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Can 3D cone beam computed tomographic measurements replacing their real counterpart: A comparative study

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Abstract
Aim: To verify whether the measurements obtained from three-dimensional cone beam computed tomographic (CBCT) imaging could replace those obtained from their real counterpart.
Methodology: Fifteen human dry mandibles were enrolled in the current study. Multiplanar reformatting 2dimentional(2D) and generated 3dimentional(3D) images were used to perform the linear measurements between the markers then 2D and 3D measurements were compared with the physical measurements taken with an electronic digital caliper.
Results: 2dimentional measurements had the least error which is highly significantly lower than 3dimentional measurements. **Conclusion:** Linear measurements taken on multiplanar 2dimentional CBCT images are reliable and accurate for clinical diagnosis and treatment planning. Linear measurements on 3dimentional rendering images are reliable but with less accuracy than the 2 dimentional images.

Keywords: 2D, 3D images, CBCT, linear measurements

Introduction
Cone beam computed tomography (CBCT) is an ongoing continually growing three-dimensional (3D) craniofacial imaging platform, has been proved to be an accurate and reliable tool since its evolution in the field of dentistry. Not only by its availability, affordability and dose saving but also by the magical manipulative tools provided either by built-in machine software or outsider programming, e.g. linear measurements, volumetric measurements and rotation, makes it the foundation for diagnosis and treatment planning in all the specialties of oral and maxillofacial region. As a result, CBCT can offer the practioners with the most convenient accident free preoperative planning guaranteeing the best clinical outcomes and patient safety [1, 2]. 3D generated CBCT images is deeming virtual simulation of the skull, which is more resembling and closer to reality than 2D generated CBCT images especially during preoperative and intraoperative planning of skeletal deformities and assessment of growth and treatment effects in orthodontics, orthognathic surgery, pretrauma and implant planning. As the challenge for clinicians at present is to understand and interpret 3D imaging and the quality computed tomography (CT) scans, so, training is essential. At the same time as 3-dimensional imaging has been developing, virtual models produced with CAD-CAM soft-ware and 3-dimensional printing hardware have opened up a range of opportunities in education, science, technology, healthcare and industry by transfer of the virtual planning to the surgical setting using a surgical splint. CAD-CAM models are useful for both surgical planning and for communication between members of the surgical team and patients [3-9].

Materials and Methods
Fifteen human dry mandibles were enrolled in the current study in compliance with the eligibility criteria being intact regarding all the anatomical landmarks used as attachment sites of the radiographic markers including: condyles, coronoids, mental foramina and chin convexity. Sample selection was independent of age or sex either dentate or non after sample size calculation. All the mandibles were scanned with CBCT using a Promax® 3DMid CBCT device (Planmeca Oy, Helsinki, Finland) at 90 kVp, 10 mA and 0.4 mm voxel size.

Sample Preparation
Non-metallic radiopaque gutta percha ball markers were glued to nine reference anatomical landmarks (medial and lateral poles of condyles of both sides, tip of coronoid process of both sides, right and left mental foramina and to midpoint of maximum chin convexity) for standardization then Soft tissue simulation in the form of full mandibular coverage was done by adapting eight sheets of softened pink wax approximately 12mm thickness following the guidelines recommended by Caldas *et al* 2010 [10].

Image Analysis
By using multiplanar reformatting (MPR), differently oriented orthogonal (corrected coronal, corrected sagittal) through the volume can be identified via rotating the axial slices were used as

2D generated CBCT images (Fig.1). The CBCT dicom files (digital imaging and communication in medicine) were imported into outsider 3rd party software package On Demand 3D software (Seoul, South Korea) (On Demand 3D App 1.0.10.7510). The new software tools enabled us to do the linear measurements on 3D generated CBCT images (Fig.2). Both 2D and 3D generated CBCT images were used to perform the following linear measurements:

1. Inter-coronoid width: Measuring the distance between coronoid markers.
2. Inter-mental foramen width: Measuring the distance between mental foramen markers.
3. Measuring the distance between right coronoid point and right mental foramen markers.
4. Measuring the distance between right coronoid point and left mental foramen markers.
5. Distance between left coronoid point and left mental foramen markers.
6. Distance between left coronoid point and right mental foramen markers.
7. Width of the right condyle.
8. Width of the left condyle.
9. Distance between right mental foramen to midpoint of the maximum chin convexity markers.
10. Distance between left mental foramen to midpoint of the maximum chin convexity markers.

The gold standard measurements were taken directly on the dry mandibles using an electronic digital caliper IOS-USA® [Yiwu Windex Import & Export Co., Ltd] with an accuracy of 0.01mm. Two experienced radiologists carried out both radiographic and physical measurements, which were repeated after a time interval of two weeks then averaged to achieve the greatest degree of accuracy and to assess reliability.

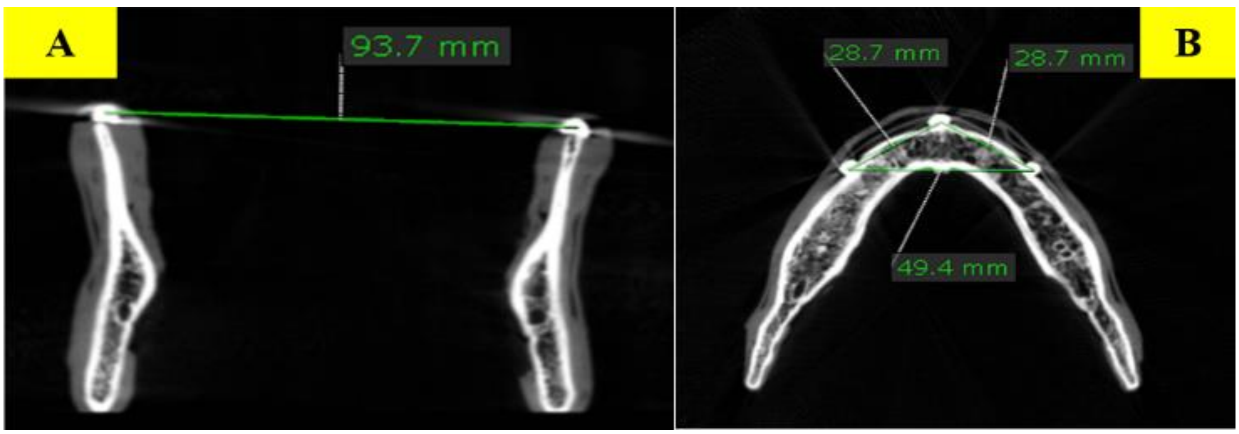

Fig 1: Showing 2D multiplanar image of one of our conducted mandibles demonstrating the measured distances of intercoronoid (A), intermental and both right and left mental-chin (B).

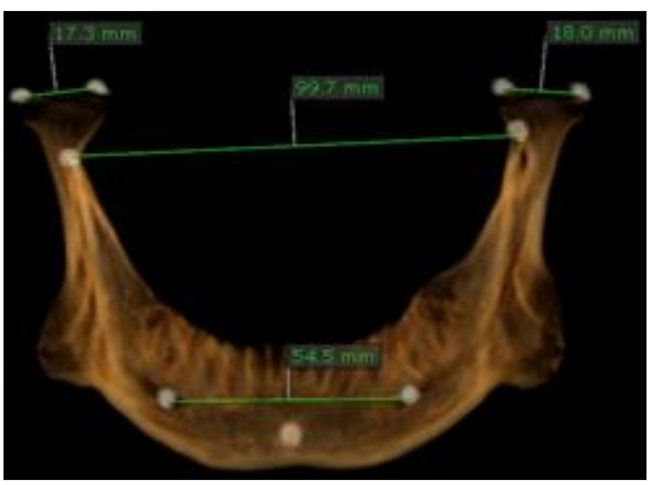

Fig 2: Showing 3D volume rendering image of one of our conducted mandibles demonstrating the measured distances of both right and left condylar width, intercoronoid and intermental distances.

Statistical Methods

All Data were collected, tabulated and subjected to statistical analysis. Statistical analysis is performed by SPSS in general (version 17), also Microsoft office Excel is used for data handling and graphical presentation. For quantitative assessment of the error between 2D and 3D measurements, reference method Dahlberg error and Relative Dahlberg Error (RDE) were used together with Intra-class Correlation Coefficients (ICC) including the 95% confidence limits were calculated assuming analysis of variance two way mixed model ANOVA with absolute agreement on SPSS. To measure and quantify the size of the differences, Bland and Altman 95% confidence Limits of Agreements (LOA) were applied. Also inter observer reliability analysis, Dahelberg error and Relative Dahelberg Error (RDE) were used together with Interclass Correlation Coefficients (ICC) including the 95% confidence limits of the coefficient. For comparing the errors of 2D and 3D measurements, independent samples t test was used. For comparing the inter observer Dahlberg errors of the three methods, One way analysis of variance ANOVA was applied followed by Bonferroni method for multiple comparison. Significance level is set at $P<0.05$ while $P<0.01$ is considered highly significant. Two tailed test assumption was applied all through the analysis.

Results

In this study, The Interclass Correlation Coefficients (ICC) symbolized the agreement between observers good to excellent regarding 2D relative to physical measurements and good to excellent regarding 3D relative to physical measurements except for left condylar width and left mental- chin measurements which imply poor agreement. Relative Dahlberg Error (RDE) between the 2D and physical measurements was the least for right coronoid to left mental and left coronoid to right mental (1.3%) denoting that those measurements are the most accurate. While the highest for the left condylar width (6.7%) denoting that this measurement is the least accurate one. Relative Dahlberg Error (RDE) between the 3D and physical measurements was the least for right coronoid to left mental and left coronoid to right mental (1.6%, 1.2% respectively) denoting that those measurements are the most accurate. While the highest for the left condylar width (9.2%), right condylar width (7.2%) and left mental-chin (8.8%) denoting that those measurements are the less accurate. Mean of difference (2D-physical and 3D-physical) values were ranged between positive and negative values which means that we had almost no bias regarding our results. Negative values mean underestimation while positive ones mean overestimation. Independent samples t test was used for comparing the errors of 2D and 3D measurements. The mean error of 2D measurements is statistically significant lower than that of 3D measurements (Fig.3). One way analysis of variance ANOVA was applied followed by Bonferroni method for multiple comparisons to assess the reliability of the three methods of measurements. Physical method showed statistically significant large error compared to other two methods, 2D measurements had the least error which is highly significantly lower than Physical method and almost statistically significant lower than 3D measurements (Fig.4).

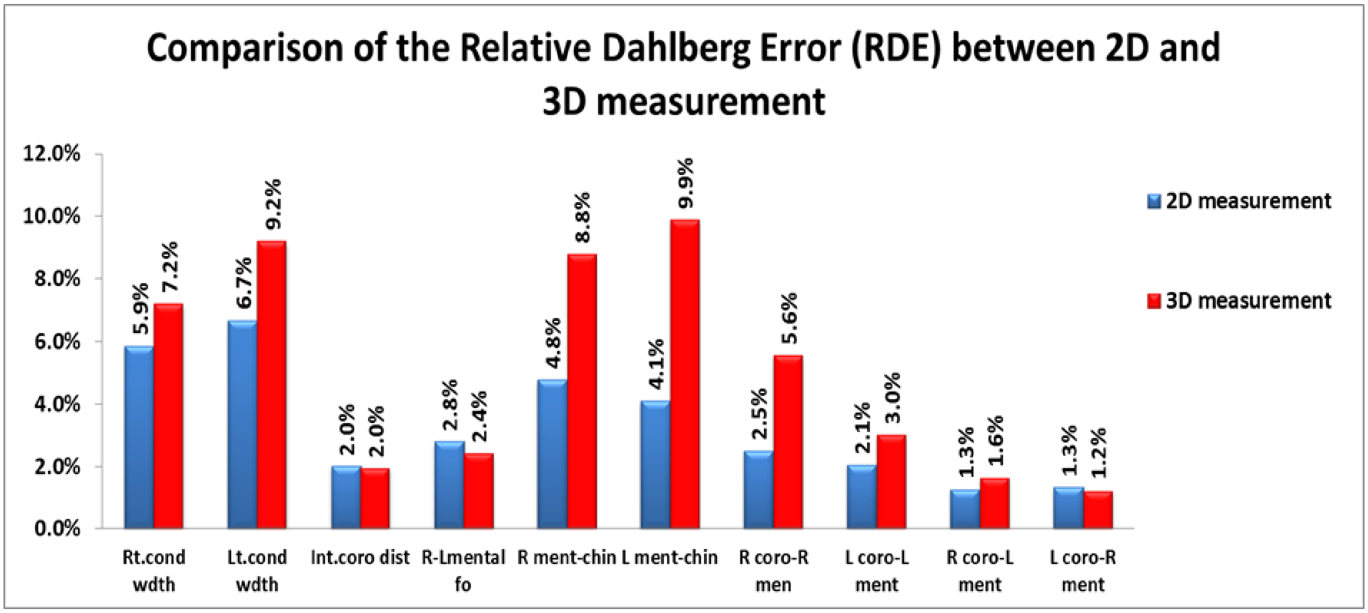

Fig 3: Comparison of the relative Dahlberg Error (RDE) between 2D and 3D measurements.

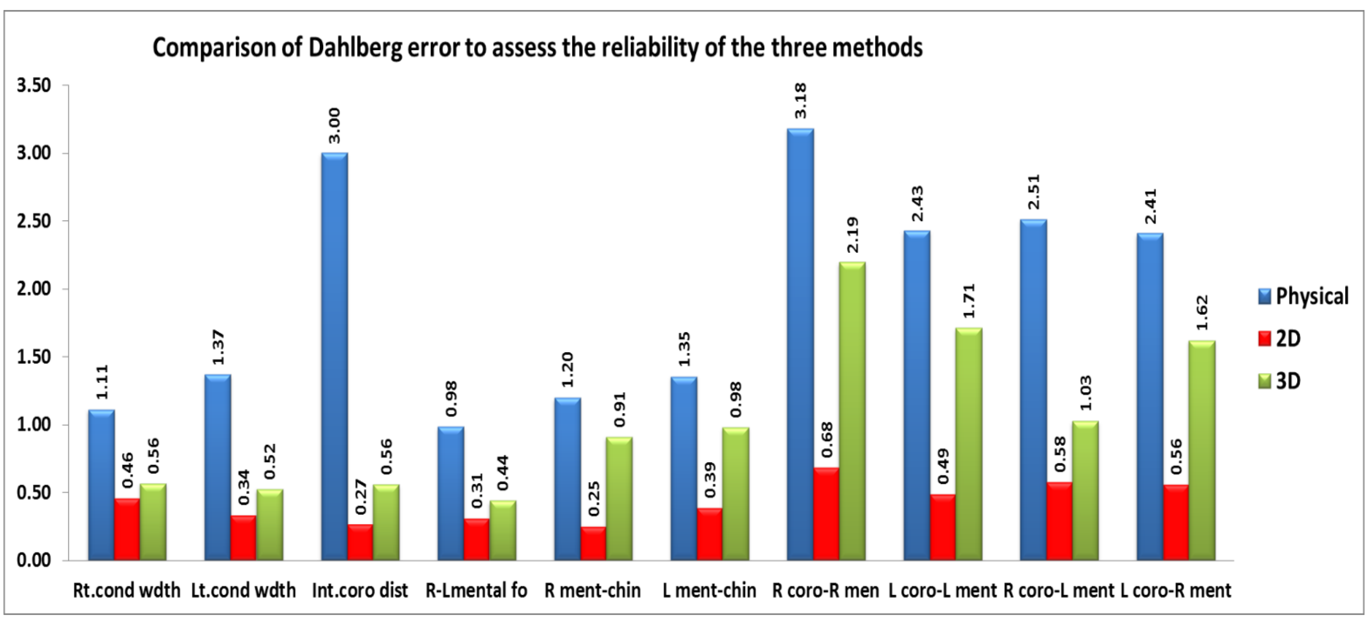

Fig 4: Comparison of Dahlberg Error to assess the reliability of the three methods (physical, 2d and 3d measurements).

Discussion

CBCT offers the likelihood visualization of those structures over three dimensions, without those overlaps, distortions, or magnifications that would almost impossible for traditional radiographic routines [11]. Since the evolution of virtual three dimentional CBCT, it is continually blooming resulting in increased its popularity in oral and maxillofacial region safe and accident free diagnosis and treatment planning. The purpose of this study was to determine the accuracy and reliability of measurements made on computer generated two dimensional and three-dimensional volume rendering images [12]. Previously, late decades, the utilization of computerized methods to help diagnosis and treatment in oral and maxillofacial surgery has developed significantly. This is affirmed by the 375 papers pertaining with its utilization over orthognathic surgery over major databases [4]. None of the past investigations remark on the repeatability of measurements. When measuring anatomic points in the human body, it is tricky to delineate an exact measuring point with commonly used measuring equipment due to the smooth forms [3]. Eventually with utilizing the measuring balls portrayed and deciding their centers, we were able to attain fantastic repeatability of the measurements. These balls have the limitations of being artificial structures that are problematic in the actual surgical reproduction. Digitalization of the model and comparing it with the 3D model is a method to overcome this problem. This can be achieved, for example, by using a laser scanner, photogrammetry, micro tomography or structured light. The problem is that digitizing every medical model for verification is unreasonable and thus an industrial quality control would be necessary [3]. To overcome this problem in our study, non-metallic radiopaque gutta percha ball markers were used and glued to nine reference anatomical landmarks (medial and lateral poles of condyles of both sides, tip of coronoid process of both sides, right and left mental foramina and to midpoint of maximum chin convexity). Although the use of human dried skulls has a limitation compared with in vivo studies, this approach has permitted direct measurements of linear distances eliminating the confounding effects of overlying soft tissues. Physical measurements have been considered as gold standard and their reliability has been successfully demonstrated in Sfogliano *et al* 2016 [13]. So, in our study dried mandibles were used and physical measurements were considered as gold standard. In the current study, The Interclass Correlation Coefficients (ICC) symbolized the agreement between observers good to excellent regarding 2D relative to physical measurements and good to excellent regarding 3D relative to physical measurements except for left condylar width and left mental- chin measurements which implied poor agreement. Relative Dahlberg Error (RDE) between the 2D and physical measurements was the least for right coronoid to left mental and left coronoid to right mental (1.3%) denoting that those measurements are the most accurate. While the highest for the left condylar width (6.7%) denoting that this measurement is the least accurate one. According to Hilgers *et al* 2005 [14] and Tarazona-Álvarez *et al* 2014 [15] in craniofacial imaging the error is considered clinically acceptable up till the value of 5%. Engelbrecht *et al* 2013 [16], have suggested the demand of a more advanced segmentation technique especially at the condylar region and the lingual side of the mandible. According to our observations, the left condyle width was also affected by the surface extraction process, lead to an error which is statistically significant different from the direct measurements (6.7%). In this study, Relative Dahlberg Error (RDE) between the 3D and physical measurements was the least for right coronoid to left mental and left coronoid to right mental (1.6%, 1.2% respectively) denoting that those measurements are the most accurate. While the highest for the left condylar width (9.2%), right condylar width (7.2%) and left mental-chin (8.8%) denoting that those measurements are the less accurate. In consistence with our results Patcas *et al* 2015 [17] demonstrated that MPR (multiplanar reconstruction) images produced the most accurate results with measurements in highest agreement to the anatomical findings (that is, the narrowest limits of agreement and the smallest range of differences). Comparison was performed between direct volume rendering and two examined projectional viewing modules, showing only slight less accuracy than MPR.

In contrast, Baumgaertel *et al* 2009 [18] and Tarazona-Álvarez P *et al* 2014 [15], who compare the linear measurements obtained with CBCT and digital caliper in mandibles from human cadavers demonstrated that the measurements obtained with the digital caliper were greater indicating that the CBCT technique underestimated distances of the actual measurements. Glover and Pelc 1980 [19] and Baumgaertel S *et al* 2009 [18] have explained the underestimation and overestimation in the CBCT measurements with so called partial volume effect, which results when a voxel is involved with two structures with different densities, and the voxel reflects an average density value or due to measurement software. In the current study, the Mean of difference (2D-physical and 3D-physical) values were ranged between positive and negative values which means that we had almost no bias regarding our results. Confirming our results, Gupta *et al* 2017 [7] indicated that the measurements made on slices, segmented surfaces, and volume-rendered images showed good accuracy when compared with gold standards (measurements using calipers on a dry skull). Fernandes *et al* 2015 [20] declared comparable reproducibility for linear measurements on multiplanar images and volume rendering, the multiplanar views indicated slightly superior accuracy. By comparing landmark identification on isosurface with a combination of MPR alongside the isosurface, a more excellent precision to the last might be validated [17]. In this study, the mean error of 2D measurements is statistically significant lower than that of 3D measurements which indicating that the 2D measurements are more accurate than 3D measurements. In 3D images, landmarks are difficult to demonstrated, and there are more chances of subjective error due to the curved anatomic surfaces. The orientation of the skull may influence landmark identification especially on these curved structures. Sometimes, the reorientation and reformation of the 3D image data are mandatory before landmark plotting. On the other hand, artifacts in CBCT imaging may also cause difficulty in identification the landmarks in CBCT images [7]. Similarly, Grauer *et al* 2009 [21], generating measurements in 3D volumetric images rather than simultaneously in sets of 2D multiplanar images produces error due to the difficulty in locating landmarks in 3D space and the inaccuracies of the user entered threshold used for the construction of 3D virtual images. However, Gupta *et al* 2017 [7] found that the differences in measurements on 3D CBCT images were to be statistically insignificant from dry skull measurements. Fernandes *et al* 2015 [20] also reported the reliability and accuracy of linear measurements obtained on multiplanar 2D CBCT images with 0.2 and 0.4 voxel sizes using i-Cat scanner and Dolphin software for clinical diagnosis and treatment planning but attention should be taken in linear measurements on 3D rendering images, because the measurements were reliable, but not accurate [22]. On the other hand, Bengtsson *et al* 2017 [6] reported that there was a challenge in comparing 3D with 2D cephalometrics. Xia *et al* 2015 [23] reported differences in measurements between markers in 3D compared to 2D. From the precision measurements, it can be assumed that the error increases when a higher number of markers and dimensions are included. This also expands the opinion that a direct comparison of 2D and a 3D cephalometric measurement is misleading and it is better to be avoided. Bengtsson *et al* 2017 [6].

Conclusions

Linear measurements taken on multiplanar 2D CBCT images are reliable and accurate for clinical diagnosis and treatment planning. Linear measurements on 3D rendering images are reliable but with less accuracy than the 2D images. So, attention should be taken when linear measurements are carried out on 3D images.

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