J Maxillofac Oral Surg 8(1):8–12

COMPARATIVE STUDY

# Three dimensional CT reconstruction: a comparison between 2D, 3D CT and original anatomical structures

Eldho Markose[1] ✉ · Vikraman B[2] · Veerabahu M[3]

[1] Senior Lecturer
Dept. of Oral and Maxillofacial Surgery,
Mar Baselios Dental College,
Kothamangalam, Ernakulam

[2] Professor
[3] Professor and Head

Dept. of Oral and Maxillofacial Surgery,
Ragas Dental College and Hospital,
Chennai

*Address for correspondence:*

**Eldho Markose**
Dept. of Oral and Maxillofacial Surgery
Mar Baselios Dental College
Kothamangalam, Ernakulam, India
E-mail: dreldho@rediffmail.com

Received: 17 January 2009 / Accepted: 28 February 2009


**Abstract** Conventional two dimensional computed tomography has provided significant advancement in clinical diagnosis with information on cross-sectional anatomy of various parts of the body. However, three dimensional representations are not directly available. This is now made possible by recent development of CAD software and CT equipments and technique such as multiplanar reformation capable of providing 3D reconstruction using 2D CT data. This article evaluates the accuracy of measurements and dimensions in 3D CT reconstruction.

**Keywords** Three-dimensional · 3D CT

## Introduction

Diagnosis and treatment planning of abnormalities with complex anatomy such as skulls and maxillofacial region requires accurate measurement between anatomical landmarks to aid in determining the degree of abnormality and the extent of surgical correction. Three dimensional tomography avoids the superimposition and problems due to magnification and offers the opportunity to evaluate the craniofacial structures in greater detail and with more precision [5].

Three dimensional (3D) computed tomography imaging is a technique that uses conventional CT data to reconstruct an image for viewing all three planes of viewing. The use of 3D CT imaging has increased the qualitative information yield, but little has been done to assess the quantitative capabilities of 3D CT. The accuracy of 3D CT imaging program MediCAD surgical stimulation software has been done in various studies [3–5,7,12,13]. These studies also showed that linear measurement accuracy of 3D CT reconstructed image was not precise [1]. The reconstructed 3D CT images are much more refined now. The provision of independent workstation with parallel architecture computer coprocessor and user friendly softwares has permitted much faster reconstruction [7,8]. This has led to renew interest and enthusiasm in this field to make use of 3D reconstruction routinely for selected cases.

The development of helical CT scanning technique in combination with 3D rendering technique enables the use of high quality 3D CT images [9]. The helical CT scanner provides adequate data to create 3D images with reduced radiation and scanning time compared with conventional CT scans because of the continuous scanner rotation and table top movement. By means of software, it is possible to measure directly a distance between two specific points. With this procedure, the measuring points can be selected with a mouse click on the computer screen. When selecting a point on 3D reconstructed virtual image of the skull, its position can be visualized and verified in one or more sectional views of the CT image. These views are always available during the measuring procedure. Sometimes measurement on a 3D reconstructed image cannot be well identified because of anatomical position of landmarks. This can be overcome with software by sectioning the corresponding plane. The actually defined corresponding points can be observed by magnifying that specific bone surfaces with the use of software. So its position can be well identified and measure it accurately. In addition, through the rotating of skull in all directions, each measuring points can be selected optimally.

The objective of present study was to determine the dimensional accuracy and its reproducibility of 3D CT images of three different objects of different nature taken by helical CT.

## Materials and methods

To evaluate dimensional accuracy of 3D CT by comparing linear measurement obtained from the CT scan data, 3D reconstructed virtual image and the original structure of acrylic block, dry mandible and fresh wet goat's head with soft tissue.

### *Preparation of block*

Rectangular acrylic block measuring 7.5 x 6.5 x 5.5 cm was implanted with three titanium screws measuring 4.5mm in x, y, z direction. The axis was marked according to the direction of beam. The blocks were prepared with self cure clear acrylic. The titanium screws which are used to stabilize Halo frame distractor were implanted in the acrylic block. The landmarks for measurement decided are

1. The length of the screw
2. Diameter of the head of the screw
3. The interpitch distance

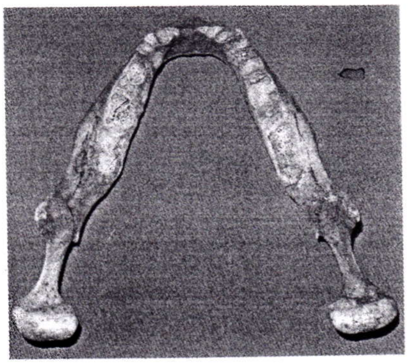

**Fig. 1** Mandible

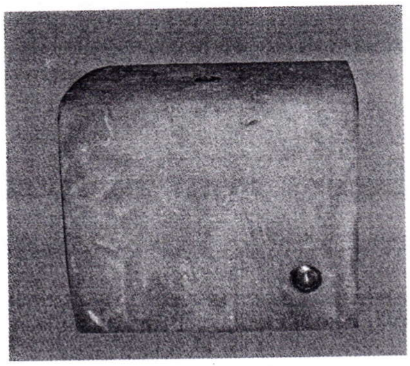

**Fig. 2** Acrylic block

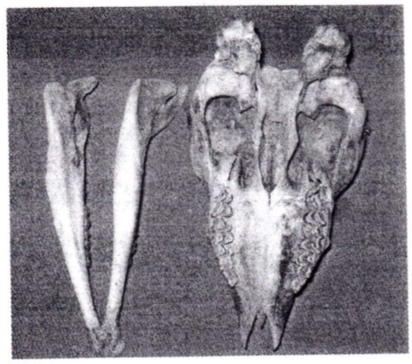

**Fig. 3** Goats head

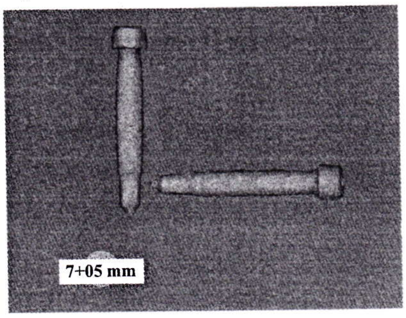


**Fig. 4** Ti screws in x,y,z direction

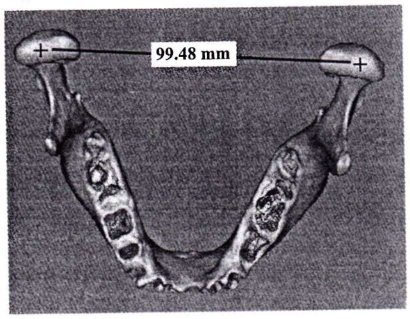


**Fig. 5** Intercondylar distance

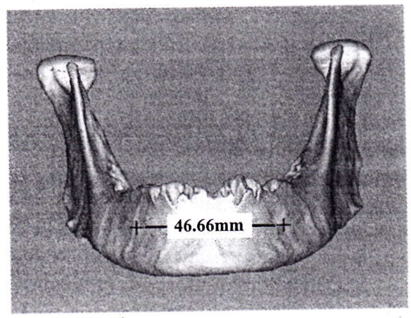


**Fig. 6** Distance b/w mental foramina

*Preparation of mandible*

A dried human mandible was taken from a commercial shop and the following landmarks were decided for measurements.

1. Intercondylar distance (Fig. 5)
2. Mental foramen to lower border of the mandible (right and left) (Fig. 6)
3. Ramal width along the plane of inferior alveolar nerve canal (right and left) (Fig. 7)
4. Length of the mandible from the vertical axis of mandibular foremen to vertical axis of mental (right and left)
5. Distance between the mental foramen

*Preparation of goat's head*

A freshly sacrificed wet goat head was purchased from the market and no measurements was done to the head and it was scanned with the soft tissue. Then goat's head is buried into the soil for three weeks. After three weeks goat's head was taken back from the soil. Even though some of the anatomic structures such as horn, nasal bone hump damaged during this procedure, but could manage to get most of the structures without further damage. The anatomic landmarks derived are:

1. Inter distance between frontal foramina
2. Bizygomatic width
3. Distance between hamulus of pterigoid process
4. Distance between procassus lacrimalis caudalis and arcus zygomaticus
5. Inter orbital width in transverse plane

All objects are scanned with helical 64 slice CT scan. The data was obtained in a digital imaging and communications in medicine (DICOM) format. The measurements were made from 3D CT scan and 3D reconstructed virtual object.

*Collection of CT data*

All scans were performed on a Siemens Somatum Sensation CT scanner. Acrylic block and dry mandible was scanned using single window; 1 mm thick contiguous slices with Helical 64 slice CT scan, whereas goat's head had done with 0.60mm slice thickness. The scans were taken with the following parameters: 120kv, 380mA with a 6.8 sec exposure and Pitch 0.8. After image acquisition, CT data were saved in DICOM format.

The acquired CT data were imported into a CAD based software Three dimensional reconstruction of virtual image done with this software and measurement were made in x-axis (coronal), y-axis (sagittal) and z-axis (transverse).

**Results**

The measurement taken from 2D CT, 3D reconstructed virtual image and direct method were tabulated. The comparison between the direct measurement, 2D CT and the 3D CT image linear measurements in mandible revealed that there were no significant differences (Table 5). Two measures were not completed in 2D CT (mandibular ramal width and body length) as the landmarks were in different planes and cannot be visualized in one single plane. In comparing goat's head between the 3D reconstructed virtual image, 2D CT and physical measurements presented with insignificant differences (Table 4). In case of acrylic block statistically significant differences were present. The length and diameter of the Ti screws differed significantly in 2D CT and 3D virtual image from actual measurement. Inter pitch distance were not able to measure due to lack of screw morphology. (Table 1,2,3,4,5)

**Discussion**

In this study, all the three objects scanned in a single window with helical 64 slice CT scan by Siemens Somatum scanner. After image acquisition, the CT data were transferred from the console of the scanner to the workstation computer. The software then used to identify anatomic landmarks from the CT scan in a process known as segmentation [3]. During segmentation, we can separate the maxilla and mandible to facilitate treatment planning step and also can labels with different colour, for example mandible with one colour and the skull base with another colour in each slice of CT scan. Soft tissue and hard tissue were segmented using the interval thresholds based on Hounsfield numbers and visual interpretation of tissue boundaries. The segmentation data fed into an algorithm that reconstructs three dimensional surface models.

However, the measurement of distances on 3D reconstructed image may include some sources of error. Occasionally, various landmarks cannot be well identified and deviations of the actually, defined corresponding points can be observed particularly, when the landmarks are positioned on large bone surfaces [2]. The 3D reconstruction phase is also subjected to errors namely threshold value determination and volume averaging effect. Threshold value is the specific density of slice image that separates area of interest from other structures by defining its boundaries. The problems of identifying the defined landmarks on the reconstructed images are mainly associated with the threshold level used for the 3D representation of the skulls. During this procedure a suitable threshold level should be found in order to represent all bone structures by eliminating air at the same time. When creating a 3D CT image of the skull, the soft tissues surrounding the bones, such as muscles or connective tissue should not be represented at the same time. For these reasons a suitable threshold level to be done, by which all bony structures, including the finest, can be reconstructed correctly. As a result, the whole procedure represents a source of accuracy for identifying the defined landmarks and performing the corresponding measurements. For the mandible used in this study, it was easier to find a suitable threshold level, since the mandible contrasted against the air and not against the soft tissue.

In this study, the source of error in determining the dimensional accuracy in two dimensional CT and three dimensional reconstructed virtual images is the measurement error mainly includes human error. The major component of human error is defining the exact location of anatomical landmarks used. An incorrect placement of landmarks can alter the accuracy of measurement. Marker reference would have been placed to overcome this problem. Some of the measurements in sagittal view of two dimensional images of mandible were not able to complete. This could be explained by the position of these landmarks. The landmarks of measuring points were positioned in different planes and thus were difficult to identify. In the literature, the accuracy and reproducibility for linear measurements in 2D CT is reported to be excellent, but the use of metallic markers has significantly influenced the ease with which points could be defined [2].

Matteson et al. [13] investigated the quantitative value of three dimensional images compared with cephalometric techniques in assessing craniofacial deformity. Metallic marker references were used in this study. The authors concluded that 3D image reformation provided a more accurate representation of the deformity. Tyndal et al. [12] concluded similarly that 3D CT is more accurate when testing the validity and reliability of 3D CT for quantification of positional changes of the condyle in a dried human skull. Their findings based on metallic markers and do not reflect the clinical reliability of the methods. Only one article has dealt with validation of 3D CT without use of metallic markers [1]. They concluded that 3D CT measurement techniques are superior to those in which measurement obtained directly from the original CT slices.

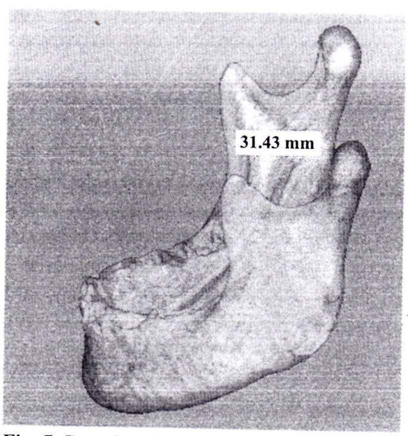


**Fig. 7** Ramal width along the inferior alveolar canal

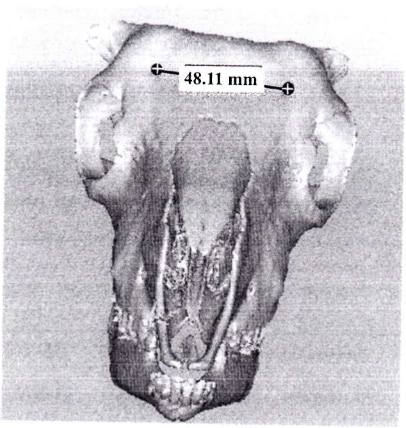


**Fig. 8** Distance b/w frontal foramina

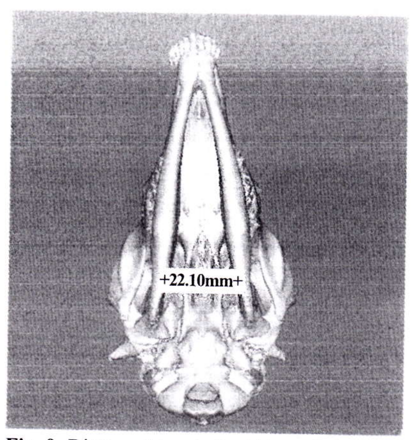


**Fig. 9** Distance b/w pterigoid hamulus

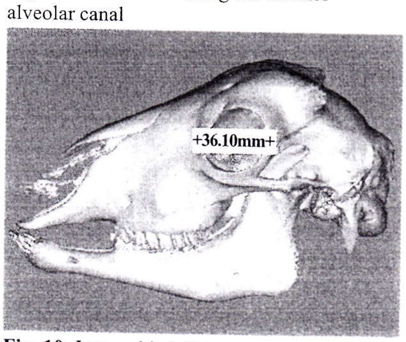


**Fig. 10** Inter orbital distance

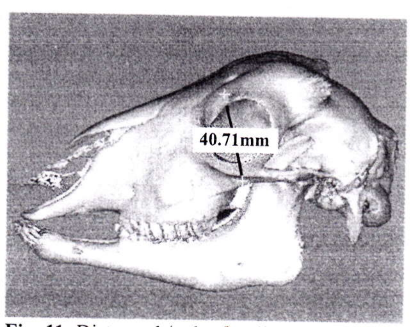


**Fig. 11** Distance b/w lacrimalis caudalis and arcus zygomaticus


**Fig. 12** Length of the screw

**Table 1** Ti screw in x direction

| Landmarks | Actual | 2D CT | 3D CT |
|---|---|---|---|
| Screw length | 44.95mm | 43.94mm | 44.20mm |
| Screw head | 78.4mm | 76.9mm | 80.09mm |
| Inter pitch distance | 1mm | | |

**Table 2** Ti screw in y direction

| Landmarks | Actual | 2D CT | 3D CT |
|---|---|---|---|
| Screw length | 44.95mm | 44.70mm | 44.06mm |
| Screw head | 78.4mm | 72.7mm | 80.07mm |
| Inter pitch distance | 1mm | | |

**Table 3** Ti screw in z direction

| Landmarks | Actual | 2D CT | 3D CT |
|---|---|---|---|
| Screw length | 44.95mm | 45.30mm | 45.00mm |
| Screw head | 78.4mm | 72.7mm | 76.4mm |
| Inter pitch distance | 1mm | | |

**Table 4** Goat's head

| Landmarks | Actual | 2D CT | 3D CT |
|---|---|---|---|
| Dist.b/w Frontal foramina | 48.11mm | 48.11mm | 48.11mm |
| Bizygomatic width | 84.80mm | 84.23mm | 84.11mm |
| Dist. b/w pterigoid hamlus | 22.16mm | 22.24mm | 22.18mm |
| Dist. b/w processus lacrimalis caudalis and arcus zygomaticus | 40.68mm | 40.57mm | 40.70mm |
| Inter orbital distance | 36.10mm | 36.12mm | 36.10mm |

**Table 5** Mandible

| Landmarks | Actual | 2D CT | 3D CT |
|---|---|---|---|
| Inter condylar distance | 99.48mm | 99.48mm | 99.48mm |
| Mandibular ramal width (Lt) | 34.43mm | – | 34.43mm |
| Mandibular ramal width (Rt) | 31.43mm | | 31.43mm |
| Mental foreman to base of mandible (Lt) | 15.06mm | 15.08mm | 15.06mm |
| Mental foreman to base of mandible (Rt) | 14.58mm | 14.5[illegible]mm | 14.58mm |
| Length of mandible from vertical axis of mandibular foramen to vertical axis of mental foremen (Lt) | 49.32mm | – | 49.32mm |
| Length of mandible from vertical axis of mandibular foramen to vertical axis of mental foremen (Rt) | 65.62mm | – | 65.62mm |
| Distance between the mental foramina | 46.66mm | 46.45mm | 46.66mm |

In this study no markers were used to identify the anatomical landmarks. Most of the problems in identification of landmarks were overcome with the help of CAD software, as the software allows viewing the data in four windows consisting of axial, coronal, saggital and the 3D reconstructed virtual image, so the landmark can be viewed and verified in anyone of the planes. All the measurement done in mandible and the goat head had no significant differences.

The linear measurements done in this study looked at the x, y, and z dimensions of the object. It therefore gave a comprehensive picture of the possible dimensional distortions that may occur in the three dimensional reconstructed image. Measurement errors in the z-plane of 3D reconstructed virtual images were reported in previous studies [1,6]. Error in the z plane mainly due to manipulation of viewer controls by CT technicians, calibrations of CT data to 3D CT data, and investigator error. Motion artifact also should be considered, because data acquisition also occurs overtime. However, it was not a factor in this study because only objects were used. In this study, linear measurement in the z-plane was not subject to any error in both mandible and goat's head. The accuracy and precision of measurement in the z axis is increased, if thinnest slices were used [6,10]. Although a strict protocol for data collection was established, the possibility of human error cannot be discounted.

Covino et al. [6] evaluated measurements obtained from 3D CT in acrylic phantoms with Titanium markers to demonstrate the accuracy of computer derived linear measurement. He concluded that all of the measurement made on the 3 mm was different from the actual measurement and that these measurements were statistically significant. When 1.5 mm or thinner slices were used, there were no significant differences in measurement [6].

The use of acrylic block and Ti screws in this study showed some source of measurement error in both two dimensional images and three dimensional reconstructed images. The length and diameter of the titanium screws differs in both two dimensional images and three dimensional reconstructed virtual images in all dimensions from the actual length of the screw. The interpitch distance was not able to visualize and measure because screw morphology was lost in reconstructed image. This could be mainly because of metal artifacts or beam hardening artifact, and maybe indicating that non biological structures should be scanned with industrial CT scans.

## Conclusion

CT was considered to be revolutionary with its introduction in 1972, providing sectional images of the head and later the whole body. Since then sectional imaging technique has become the main stay in modern radiological diagnosis. Development of 3D reconstructions aims to improve the way of presentation by simulation of real specimens. It is applicable currently to cross-sectional imaging modalities like CT or MRI. We have already seen usefulness of 3D reconstruction in craniofacial abnormalities, orthognathic treatment planning, trauma and tumors, where 2D sections may not be informative as 3D CT.

The data produced by CT machines are series of images. These images are usually printed on large sheets of film and are viewed as conventional 2–dimensional (2D) images. In addition, all the images are available in DICOM format. The distance between two points can be measured directly with the help of measuring tools available in DICOM format and also can be viewed by magnifying the area of interest.

Although soft tissue contrast in CT is less optimal for 3D reconstruction than MRI, 3D CT still has its potentials in soft tissue structure where there is large difference in attenuation values. There are various softwares are available for the 3D CT reconstructions from series of 2D images. These softwares are available in two modalities open source softwares and commercial softwares. Commercially available softwares are very good when compared to open source softwares.

3D CT is of course, not with out pit falls. For thin plate like structure e.g. Facial bones, 3D CT programs can create artifacts due to partial volume averaging, creating pseudo foramina. The full potential and clinical application of 3D CT have yet to be defined. 3D CT offers an exciting area needed further research.

According to this study, the measurement performed directly as well as on the corresponding two dimensional tomography and three dimensional tomography reconstructions present with minimal difference. Furthermore, analysis on 3D CT reconstructed images by means of a CAD software includes fewer identification problems, but it seems to be accurate and reliable if thinnest slices were used.

## References

1. Waitzman AA, Posnick JC, Armstrong DC, Pron GE (1992) Craniofacial Skeletal Measurements Based on Computed Tomography Part II. Normal Values and Growth Trends. Cleft Palate Craniofac J 29(2): 118–128
2. Waitzman AA, Posnick JC, Armstrong DC, Pron GE (1992) Craniofacial skeletal measurements based on computed tomography: Part II. Normal values and growth trends. Cleft Palate Craniofac J 29(2):118–128
3. Altobelli D, Kikinis R, Mulliken J, Cline H, Lorensen W, Jolesz F (1993) Computed assisted three dimensional planning in craniofacial surgery. Plast Reconstr surg 92(4): 576–585
4. Barker TM, Earwaker WJ, Lisle DA (1993) Accuracy of stereolithographic rapid prototyping model anatomy. Australas Radiol 38(2): 106–111
5. Brooks SL (1993) Computed tomography. Dent clin North Am 37(4): 575–590
6. Covino SW, Mitnic RJ, Shprintzen RJ, Cisneros GJ (1996) The accuracy of measurements of three dimensional computed tomography reconstructions. J Oral Maxillofac Surg 54(8): 982–990
7. Halazonetis DJ (2005) From 2–dimensional cephalograms to 3–dimensional computed tomography scans. Am J Orthod Dentofacial Orthop 127(5): 627–637
8. Adams GL, Gansky SA, Miller AJ, Harrell WE Jr, Hatcher DC (2004) Comparison between traditional two dimensional cephalometry and a three dimensional approach in human dry skulls. Am J Orthod Dentofacial Orthop 126(4): 397–409
9. Swennen GR, Schutyser F (2006) Three-dimensional cephalometry: spiral multi-slice vs cone-beam computed tomography. Am J Orthod Dentofacial Orthop 130(3): 410–416
10. Swennen GR, Barth EL, Eulzer C, Schutyser F (2007) The use of a new 3D splint and double CT scan procedure to obtain an accurate anatomic virtual augmented model of the skull. Int J Oral Maxillofac Surg 36(2): 146–152
11. Xia J, Ip HH, Samman N, Wang D, Kot CS, Yeung RW, Tideman H (2000) Computer-assisted three-dimensional surgical planning and simulation: 3D virtual osteotomy. Int J Oral Maxillofac Surg 29(1): 11–17
12. Tyndall DA, Renner JB, Phillips C, Matteson SR (1992) Positional changes of the mandibular condyle assessed by three dimensional computed tomography. J Oral Maxillofac Surg 50(11): 1164–1172
13. Matteson SR, Bechtold W, Philips C, Staab EV (1989) A method for three dimensional image reformation for quantitative. J Oral Maxillofac Surg 47(10): 1053–1061
14. James Xia, Horace HS, Samman N, Dongfeng Wang, Christy SB Kot, Richie WK Yeung, Henk Tideman (2000) Computed assisted three dimensional surgical planning and stimulation: 3D virtual osteotomy. Int. J Oral and Maxillofac Surg 29(1): 11–17

**Source of Support:** Nil, **Conflict of interest:** None declared.