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Assessment of Accuracy and Reliability of Linear Measurements of CBCT- An *in vitro* study

Research Article

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Abstract

Objectives: Cone Beam Computed Tomography (CBCT) is an innovative dental imaging system characterized by rapid volumetric imaging and allows us to obtain linear measurements in three dimensions using computer software. In order to optimize application of the technique in various fields it is necessary to analyse the accuracy of the data obtained on performing linear measurements. The present study intends to compare the linear measurements made on dry mandible with those made on CBCT images.

Method: The study consisted of 15 human dry mandibles. Sixteen linear measurements including 8 horizontal and 8 vertical, were made at different anatomical points of the dry mandible using Digital Vernier calliper. CBCT images were then obtained for the mandibles. The same linear measurements were done on the CBCT image using ONDEMAND 3D and Scanora softwares.

Results and Conclusion: Both the CBCT and the caliper measurements were highly reliable. The CBCT measurements tended to slightly underestimate the anatomic truth.

Keywords: Cone beam CT; Accuracy; Reliability; 3-D Imaging; Digital caliper

Introduction

Mah and Hatcher stated that- "If the aim is to improve the quality, efficiency and accessibility of craniofacial care, then there is a great need for accurate and effective imaging modalities" [1] . Thus, this study was undertaken to evaluate the accuracy of the linear measurements made on CBCT images.

Cone-beam Computed Tomography (CBCT) is a diagnostic tool that has revolutionized diagnosis and treatment planning in the dental field since 1995 [2]. Cone beam computed tomography is an image scanning and volumetric reconstruction technique that allows us to obtain linear measurements in three dimensions using computer software [3]. Though initially introduced in the field of dental implantology, CBCT has now made a place for itself in other fields like oral surgery, orthodontics, endodontics, periodontics, Temporomandibular Joint (TMJ) disorders, sleep apnea and in Ear, Nose and Throat (ENT) medicine [4,5]. Hence it becomes necessary to ascertain that the data obtained is accurate and reliable [6].

Materials and Method

The study group included 15 intact human dry mandible irrespective of age and gender. Five different anatomical points were chosen namely; Cd, Cr, Sc, Ma, Mf (Table 1). Based on these 5 anatomical landmarks, sixteen linear measurements (8 vertical and 8 horizontal) were made as depicted in Figures 1A-1C. The measurements were made on both sides of the jaw.

The digital caliper measurements were considered the "gold standard" to which all CBCT measurements were compared.

Table 1: Anatomical points used as references for linear measurements.

Anatomical Points	Description of Anatomical Points
Cd	Superior most part of condylion
Cr	Superior most part of Coronoid process
Sc	Lowermost point of the sigmoid concavity
Ma	Midpoint along the curvature of the mandibular angle or gonion
Mf	Mental foramen

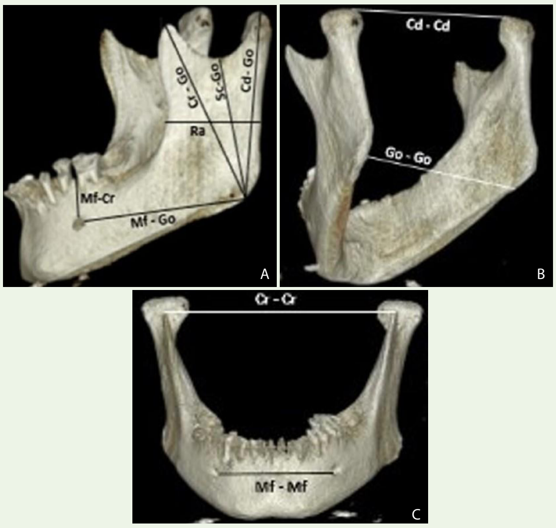

Figure 1: A: showing 2 horizontal and 4 vertical linear measurements over ramus and body of mandible. **B:** showing horizontal linear measurements between right and left condylion and right and left gonion. **C:** showing horizontal linear measurements between right and left coronoid process and right and left mental foramen.

Measurements on the dry mandibular skulls were made by using a high-precision digital caliper Digimatic (Mitutoyo Corp, Kawasaki, Japan) which is calibrated to the nearest 0.01 mm.

Each mandible was scanned with the Scanora 3D CBCT Unit (Soredex, Finland) with CMOS Flat panel detector. The exposure parameters for the CBCT were as follows:- Field of view of 75 mm x 145 mm with a voxel size of 0.25 mm, 75 kVp, 13 mA and exposure time of 15 seconds. The ONDEMAND software was used for image processing and analysis. Images were viewed and analysed on a 24" DELL Flatron monitor (DELL, Precision T79110 XL, United States) with screen resolution of 1920 x 1200 pixels and 64- bit colour depth. Measurements on the scans were made with the computer program ONDEMAND. In the setting Volume Operation, the function "Measure Length" was used to measure distances on the 3D volumes. After marking 2 points (voxels) on the object of interest, the computer calculated the shortest distance between these points. Data were entered into an Excel 2013 spreadsheet (Microsoft).

All caliper and CBCT measurements (millimeter) were separately recorded by two independent trained observers. Each observer measured the distances using both digital caliper and ONDEMAND software, with calculation of the average of the distances obtained by the two observers with both methods. Intraoperator reliability was estimated by using the intraclass correlation coefficient. Reproducibility of measurements was assessed by repeating 80% of the measurements after a 2-weeks interval to eliminate memory bias.

The accuracy of the computer-generated measurements was assessed by comparing these measurements with the anatomic truth. Preliminary data analysis showed normal distribution for both samples, and the paired Student t test was used to determine statistically significant difference between the 2 groups. The level of significance was set at $p<0.0025$. Intraclass correlation coefficients were used to determine how well the 2 methods were correlated. All calculations were made with Statistical Package for the Social Sciences (SPSS) software (version 22).

Results

Comparison of the linear measurements made with digital caliper and CBCT showed no significant differences for 95% of the distances analysed [$p>0.0025$]. The intraclass correlation coefficient ranged from 0.981-1.000 mm in the measures analyzed using CBCT and from 0.997-1.000 mm in the measures obtained with the digital caliper, reflecting high reliability between the two observers.

The average discrepancy between the linear distances obtained with both methods ranged from 0.2 to 0.7 mm. Observer 1 did not report statistically significant differences for any of the 16 distances analysed while Observer 2 reported a statistically significant discrepancy for one of the 16 linear distances (Table 2). However, both the observers noted that CBCT underestimated the actual measurements in 15 of the 16 distances.

Discussion

A linear measurement assigns a numerical value for the length of an object or between objects. Human craniofacial dimensions were first analysed by anthropologists and anatomists who were based on osteolytic landmarks. With the invention of the x-ray machine, measurements were made on 2-Dimensional (2-D) diagnostic image rendered from a 3-Dimensional (3-D) structure [7,8].

All conventional two-dimensional (2-D) imaging procedures suffer from inherent limitations such as magnification, distortion, and superimposition leading to the misrepresentation of anatomic structures [9]. For these reasons, 3-D digital imaging systems have almost superseded 2-D analog imaging. Computed Tomography and CBCT represents a paradigm shift from two-dimensional (2-D) to three-dimensional (3-D) data acquisition and visualization.

Identification of anatomical structures, landmarks and accuracy of linear measurements is found to be superior in CBCT when compared to 2-D imaging [10,11]. Several studies have been undertaken to calibrate and test the accuracy of the quantitative measurements of the CT images. In various studies the accuracy of CT scans were found to be 1%, 0.28% with a range of 0.1% - 3.0 [12-14]. Linear measurements made on human mandible by axial CT demonstrated the accuracy which was within acceptable limits (0.4-0.9 mm) [15]. Hence, there is enough evidence to suggest that CT provides diagnostically accurate images.

Last decade has seen a significant upsurge in the manufacture, utility and availability of CBCT. Low radiation dose, sub millimeter

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Table 2: Linear measurements obtained in the mandibles with digital caliper and CBCT (X A: CBCT underestimated measurements by Observer 1; X B: CBCT underestimated measurements by Observer 2). *$p<0.0025$ is statistically significant.

	Methods	Means	Mean Differences	*p*-Value
V1	Caliper	61.9± 6.23	0.3^{AB}	0.073
	CBCT	61.6±6.28		
V2	Caliper	61.8±5.83	0.3^{AB}	0.03
	CBCT	61.5±5.90		
V3	Caliper	47.1±4.67	0.6^{AB}	0.001*
	CBCT	46.5±5.06		
V4	Caliper	46.0±4.38	0.3^{AB}	0.004
	CBCT	45.7±4.48		
V5	Caliper	59.4±9.83	0.3^{AB}	0.002
	CBCT	59.1±9.73		
V6	Caliper	60.5±10.2	0.7^{AB}	0.003
	CBCT	59.8±9.72		
V7	Caliper	10.1±3.56	0.3^{AB}	0.005
	CBCT	9.8±3.64		
V8	Caliper	11.1±3.35	0.2^{AB}	0.002
	CBCT	10.9±3.38		
H1	Caliper	77.3±7.29	0.2^{AB}	0.027
	CBCT	77.1±7.44		
H2	Caliper	92.7±4.19	0.4^{AB}	0.02
	CBCT	92.3±4.22		
H3	Caliper	44.4±4.18	0.1^{AB}	0.7
	CBCT	44.3±4.16		
H4	Caliper	47.8±10.6	0.1^{AB}	0.1
	CBCT	47.7±10.6		
H5	Caliper	48.1±10.6	0.5^{AB}	0.002
	CBCT	47.6±10.4		
H6	Caliper	35.4±7.24	0.6^{AB}	0.02
	CBCT	34.8±7.76		
H7	Caliper	36.9±7.19	0.4^{AB}	0.04
	CBCT	36.5±7.42		
H8	Caliper	85.8±8.99	-0.2	0.2

spatial resolution, reduced scanning time and increasing access, have made CBCT a preferred imaging modality for the maxillofacial region. Hence, assessment of accuracy and reliability of CBCT images in terms of linear measurements gains significance.

Two hundred and forty linear measurements were made on human dry mandible, out of which 226 measurements [95%] showed no significant difference between digital caliper measurements and CBCT measurements. The observed minimum discrepancy of 5% being considered clinically acceptable. Average discrepancy demonstrated by our study was 0.2-0.7 mm which is similar to previous studies done by Brown et al. Waltrick et al. and Torres et al. with values 0.45 mm ± 0.17 mm, 0.23 mm ± 0.2 mm, 0.68 mm to 0.72 mm [16-18]. Studies done by Stratemann et al. Moreira et al. showed lesser average discrepancy than our study [19,20]. Kamburoglu et al. concluded that CBCT provides highly accurate data with less than 1% error when compared to physical measurements [21]. Most of the studies which compared CBCT to physical measurements found a tendency of CBCT to underestimate the anatomic truth [6,16-24]. Lascala et al. who showed that CBCT measurements for internal and external cranial anatomic sites tend to be slightly smaller than the same measurements made with caliper [5]. Underestimation was recorded on CBCT when synthetic mandible were used [22,23]. Hilgers et al. reported good accuracy and reliability of CBCT but Brown et al. concluded that 3-D CBCT data set using commercial analysis software have variable accuracy [16,24]. Baumgaertel et al. reported a systematic overestimation when analysis was performed [25].

Cone Beam Computed Tomography is known to produce 1:1 images as the magnification of these images are auto corrected [26]. The reasons for underestimation of linear measurements on CBCT images can be due to measurement software or partial volume effect [25]. The software defined the center of the volume from which to measure. In other words, the software might actually have measured the distance between the midpoints of the voxels. The caliper measures the distance between the contours of the skull, while the measurement software could have measured the distance between the centers of the mesial and distal voxel. For the field of view used in this study, the voxel size was 0.25 mm. If measurements were made from the center of the voxel, half of the voxel would not have been included in the measurement on either side (Figure 2). This would lead to CBCT measurements that are 0.25 mm smaller than caliper measurements. But all measurements were not necessarily 0.25 mm less in our study. Hence, this may not be the only reason for underestimation [27].

A different theory termed "partial volume effect" could also explain our findings. According to this theory, if a voxel lies completely within an object, it would reflect that object's density. However, if a voxel is at the junction of 2 objects of different densities-eg, bone and surrounding air-the voxel reflects an average value somewhere between the true values for bone and air (Figure 3) [27]. The ratio of bone to air in the voxel determines the voxel value. Such

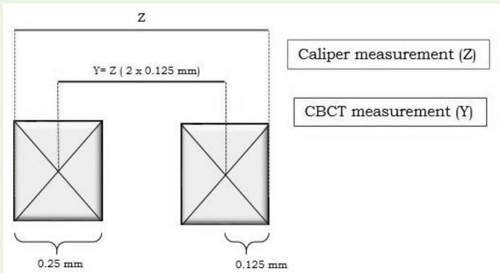

Figure 2: Description of theory explaining origin of measurement error (If measurements were made from the center of the voxel, half of the voxel would not have been included in the measurement on either side or would lead to CBCT measurements that are 0.25 mm smaller than caliper measurements).

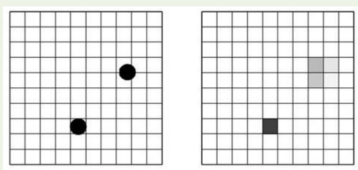

Figure 3: Description of theory explaining the Partial volume effect (If a voxel lies completely within an object, it would reflect that object's density. If a voxel is at the junction of 2 objects of different densities, the voxel reflects an average value).

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a "hybrid voxel" can be interpreted as part of the tooth or part of the surrounding air depending on the threshold value. High threshold values therefore create smaller than actual objects and vice versa.

The present study was designed to assess the reliability and accuracy of dental measurements made on CBCT images. Very few studies assessing the accuracy of CBCT measurements using dry skull have been documented in India. On reviewing the literature thoroughly, probably this is the first study made on Scanora 3D CBCT unit in comparing the linear measurements. One limitation of the present study is that no soft tissue or soft tissue equivalent was utilized so as to simulate a clinical situation. But using dry mandible could lead to better contrast in turn providing a higher level of accuracy.

Conclusion

The results of the study re-emphasize the fact that CBCT is an accurate and reliable measuring tool. Scanora 3D equipment like many other standard CBCT equipment also provides an accurate image. Hence CBCT images can therefore be used as an objective data that provides a near 1:1 accuracy of dimensional value.

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