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ORIGINAL RESEARCH

Assessment of the Accuracy of Linear Measurements on Human Mandible using Cone Beam Computed Tomography

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ABSTRACT

Aim: The aim of this study was to assess the accuracy of linear measurements on cone beam computed tomography (CBCT) images of human cadaveric mandibles and to establish its use in various diagnostics and dental treatment modalities.

Materials and methods: A prospective cohort study was carried out using four dried human mandibles that were obtained from the Department of Anatomy Topiwala National Medical College (TNMC) on which 10 different linear distances between defined anatomical points were identified and instrumented with K files (number 08) and then imaged using Kodak 9000 3DVT X-ray machine-CBCT mode. Electronic linear measurements of bone height were measured using Kodak viewing software. Physical measurements were done with digital calibrated calipers at the same location. The measurements were performed three times by three experienced observers and the mean of the measurements was taken as dimensional truth.

Results: Intraclass correlation obtained with respect to each mandible and for each method of evaluation (Vernier caliper and CBCT) by the three observers was found to be highly significant ($p < 0.001$) and amounted to 0.996 [95% confidence interval (CI)], making all the readings justifiable. On comparing measurements by CBCT with gold standard Vernier calipers, we found the p-value to be greater than that of 0.05, mean difference of Vernier Callipers (VC) and CBCT is -0.0283, indicating that the mean difference is not equal to zero, and thus the CBCT results are almost equal to VC.

Conclusion: The present study reveals that we are now able not only to provide more accurate diagnosis with this imaging modality, but also to guide and assess various surgical and clinical interventions.

Keywords: Cadavers, Cone beam computed tomography, Maxillofacial imaging.

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INTRODUCTION

In the past, dentomaxillofacial imaging has mainly been based on panoramic and intraoral radiography. It is difficult to visualize important anatomical structures due to the superimposing structures of the complex anatomy of the oral and maxillofacial region. While the information gleaned from a dental radiograph is substantial, there are limitations associated with the use of a two-dimensional (2D) image.[1] They include localization and size of a lesion in a buccolingual plane,[2] surface characteristics of the lesion (i.e., smooth *vs* rough),[3] and changes that appear over time when comparison of films to detect progression or healing is made.[3,4] Quality imaging is critical to localize the lesion and its proximity to important structures when there is a need for surgical access and this led to evolution of computed tomography (CT).

Since many years, medical CT has been the technique of choice for more demanding imaging tasks in the maxillofacial region. However, it places a high burden on the patient owing to high costs and radiation dosages.[5] This leads to the evolution of CBCT which allows three-dimensional (3D) visualization of the oral and maxillofacial complex at a much smaller radiation dose than that produced by conventional CT.[6] One of the major uses of CBCT is presurgical implant planning. Linear measurement is used often in presurgical implant planning for the determination of the exact amount of alveolar bone (height and width) and consequently, the size of the dental implants. Also linear measurements are used in orthodontic analysis and definition of jaw tumor size.

Although the previous studies have shown CBCT to be accurate, there is a need for diagnostic accuracy studies on CBCT where accepted methodological criteria for diagnostic thinking, efficacy, and therapeutic efficacy can be incorporated. Thus, the aim of this study was to assess the accuracy of linear measurements on CBCT images of human cadaveric mandibles, thereby establishing its use in various diagnosis and dental treatment modalities.

MATERIALS AND METHODS

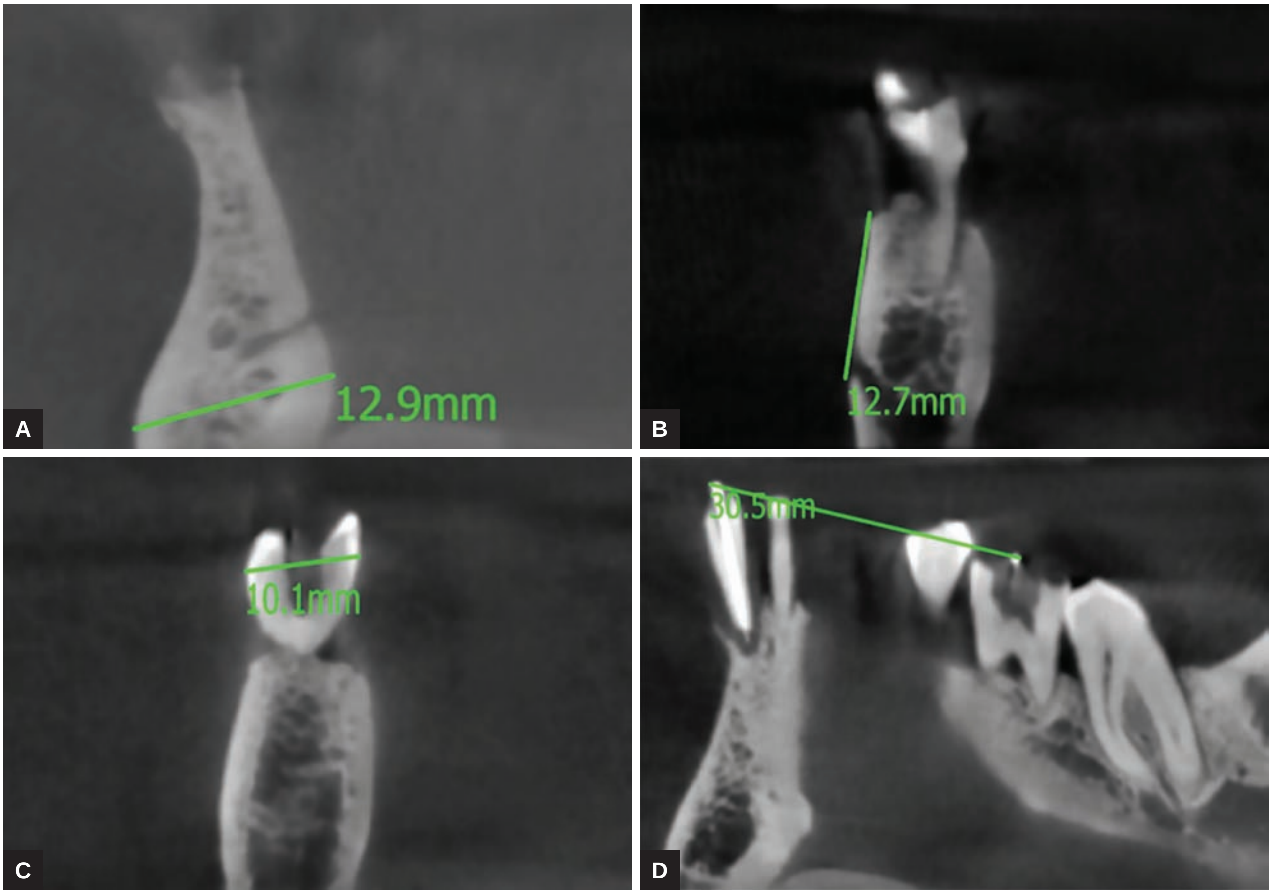
This *in vitro* study was carried over a period of 2 years (2011–2013). Four mandibles were obtained from the Department of Anatomy, TNMC. (on loan basis) belonging to four males and only dentulous mandibles were included in this study (inclusion criteria). Ten different linear distances between defined anatomical points were identified on a dried human mandible. Human mandible were instrumented with K files (number 8 files) in the distobuccal root canal of mandibular left second molar (tooth no. 37), root canal of mandibular right central incisor (tooth no. 41), alveolar socket of mandibular left canine (tooth no. 33), and mandibular right first premolar (tooth no. 44), horizontally in alveolar socket of mandibular left first premolar (tooth no. 34). The file handles were cut just above the crown level and the files were stabilized with composite resin to prevent any mobility. The mandible was mounted on an adjustable table and secured with silicone. The defined distances were measured manually with the digital calibrated calipers with a precision of 0.1 mm. The study comprised of two groups. Various linear measurements were taken

1. On the mandible
2. On the CBCT image of the same mandible

A total of more than 200 measurements were taken. The following distances were measured (Fig. 1).

- Length of K file inserted into the mandibular left second molar, i.e., tooth no. 37
- Alveolar depth of mandibular left canine, i.e., tooth no 33
- Distance between the top ends of the file from mandibular left second molar to mandibular right central incisor (37–41)
- Mesiodistal width of the crown of mandibular right first molar, i.e., tooth no 46
- Buccolingual width of the crown of mandibular right first molar, i.e., tooth no 46
- Alveolar mesiodistal width of mandibular left first premolar, i.e., tooth no 34
- Depth of alveolar bone referred to the mesial crest of mandibular right first premolar, i.e., tooth no 44
- Depth of alveolar bone referred to the distal crest of mandibular left canine, i.e., tooth no 33
- Lower margin of mental foramen to mesial crest of mandibular right second premolar, i.e., tooth no. 45 alveolar bone
- Width of the mandible at midline

Figs 1A to D: Measurements taken by Vernier caliper



Figs 2A to D: Measurements taken on CBCT images

The same mandibles were then imaged and measured using a Kodak 9000 3DVT X-ray machine (CBCT mode 120 kV, 7.0 mAs, and 6 mm aluminum filtration) (Fig. 2). The measurements were performed three times by each of the three observers (male:female = 2:1) with 1-week interval between each session and the mean of the measurements served as the dimensional truth. The sequence of measurements was randomly assigned between and within examiners, in order to minimize the potential bias of repeated measurements. A reliability analysis was performed between groups of measurements identified by the examiner and repeated measures by calculating the intraclass correlation coefficient (ICC) for the single measurement to reduce the inter- and intraobserver bias. The results were measured with the software provided by the manufacturer on a 19-inch monitor in native resolution (HP LE1911, 1280 × 1024 pixels; refresh rate 60 Hz; color depth-32 bit; 200 cdm22; 300:1 contrast; 25 minutes reaction time).

PROCEDURE

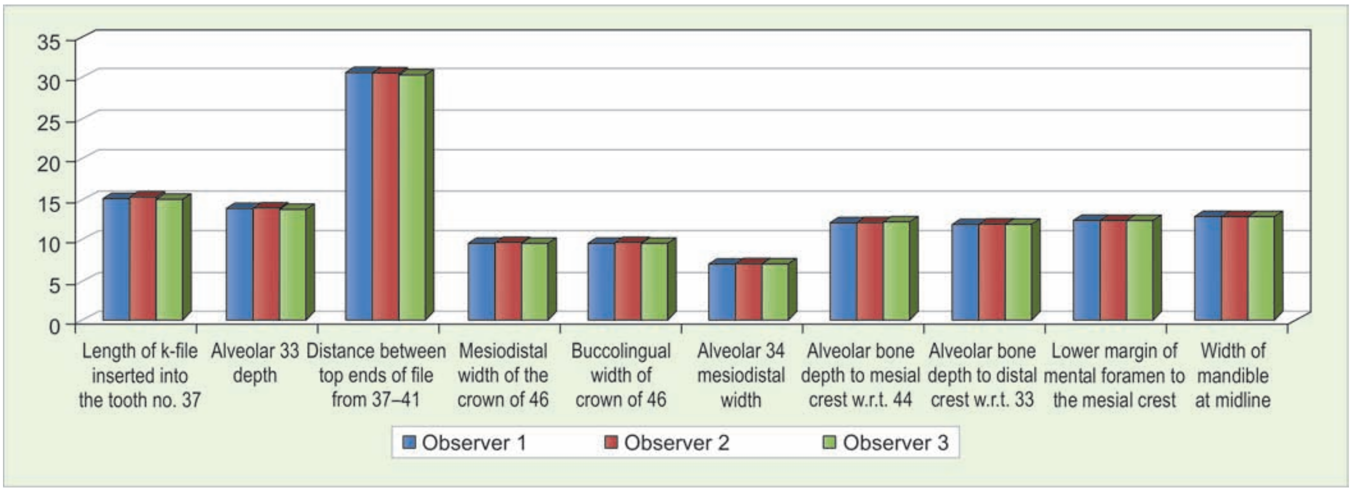
Procedures include the following steps:

- Collection of human mandible
- Preparation of the mandible for the radiograph
- Taking all due radiation protection precautions (lead aprons and thyroid collars), CBCT images were taken
- Linear measurements were taken first on the mandible itself with the help of digital calibrated calipers and then on CBCT images with the help of Kodak viewing software
- Three observers with minimum 5 years of clinical oral and maxillofacial radiology experience were appointed to measure the various linear measurements both on the mandible and its CBCT image. Reading of the images was done under ideal conditions
- The resulting data were used to compare the difference between various linear measurements taken by Vernier caliper and CBCT on mandible
- Student's t-test was used for statistical analysis between the two groups

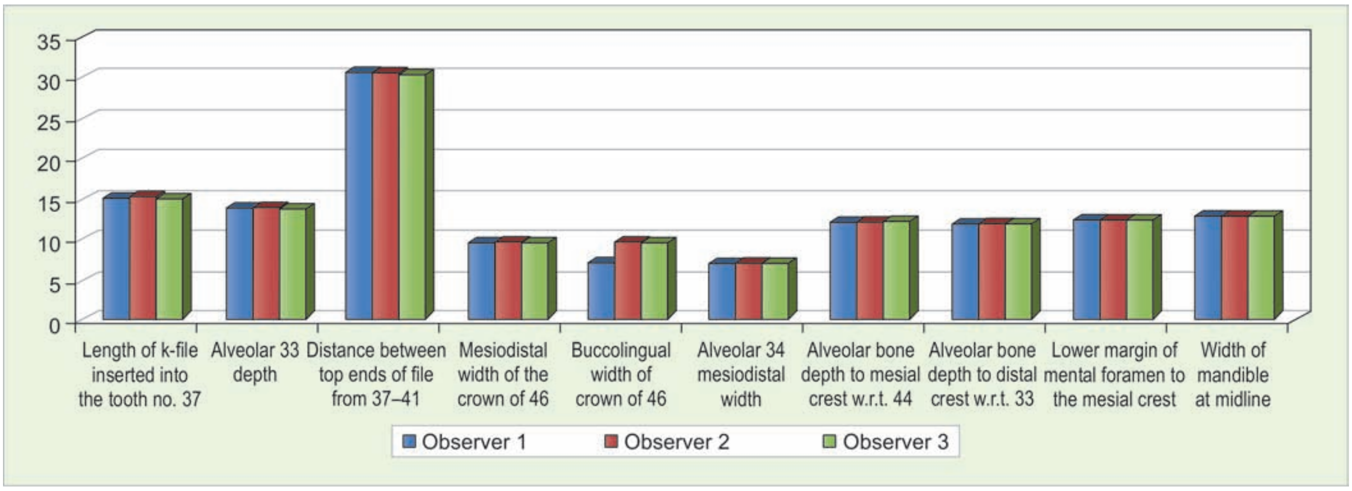
The results were recorded in the form of graphs and tables and subjected to statistical analysis using Statistical Package for the Social Sciences version 16 and were also verified by using Bland and Altman plot to check absolute agreement.

RESULTS

The measurements were performed three times by each observer and the mean of the measurements was taken as the dimensional truth (e.g., sample of mandible 1;



Graph 1: Linear measurement by Vernier caliper



Graph 2: Linear measurement taken by Kodak viewing software on CBCT

Table 1: Coefficient of variation for the observers

	VC			*CBCT*		
	Mean	*SD*	*CV (%)*	*Mean*	*SD*	*CV (%)*
Observer 1	14.04	6.34	45.16	14.00	6.43	45.93
Observer 2	14.02	6.31	45.01	14.08	6.40	45.45
Observer 3	14.04	6.31	44.94	14.11	6.37	45.15

The CV value for observer 3 is less than observer 2 and is less than observer 1 in case of Vernier caliper and CBCT as well. But no marked difference is seen between the coefficients of variation among the observers, making all the readings justifiable

Graphs 1 and 2). In total, 720 measurements were taken involving both the groups.

The consistency of observers was measured using coefficient of variation (CV). To find the consistency for the observer, data from all the mandibles were considered. We found that observer 3 was most consistent in his measurements while observer 1 was least consistent in his measurements. But, no marked difference was seen between the CV among the observers making all the readings justifiable (Table 1).

Intraclass correlation with respect to each mandible and for each method of evaluation (Vernier caliper and CBCT) was obtained to find the agreement between three different observers. The degree of correlation between the measurements recorded from different examiners as testified from the ICC was significant ($p < 0.001$) and amounted to 0.996 (95% CI 0.995–0.997).

For comparison of CBCT with gold standard, we calculated the difference of CBCT from VC (i.e., difference = VC-CBCT). We found p-value greater than 0.05, and the mean difference of VC and CBCT to be -0.0283.

Comparison of CBCT with VC

For comparison of CBCT with gold standard, we calculated the difference of CBCT from VC (i.e., difference = VC-CBCT). It was assumed that if CBCT behaves exactly like VC, then mean difference should be zero.

Null hypothesis: The mean difference of VC and CBCT was equal to zero, i.e., mean difference = 0.

Alternative hypothesis: The mean difference of VC and CBCT was not equal to zero, i.e., mean difference $\neq 0$.

Table 2: Overall mean, SD, and SEM

n	*Mean*	*SD*	*SEM*	*Mean ± 2SD*
120	−0.0283	0.32050	0.02926	(−0.35, 0.29)

SEM: Standard error of the mean

Interpretation

Since the p-value for t-test was greater than 0.05, the mean difference of VC and CBCT is −0.0283, which indicated that the mean difference was not equal to zero, i.e., mean difference ≠ 0. The value indicates that CBCT results were almost equal to VC.

Mean values and standard deviations (SDs) were calculated for descriptive purposes (Table 2). The absolute error (AbsErr) between measurements on the dried mandible, i.e., by Vernier caliper (D) and CBCT measurements (C) was calculated as:

$$\text{AbsErr} = | C - D |$$

The relative error (RelErr) was calculated by dividing the AbsErr by the mean measurement on the dried mandible and multiplying by 100:

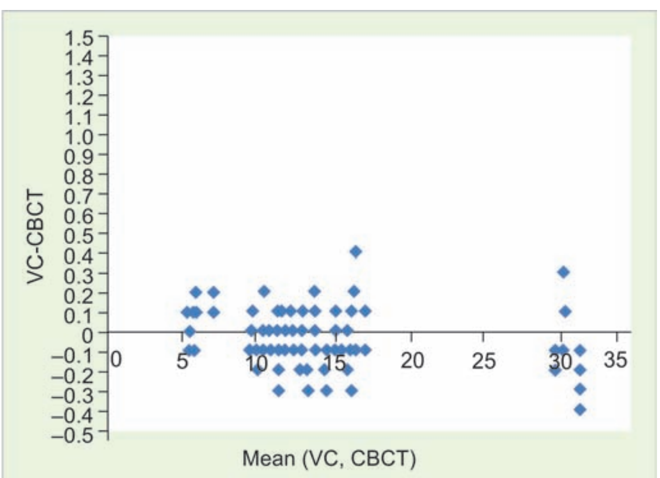
$$\text{RelErr} = \frac{(C - D)}{D \times 100}$$

where AbsErr came out to be 0.03 and RelErr to be 0.21.

The results were also verified by using Bland and Altman plot to check absolute agreement (Graph 3). The percentage of errors that exceeded 1 mm was 15%. The AbsErr ranged from 0 to 0.3%, while RelErr ranged from 1 to 30% according to the different segment.

DISCUSSION

In the current study, specimens selected were human cadaveric mandible in its original anatomic relationship. This is in contrast to previous studies which utilized foreign simulated objects like metal spheres, acrylic blocks, etc., for the evaluation of accuracy of linear



Graph 3: Bland–Altman plot

measurements. Except for Pinsky et al,[7] and Marmulla et al,[8] all previous studies used skull material and performed measurements between different anatomical structures or predefined measuring points. Pinsky et al[7] used a combination of a skull material and an acrylic block with small holes to investigate the accuracy of volume measurements based on linear measurements and using i-CAT unit (Imaging Sciences International, Hatfield, PA) with a voxel size of 0.2 mm and found a mean linear accuracy lower than 0.1 mm. Overall, their measurement differences were either smaller or within two voxels.

Our results ($p < 0.001$) showed that CBCT measurements in the craniofacial area were highly reproducible, which was in agreement with the results of Kamburoğlu et al,[9] who found the interobserver reliability to be 0.995 to 1 and intraobserver reliability to be 0.992 to 1, and also with that of Oz et al,[10] who also found high interobserver reliability of the CBCT measurements in the craniofacial area.

Our study showed that the real distances measured on dry mandible with the Vernier caliper were mostly larger than those obtained from the CBCT images. The error in the measurement varied from 0.03 ± 0.29 mm. This is in confirmation with the study of Lascala et al,[11] in which distances between 13 sites on human dry skull were measured using NewTom 9000 (Quantitative Radiology, Verona, Italy), and found statistically significant differences between CBCT and the real measurements of the skull base.

Fatemitabar and Nikgoo[12] evaluated the accuracy of CBCT (Planmeca) and found the mean differences vary from 0.37 to 0.58 mm for CBCT, and from 0.37 to 0.72 mm for a 64-channel CT (Siemens). Stratemann et al[13] also found high accuracy in the CBCT images for linear distances compared with the real measurements. The error was small for two evaluated CBCT systems varying from to 0.07 ± 0.41 mm for NewTom 9000 and 0.00 ± 0.22 mm for CB Hitachi MercuRay. The measurements in these studies were carried out between external points on the mandible. As the X-ray beam undergoes attenuation on passing through not only external soft tissue but also the soft tissue within the bone, there was a significant difference in measurements made from points within the bone.

In all dental specialties, use of linear measurements is a necessity for accurate treatment planning. When combining measurements of two modalities (CBCT and physical) together, no statistically significant differences were found between the first and second measurements ($p \leq 0.05$), between the first and third measurements ($p \leq 0.05$) and between the second and third measurements ($p \leq 0.05$). This indicates good agreement between the two methods. In addition, intraclass correlation was computed as a measure of intraobserver agreement between all the mandibles for both Vernier caliper and CBCT.

Since the p-value for t-test is 0.335, i.e., greater than that of 0.05, it indicates that the mean difference of VC and CBCT is not equal to zero. Plotting the mean difference of Vernier caliper and CBCT on Bland–Altman plot shows that almost 90% points were lying within the range of interval of agreement (mean ± 2SD), suggestive of good agreement between the two methods and indicates that CBCT results are almost equal to VC.

Due to a high image quality in terms of resolution and contrast that allowed the examiner to easily identify the various anatomical structures used as reference points for the measurements, the study showed that reliability of the measurements were not dependent on the experience of the operator.

A phenomenal and unprecedented interest in CBCT from all fields of dentistry is currently underway. The CBCT has facilitated the transition of dental diagnosis from 2D to 3D images and is expanding the role of imaging from diagnosis to image guidance of operative and surgical procedures. The present study indicated that not only we are able now to provide more accurate diagnosis with this imaging modality, but also we are able, based on the new radiographic data, to guide and assess various surgical and clinical interventions.

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