EGYPTIAN
DENTAL JOURNAL
www.eda-egypt.org

VOL. 69, 1015:1024, APRIL, 2023

PRINT ISSN 0070-9484 • ONLINE ISSN 2090-2360

ORAL MEDICINE, X-RAY, ORAL BIOLOGY AND ORAL PATHOLOGY

Submit Date : 06-12-2022 • Accept Date : 07-01-2023 • Available online: 01-04-2023 • DOI : 10.21608/edj.2023.179198.2369

COMPARISON BETWEEN TWO-DIMENSIONAL MULTIPLANAR SLICES AND THREE-DIMENSIONAL VOLUME RENDERING DERIVED FROM CONE BEAM COMPUTED TOMOGRAPHY IN ACCURACY OF LINEAR SKULL MEASUREMENTS

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ABSTRACT

Obtaining accurate linear measurements is of paramount importance in different dental fields, owing to their critical role in treatment planning and follow up of various procedures. The lack of accuracy of these measurements may lead to serious complications which might endanger the patient or adversely affect the treatment outcome. This leads the dental researchers to innovate new ways for ensuring the production of the highest possible precision levels in this domain. **AIM**: The aim of this study was to determine the accuracy of linear measurements obtained from two-dimensional multiplanar slices and three- dimensional volume rendering of cone beam computed tomography in comparison to direct skull measurements.

Materials and Methods: In the present study twelve dry human skulls were conducted. Ten linear measurements were obtained between certain identified landmarks on each skull using a digital caliper. The skulls were subjected to cone beam computed tomography examination. The measurements were obtained from two-dimensional multiplanar slices and three- dimensional volume rendering of cone beam computed tomography images, then compared to the real skull measurements and statistically assessed for accuracy

Results: In the present study from the ten linear measurements evaluated from CBCT only three measurements from two-dimensional multiplanar slices, while four measurements from three-dimensional volume rendering images showed significant difference in relation to the gold standard.

Conclusions: Linear measurements obtained from two-dimensional multiplanar slices and three-dimensional volume rendering CBCT are highly accurate and reliable and can be confidently used fordifferent maxillofacial clinical applications especially in orthodontics. CBCT linear measurements obtained from two-dimensional multiplanar slices images are relatively more accurate than those obtained from three- dimensional volume rendering images.

KEYWORDS: Linear measurements, Cone beam computed tomography, Orthodontics, Accuracy

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INTRODUCTION

Over the past century, craniometric measurements have been considered of great importance in the field of dentistry. Craniometric analysis involve taking measurements of the skull's dimensions, such as its maximum and lowest length or width or the distances between specific anatomical landmarks. These measurements have been used for several purposes in anthropology, forensicsciences, and neurosciences. In addition, different angular and linear craniometric measurements have been established to quantify growth changes.[1]

Craniometric measurements have been considered of great significance in different dental fields. In orthodontics and orthognathic surgery, obtaining precise measurements is a top priority since the treatment success in orthodontics is highly dependent in the clinician's ability to understand the link between dental structures, soft tissues, and bone which are the three critical components of the orthodontic therapy. [2,3]

To identify whether the malocclusion is caused by a skeletal relationship, a dental relationship, or both, the etiology of the malocclusion is assessed using precise measurements. In orthodontics, before any diagnosis or treatment planning certain accurate linear and angular measurements must be obtained, usually from **"cephalometry"**. [2,3]

However, cephalometric measurements have several drawbacks. As all traditional radiographic methods, cephalometric radiographs reduce a three-dimensional (3D) structure to a two-dimensional (2D) plane. The resulting superimposition of anatomical structures complicates image interpretation and landmark identification. In addition, image distortion and magnification may lead to reduced measurements' accuracy. In order to overcome the drawbacks of 2-D radiography, a shift towards three-dimensional imaging was essential. [4]

Over the last decade, the usage of Cone Beam Computed Tomography (CBCT) has tremendously escalated to overcome the drawbacks of 2D imaging techniques. Dental researchers have been thriving to innovate new methods for obtaining accurate radiographic linear and angular measurements, since the precision and reliability of linear measurements of the jaws is mandatory for planning of different procedures and obtaining successful treatment results. Therefore, it is of vital importance to realize the accuracy and reliability of different radiographic techniques. [5]

An accurate volumetric dataset for extra-oral radiography was made possible by the quick acquisition technology known as dental and maxillofacial cone beam computed tomography. [6,7] The raw data from CBCT acquisition and detection is a series of approximately 100 to more than 1000 individual 2D basis images which carryover a million pixels with 12- to 16-bits of data assigned to each pixel. This data is then processed to create a volumetric dataset composed of cuboidal volume elements (voxels) by sequence of software algorithms in a process called reconstruction.[8,9]

Moreover**,** CBCT software provides [10,11] Multiplanar Reformations (MPR) owing to the isotropic nature of image voxels, CBCT images can be sectioned non-orthogonally to give non axial 2D planar images referred to as multiplanar reformation modes (MPR). [11] and Volume rendering (VR) that refers to techniques which allow the visualization of volumetric data by construction of 3D surface model.[12]

CBCT possesses a number of advantages over medical CT in clinical practice that is why it has gained popularity in the field of dentistry in the last few years as it has rapid scan time, reduced radiation dose, image accuracy, Interactive display modes applicable to maxillofacial imaging and availability of the CBCT machine as its size is suitable for the dental office setting, moreover, CBCT machines are less expensive than CT units.[13]

To date, research has not conclusively validated whether Craniometric parameters taken from

2-D and 3-D data sources are equivalent and interchangeable. There is still need for studying and comparing the reliability and reproducibility of 2D and 3D modalities in linear cephalometric measurement. Hence, the focus of the present study was to assess the reliability of linear measurement obtained from 2-D multiplanar slices and 3-D volume rendering of CBCT in comparison to direct skull measurements (gold standard).

MATERIALS AND METHODS

I) Study settings:

According to sample size calculation twelve skulls were found to be sufficient to be used in this study using G*Power software version 3.1.9.2. detect a power of 80% at a significant level of 5% ($p<0.05$) [14]The dry human skulls with mandibles that were collected from the Department of Anatomy, Faculty of Medicine, Suez Canal University. The study was performed in the Oral Radiology Department, Faculty of Dentistry, Suez Canal University after being waved from the approval of our research ethical committee number (589/2022), since it was conducted on unidentified twelve human dry skulls.

Inclusion criteria:

The skulls with mandibles used in the present study were chosen to fulfill the following requirements: absence of fracture and pathological lesions at the examined areas and absence of metallic restorations (e.g., amalgam filling, implant).

II) Study design:

The principal investigator randomly assigned numbers 1 through 12 to the skulls. Fifteen anatomical landmarks were identified on each dry skull and used for obtaining linear measurements. (Table 1)

TABLE (1) Anatomical landmarks used for linear measurements: [15]

Landmark name andabbreviations	Definition
Midline landmarks	
Nasion (N)	The most anterior point of the nasofrontal sutureon the midsagittal plane (MSP).
Anterior Nasal Spine (ANS)	The anterior tip of the sharp bony process of themaxilla at the lower margin of the anterior nasal opening.
Menton (Me)	The most inferior point of the mandibularsymphysis on the MSP.
Bilateral landmarks	
Jugal (JR-JL)	The most superior aspect of the concavity of themaxillary bone as it joins the zygomatic process. (Right and left)
Gonion (GoR-GoL)	A point on the curvature of the angle of the mandible located by bisecting the angle formed by lines tangent to the posterior ramus and the inferior border of the mandible. (Right and left)
Zygion (ZYR-ZYL)	The most lateral point of the zygomatic arch.(Right and left)
Lateral Orbital (LOR-LOL)	The most lateral point on the orbital margin.(Right and left)
Medial Orbital (MOR-MOL)	The most medial point on the orbital margin.(Right and left)
Antegonion (AGR-AGL)	The antoganial notch at the lateral inferiormargin of the antegonial protuberances. (Right and left)

Sample preparation:

The exact positions of the landmarks were marked on the dry skulls using a blue permanent marker, then, a radiographic radiopaque marker (gutta-percha size 80) was fixed at each landmark for standardization of direct measurements and radiographic identification. The gutta-percha cones were cut into pieces of about 1-1.5 mm in length from the cone tip and subsequently bonded to the chosen landmarks. Fig(1A&B)

Linear measurements:

Ten linear measurements were taken between the identified landmarks on each skull. Table (2)

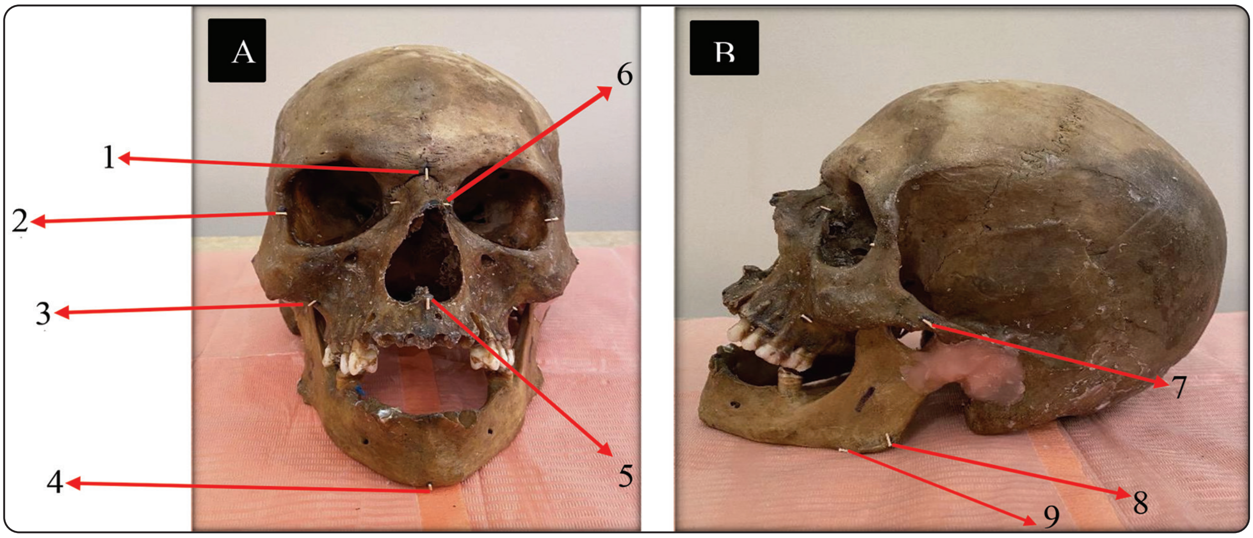

Fig. (1) **(A)** A photograph demonstrating the frontal aspect of the skull with the radiopaque markers fixed at each landmark. 1.Nasion (N) 2. Lateral Orbitale (LO) 3. Jugal (J) 4.Menton (Me) 5. Anterior Nasal Spine (ANS) 6. Medial Orbitale (MO) **(B)** A photograph demonstrating the lateral aspect of the skull with the radiopaquemarkers fixed at each landmark: 7. Zygion (ZY) 8. Gonio(GO) 9. Antegonion (AG)

TABLE (2) Linear measurements assessed in the present study: [15-17]

Measurements	**Definition**
Horizontal measurements	
Inter-orbital width(MOR-MOL)	Distance between the right and left medialorbitales (MO).
Bi-orbital width(LOR- LOL)	Distance between the right and left lateralorbitales (LO).
Width of each orbit(LO-MO) (2 measurements R and L)	Distance between LO and MO on each orbit.
Mandibular width(GOR-GOL)	Distance between the right and left gonion(GO)
Maxillary width (JR-JL)	Distance between right jugal point and leftjugal point.
Facial Breadth(ZYR-ZYL)	Distance between the most lateral point on the zygomatic arch (ZY) on both right and left sides.
Vertical measurements	
N- Me	Distance between nasion and menton.
Nasal height (N- ANS)	Distance between the nasion and anterior nasalspine.
ANS- Me	Distance between anterior nasal spine andmenton.

III) Direct measurements (Gold standard):

1- Linear measurements:

The actual linear measurements between the gutta-percha markers were taken directly on the dry skulls using a precise sliding electronic digital caliper with a measurement range of 0-150 mm and 0.01 mm resolution accuracy. To ensure standardization, the measurements were taken from the outer end of the gutta-percha of one point to the outer end of the gutta-percha of the other point. All parameters were assessed separately at two different sessions by the principle and the second investigators at two weeks interval for assessment of intra-observer and inter-observer reliability.

IV- Soft tissue simulation :

To simulate soft tissue of the patients, ten layers of pink modeling wax covered the skulls providing an average thickness of about 13-17 mm according to Schropp et al. [18] recommendations.

V- Radiographic Evaluation:

The twelve dry skulls were radiographed using Scanora 3Dx Cone Beam Computed Tomography scanner (Scanora 3DX, Soredex, Finland). The images were used for obtaining linear measurements for analysis and comparison with the gold standard. The field of view was set at 240x165mm for all images using standard resolution mode. The operating parameters were 90 KVp, 10mA and the effective exposure time was 3.2 seconds. The voxel size was 0.5 mm using a flat panel detector. The projection data was reconstructed with the machine dedicated OnDemand 3D (Cybermed.Co., Seoul, Korea) software application.

Linear measurements from the CBCT scans:

All measurements were assessed twice by the principle and second investigators at two-weeks interval. The two investigators were blinded from the results of gold standard and the results of each other. The linear measurements were assessed from both, 3D volume rendering images and 2D MPR orthogonal images.

1. **Measurements from 3D volume rendering images (3D VR):** 3D volume rendering represents a virtual model of the skull. The images were rebuilt by "On Demand 3D" software. The intended measurements were obtained by the distance tool mounted on the software. Fig.2A

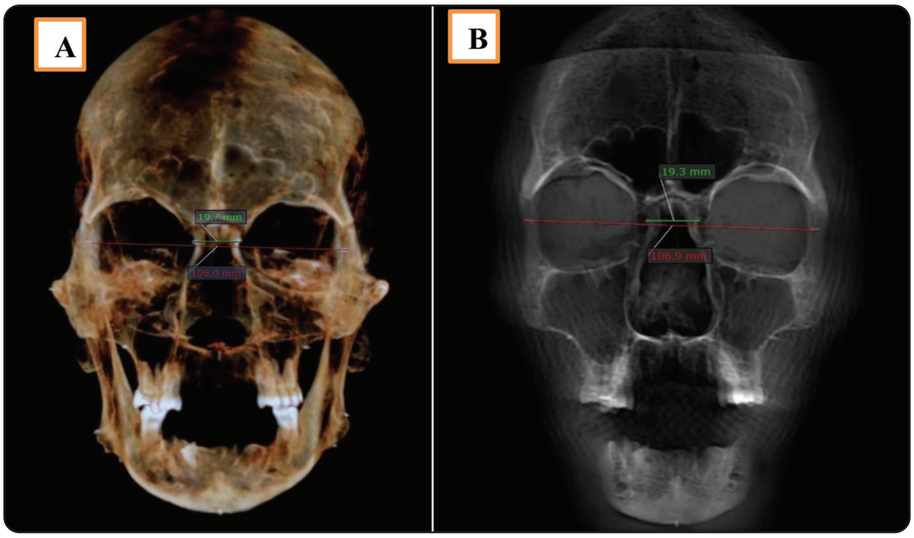

Fig. (2) A) Radiograph from the 3DVR showing Linear measurements of the bi-orbital width (LOR- LOL) (red line) and the inter-orbital width (MOR-MOL) (green line) from the facial skull view B) Radiograph from MPR showing Linear measurements of inter-orbital width (MOR-MOL) (green line) and bi- orbital width (LOR- LOL) (red line) from the coronal plane.

2. **Measurements from 2D orthogonal images:**

- The 2D orthogonal images were obtained using "On Demand 3D" software. The slice thickness was adjusted by both observers to be 30 mm which is the maximum thickness that provided best visualization of the end of the gutta-percha points. The inter-slice distance was adjusted by both observers to be 0.3 mm. The cuts of the orthogonal images were scrolled until the gutta percha points were clearly identifiable. Fig 2B

Statistical analysis

Measurements obtained directly from the skulls (gold standard) and CBCT images (2D MPR and 3D VR) were gathered, examined, and arranged in tables and figures utilizing Microsoft Excel 2016. The collected data was checked for outliers, then, was analyzed and described statistically using SPSS for Mac OS version 26.0

Intra and inter-observer agreement were assessed using Cronbach's alpha and Interclass correlation (ICC) for the assessed measurements to establish the scale's internal consistency.

Differences between measurements obtained from CBCT (2D MPR and 3D VR) in comparison to gold standard were assessed to determine accuracy of linear measurements using one way analysis of variance **(ANOVA)** at significance levels of 0.05 and 0.01. Repeated measures ANOVA was followed by Tukey's/ Duncan's multiple range tests **(DMRTs).**

RESULTS

Linear measurements: Reliability analysis: There was high intra-observer agreement regarding all linear measurements with Cronbach's alpha and ICC values ranging from (0.950 – 1.00) for CBCT-2D MPR measurements and (0.999 – 1.00) for CBCT-3D VR measurements. While there was high inter-observer agreement (between observer 1 and 2) regarding all linear measurements with Cronbach's alpha ranging from (0.904 – 1.00) for CBCT-2D MPR and (0.808 – 1.00) for CBCT-3D VR.

Upon comparing between gold standard and CBCT-2D MPR CBCT 2D MPR showed under estimated values in relation to gold standard regarding all linear measurements except for (N-Me) measurement which showed an over estimated value over the goldstandard by (0.08 mm, 0.06%).

There was no statistical significant difference ($p>0.05$) between GS and CBCT 2D MPR measurements regarding all assessed linear measurements except for the following Table (3):

- Width of the right orbit (LOR-MOR), which was statistically significant with(-0.83 mm, -1.93 %) difference.
- Width of the left orbit (LOL-MOL), which was statistically significant with (-1.33mm, -3.11 %) difference.
- ANS-Me measurement, which was statistically significant with (-0.48 mm, -0.74 %)difference.

Upon comparing between gold standard and CBCT 3D VR: CBCT 3D VR showed under estimated values in relation to gold standard regarding all linear measurements except for the nasal height (N-ANS) measurement which showed an over estimated value over the gold standard by (0.1 mm, 0.17 %).

There was a statistical non-significant difference between GS and CBCT 3D VR measurements was ($p > 0.05$) regarding all assessed linear measurements except for the following Table (3):

- Width of the right orbit (LOR-MOR), which was statistically significant with (-0.86mm, -2.01%) difference.
- Width of the left orbit (LOL-MOL), which was statistically significant with (-1.29 mm, -3%) difference.
- N-Me measurement, which was statistically significant with (-0.34 mm, -0.29 %) difference.
- ANS-Me measurement, which was statistically significant with (-0.42 mm, -0.64 %) difference.

TABLE (3) Comparison and correlation between CBCT-2D MPR, and CBCT-3D VR linear measurements in relation to the gold standard.

Linear measurements	Gold standard			CBCT-2D MPR				CBCT-3D VR				ANOVA Sign.
	Mean		SD	Mean		Difference mm	Difference %	Mean		Difference Mm	Difference %	
MOR-MOL	21.9	**a**	1.5	21.7	**a**	-0.15	-0.71	21.7	**a**	-0.19	-0.87	>0.05 ns
LOR-LOL	100.5	**a**	4.7	100.3	**a**	-0.28	-0.27	100.1	**a**	-0.39	-0.39	>0.05 ns
LOR-MOR	43.0	**a**	3.4	42.2	**b**	-0.83	-1.93	42.2	**b**	-0.86	-2.01	<0.001***
LOL-MOL	42.8	**a**	2.8	41.5	**b**	-1.33	-3.11	41.6	**b**	-1.29	-3.00	<0.001***
JUR-JUL	69.0	**a**	4.3	68.8	**a**	-0.19	-0.28	68.8	**a**	-0.21	-0.31	>0.05 ns
ZYR-ZYL	125.3	**a**	7.1	125.1	**a**	-0.20	-0.16	125.2	**a**	-0.13	-0.10	>0.05 ns
GOR-GOL	94.9	**a**	5.8	94.7	**a**	-0.19	-0.20	94.5	**a**	-0.32	-0.34	>0.05 ns
N-Me	117.5	**a**	9.2	117.5	**a**	0.08	0.06	117.1	**b**	-0.34	-0.29	<0.001***
N-ANS	56.8	**a**	2.7	56.5	**a**	-0.28	-0.50	56.9	**a**	0.10	0.17	>0.05 ns
ANS-ME	65.4		7.5	65.0		-0.48	-0.74	65.0		-0.42	-0.64	<0.001***

*,**,***; Significant at p<0.05, <0.01, <0.001; NS, non-significant at p>0.05

[a,b] Means with different letters horizontally denote significant difference according to DMRT

DISCUSSION

Due to the limitations of 2D imaging methods, CBCT has evolved because 3D technology offers a more accurate image of the patient's head. Orthodontists all across the world are using CBCT more and more frequently. The leap from 2D to 3D analysis has allowed for more comprehensive evaluation before, during, and after orthodontic therapy.[5]

The current research was designed as in-vitro study, to reduce the radiation risk to human population. It was conducted on dry human skulls based on ethical concerns. (**Pittayapat et al. 2015).**[19] Twelve skulls were found to be sufficient in this study, they were selected based on specific criteria.

Intact skulls free from fractures or pathologies were selected to avoid any factor that could affect the accuracy of landmark identification or produce abnormal appearance in the radiographic images. In addition, skulls with any metallic restorations were excluded to avoid metallic artifact production and scattering that could adversely affect the accuracy of measurement procedure.

The assessed measurements were chosen based on their high clinical relevance in orthodontics and orthognathic applications. Gutta-percha cones were used as radiopaque markers to demarcate the selected anatomical landmarks. Using a radiopaque marker ensured reproducibility and standardization by prohibiting subjective errors in landmark identification.

In the present study, CBCT measurements were obtained from both 3D VR images as well as from 2D MPR ones. The 3D VR images are commonly used by orthodontists and orthognathic surgeons in various purposes such as cephalometric analysis, cleft palate, impacted or ectopic teeth, assessment of maxillary sinus and orthognathic surgery treatment planning as reported by **Aksoy et al. 2016** [20] and **Jodeh et al. 2019** [21]. On the other hand, 2D

MPR images are frequently used in other aspects as in oral surgery and implantology as reported by **Sammartino et al. 2016** [22] and **Fokas et al. 2018.**[23]

In accordance to our results, a study by **Fernandes et al. 2014** [24] was conducted to determine the accuracy of and reliability of linear measurements obtained from CBCT 2D MPR images compared to those obtained from CBCT 3D VR ones. Ten distances were assessed on each of 10 dry adult human mandibles. In agreement with our study, they found that linear measurements obtained from CBCT 3DVR showed greater difference compared with linear measurements obtained from CBCT 2D MPR in relationto the gold standard. Consequently, they concluded that CBCT 2D MPR images are more reliable and accurate for clinical diagnosis and treatment planning, while those obtained from CBCT 3D VR were reliable but less accurate.

In addition, **da Neiva et al. 2014** [25] evaluated the reliability of 3D landmark identification in both CBCT 2D MPR and CBCT 3D VR. They found that the frequency of highly reliable values was greater for multiplanar images than the 3D reconstructions ones, which was in the same line with our results.

Nevertheless, few studies disagreed with the present results, such as the study conducted by **Hassan et al. 2008** [26] to assess the accuracy of craniometric measurements obtained from CBCT 3D VR in comparison with 2D MPR slices for cephalometric analysis. They defined 10 linear measurements on 8 cadaver heads. Their results showed that all CBCT measurements derived from both imaging types were significantly different from the gold standard measurements. In contrast to our findings, their results demonstrated that CBCT 2D MPR measurements were slightly less accurate than CBCT 3D VR ones in comparison with the gold standard measurements.

A more recent study was conducted by **Barreto et al. 2020** [27] to assess the accuracy of cephalometric measurements obtained from lateral cephalometry, CBCT 2D MPR and CBCT 3D VR. They found that the parameters obtained from lateral cephalograms were significantly different than those obtained from the skull (gold standard), while measurements obtained from CBCT were accurate and showed non statistically significant difference in relation to the gold standard. Although their results were in accordance with ours, however, in partial disagreement, they found that in spite of the non-significant difference between the CBCT assessment methods, the mean error of CBCT 2D MPR was slightly higher than that of CBCT 3D VR, accordingly, they concluded that 3D VR images were more accurate in treatment planning.

The discrepancy between the results of the present study and those of otherstudies may be attributed to several factors, the most important of which couldbe that several authors did not use radiopaque markers for identification of the anatomical landmarks, which may have added a factor contributing to inaccurate standardization and reproducibility of the measurements obtained.In addition, using different scanning protocols, different linear distances assessed and using different softwares are other factors concluded by **Ghorbanizadeh et al. 2016**[28] that can affect the accuracy of the measurements obtained from CBCT.

CONCLUSIONS

1. Linear measurements obtained from CBCT (2D MPR and 3D VR) are highly accurate and reliable and can be confidently used for different maxillofacial clinical applications especially in orthodontics.
2. CBCT linear measurements obtained from 2D MPR images are relatively more accurate than those obtained from 3D VR images.

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