that had assessed the accuracy and reliability of measurements on CBCT images, their results declared that no statistically significant differences have been found between CBCT and gold standards (generally consisting of direct calliper measurements of dry skulls).The overall reliability of measurement and landmark identification on CBCT images has been reported to be good to very good by **Grauer et al 2009** and **Oz et al 2011**[(13,14)].

Up to this moment, CBCT has not been compared with periapical radiographs regarding its reliability and accuracy in assessing tooth and root lengths. CBCT also has shown good accuracy as PA (periapical) radiography in detecting bone defects and measuring periodontal bone levels and defects [(15,16)].

El and Palomo 2010[(17)] compared 3 commercially available DICOM viewers and showed high reliability and poor accuracy in airway volume calculations. Airway measurements made by different examiners might be less reliable, especially if these examiners were not calibrated in the same way. On the other hand, **Ghoneima and Kula 2013**[(18)] reported good accuracy and reliability for analysis of airway volume when comparing CBCT measurements and manual measurements of an airway model[(19)].

CBCT images can provide good resolution images in multiple planes eliminating superimposition of surrounding structures simultaneously. The unit of composition of any 2D image is pixel, while the unit of composition of a 3D CBCT image is voxel. Essentially, a voxel is a 3D pixel. Voxels should be isotropic, which means that 3D objects can be measured in 3 dimensions with relatively good accuracy. Multiplanar reconstructions provide us great capabilities for achieving our goals[(20)].

Our study demonstrated that the physical measurement was always higher in value compared to CBCT for all the tested measurements. Hence, there was always underestimation of CBCT measurements compared to physical measurements although the intraclass correlations for the CBCT measurements and physical measurements were high between replicates which indicate a high agreement between two observers.

Also **Lenza et al 2010**[(21)] compared the linear, area, and volumetric measurements by 2 examiners and found no significant differences which confirm our results. Against our results, **Timock et al 2011**[(2)] found that CBCT measurements did not differ significantly from direct measurements, and there was no pattern of underestimation or overestimation[(19)].

In agreement with our study, **Lascala et al 2004**[(22)] reported that real measurements were always found to be larger than those from the CBCT images, with statistically significant differences involving measurements of the skull base. The variability of results between similar studies can be explained by inconsistent CBCT scans, reconstruction algorism and the imaging software used in various machines.

Previous studies suggested that operator experience influenced measurement accuracy, whereas others showed that high reliability can be obtained without formal software training[1,23,24].

Hämmerle et al 1990[25] found that radiographic measurements overestimate advanced bone loss and underestimate superficial bone loss. Differences in the definition of the reference points for the radiographic measurements may account for these variations. The most coronally located parts of the AC (Alveolar crest) can be so thin that it may be difficult to be detected radiographically, leading to an overestimation of the CEJ-AC radiographic distance compared with the intrasurgical measurements [26].

Supporting our results **Eickholz et al 1998**[27] who found that different examiners did not influence the validity of computer-assisted radiographic measurements for both well trained and calibrated examiners [26]. The **Lin et al 2015**[8] results showed that both the intra and inter examiner reliability of mandibular measurements were very good for both the senior and junior examiners. Very good intersession reliability was also found for both examiners.

According to **Sherrard et al 2010**[15] the differences between the actual and CBCT measurements were small and not statistically significant. The mean differences for tooth length were between 0.13 and 0.09 mm of overestimation (for 0.2-mm and 0.4-mm voxel sizes, respectively).

Lascala et al 2004[22] also reported underestimated computer-based linear measurements than direct digital caliper measurements of dry skulls. He justifies this underestimation as CBCT measurements were done on axial, coronal, and sagittal cuts of the 3D image and not the3D surface renderings [11].

Lascala et al 2004[22] confirmed our results as they found that CBCT-derived measurements consistently underestimated direct measurements over large distances (30-100 mm), with differences ranging from 3.43 to 6.59 mm. **Baumgaertel et al 2009**[28] showed a similar trend for underestimating dental measurements such as mesiodistal tooth widths and overjets on dry skulls. **Berco et al 2009**[1] also found that distances between traditional cephalometric landmarks made on images of dry skulls had statistically significant mean measurement errors compared with direct measurements [2].

Timock et al 2011[2] studied the reliability and accuracy of buccal bone height and buccal bone thickness measurements made from CBCT images. Excellent interrater agreement for the direct measurement technique used creating a reliable standard from which to judge the CBCT measurements [2].

Leung et al 2010[29] reported that measurements on CBCT were less accurate than direct measurements on skulls. The differences in accuracy between the direct and CBCT methods were most likely due to limitations in spatial resolution of the CBCT images.

Gerlach et al 2014[30] indicated that the underestimation of the actual diameter during mandibular canal tracings, might increase the risk of iatrogenic damage. As a consequence, a personalized adjustable canal diameter is advised.

There are some weaknesses regarding our study.

1- It is an in-vitro study.

2- Only one dental CBCT system was studied. Thus, the results of this study may not be representative of results done by using other systems.

3- Personal variations during taking physical measurements

CONCLUSION

Dental measurements taken on digital models are not as accurate as those taken manually. There is always underestimation of CBCT measurements compared to physical measurements.

As there are numerous manufacturers of dental CBCT systems, further studies are needed to assess the accuracy of measurements taken using different CBCT systems.

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