International Journal of Advanced Biotechnology and Research (IJBR)
ISSN 0976-2612, Online ISSN 2278–599X,
Vol-7, Issue-1, 2016, pp323-331
http://www.bipublication.com

Research Article

Comparing 3-Dimensional Virtual Reconstruction methods in Customized Implants

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[Received-27/01/2016, Accepted-08/02/2016, Published-21/03/2016]

ABSTRACT:
In medical and surgery applications, the implant design is the key. Any mismatch in the implant design results in the implant failure as well as psychological stress and pain to the patient. Measuring and inspecting the geometrical implant design with the reference model is very important, to ensure the proper fitting and safety of the patient. The purpose of this study is to perform the evaluation between two geometrical custom implant design techniques-mirroring and anatomical design, commonly used in the reconstruction of the mandible implants. The results of the three-dimensional (3D) deviation analyses demonstrate that the average deviation of the anatomical design model is in the range of -0.0841 to 0.1167 mm which is less compared to mirroring technique model with a range of -0.4456 to 0.4322 mm. The two dimensional (2D) geometrical surface deviation illustrates that the mirror reconstruction technique has more deviation (2.05 mm) from the reference mandible model when compared to the anatomical reconstruction technique (1.22 mm).

Keywords: CT Scans, Medical Modelling, customized reconstruction plate, Mirroring technique, Anatomical reconstruction

1. INTRODUCTION

The integration of computer aided design (CAD) in medical application has opened new frontiers in bio-medical application. Advances of medical imaging techniques such as Computer Tomography/ Magnetic resonance imaging (CT/MRI) and medical modelling software's provides the medical doctors an opportunity to perform virtual assessment of entire surgical process and can fabricate the physical models using rapid prototyping. Mandibular reconstruction is one of the challenging job in maxillofacial surgery. The loss of the mandible bone due to tumor excision, bone infection or post radiation necrosis etc., leads to severe

deformation, functional loss and cosmetic deficiency. Every year, thousands of people undergo mandible reconstruction surgery using titanium implant, which is considered the most suitable biocompatible material. Customized mandible implant is a new approach in today's surgery. As each person's physique and bone structure is unique, commercial produced standard mandible implant doesn't fit accurately. It needs manual bending before surgery using trial and error method to custom fit the patient's jaw. Any mismatch between the bone and plate interface results in the implant screw loosening and pain and stress to the patient. With the advancement of CT, MRI and medical modelling software, it is possible to design the customized implant as per the topology of the patient bone. The customized implant reduces the implant failure, number of revisions, surgical time and cost.

The mandible defects are classified according to their location and extent [1]. Urken classification [2] of mandible anatomy with respect to region and location are shown in Fig. 1. The most effected site for the involvement of tumor is the body region of the mandible [3]. The distribution of effected region sites in the mandible has been reported as 33% in the body, 29% in the condylar region, 23% in the angle, 8% in the symphysis region and the rest in the coronoid process [4].

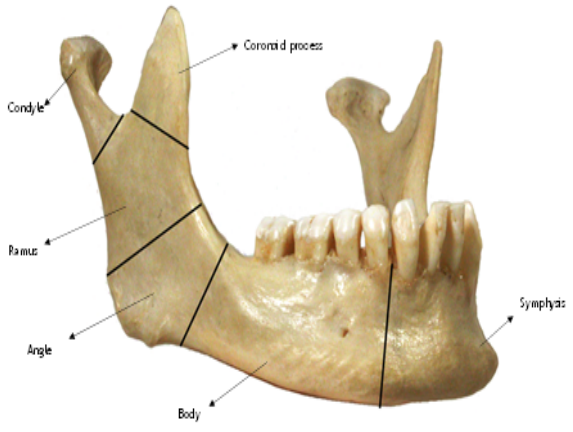

Fig: 1. Anatomical landmarks of the human mandible [5].

There are two common customized implant design techniques used in the reconstruction of the mandible in the body tumor region– the mirroring reconstruction technique and the anatomical reconstruction technique. In both the techniques the defective bone is removed and replaced by the healthy bone and the desired implant is designed on the healthy bone based on the contour of the defective region. The purpose of this study is to virtually compare the customized mirror and anatomical reconstruction design techniques and to evaluate them to select the best design technique used in the reconstruction of the mandible at the body region.

2 MATERIALS AND METHODS

2.1. Surface reconstruction and modeling

In this study, a patient suffering from jaw tumor is considered as a case study for comparing the implant design techniques. The obtained CT scan images known as digital imaging and communications in medicine (DICOM) files are grouped in order, with a -796/1530 custom Hounsfield unit (HU) scale using medical modelling software Mimics®. Mimics® is one of the commonly used medical modelling software used for the conversion of 2D images (DICOM files) into a 3D format (STL) [6].

The dicom files (Fig. 2 (a)) are in the form of 2D images which do not provide any geometrical structure until piled one above the other to form a full facial 3D model as shown in Fig. 2 (b).

Segmentation tools such as thresholding and region growing techniques in Mimics® are used to calculate and develop the 3D model. Using the edit mask tool, the region of interest- the mandible is separated from the full face 3D model as shown in Fig. 2 (d). The tumor is removed by resecting the mandible region as illustrated in Fig. 2 (e, f). Two commonly used implant design techniques- anatomical reconstruction (Fig. 2 (g (i))) and mirroring technique (Fig. 2 (g (ii))) is used for replacing the

resected tumor region with the mandible bone as illustrated in Fig. 2 (h).

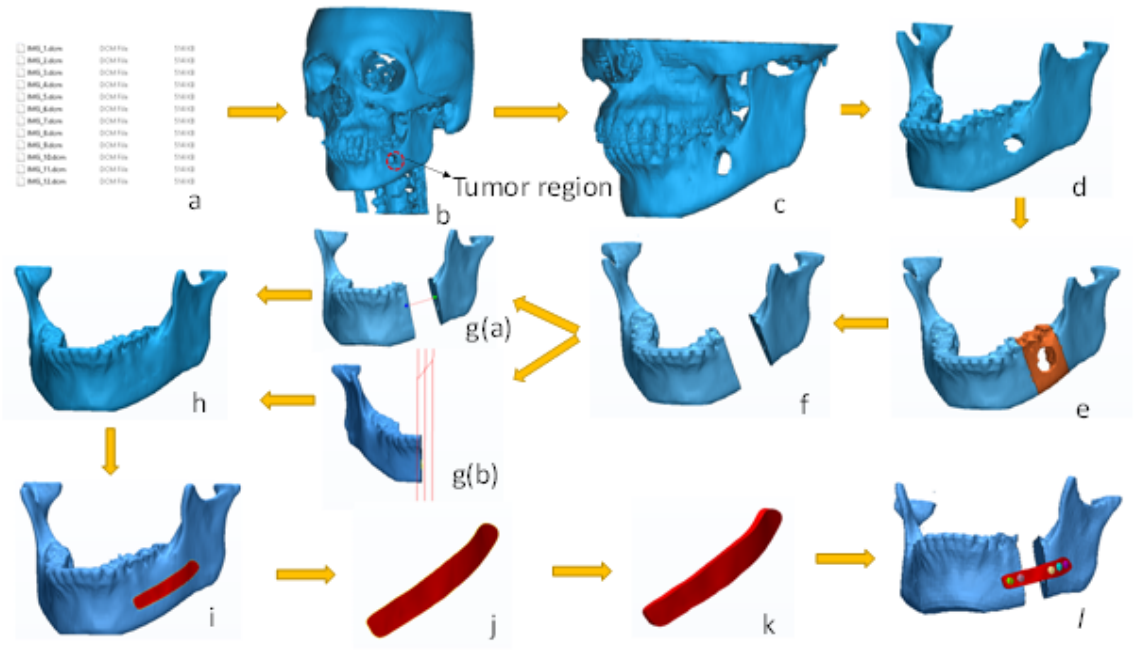

Fig: 2. Steps for the customized reconstruction plate design from DICOM files

The outer surface of the obtained clean mandible (Fig. 2 (h)) is used for the customized reconstruction plate design by applying attach smooth curves (Fig. 2 (i)) on the surface using 3-matic® software. An offset distance of 2 mm is provided on the implant design and finishing operations such as screw holes drilling and surface smoothing are done as shown in Fig. 2 (k). The customized reconstructed 2 mm thick plate with screws, fits perfectly and precisely onto the mandible region (Fig. 2 (l)) as the plate geometry is made from the mandible bone itself.

2.1.1 Mirroring reconstruction Technique

The mirroring reconstruction technique is the most commonly used implant design reconstruction technique in medical application. Juan et al. [7] described the mirror reconstruction technique in the design of customized craniofacial implant in the left frontoparietal region of the skull of a 13 year old patient. Sekou et al. [8] designed custom titanium mandible tray using the mirroring technique with better facial symmetry obtained on both ends of the condyles. Hsin Liu et al. [9] suggested 3D Stereolithographic Modelling technique for Hemimandibular reconstruction with a mirroring technique to create a symmetrical bio-implant model. Jing lee et al. [10] applied a three dimensional reconstruction and mirroring technique to fabricate a complete mandible bio-model with idealized shape.

- **Steps involved in Mirror reconstruction Technique using 3-Matic®**

The mirroring reconstruction technique is used to replace the tumor region with a clean mandible using 3-Matic®. 3-Matic® is a medical modelling, design software developed by materialise, Belgium, used in the mirror reconstruction technique [11]. As shown in Fig. 3, two extreme points (Fig. 3 (b)) are selected using 3-matic® for the creation of the datum

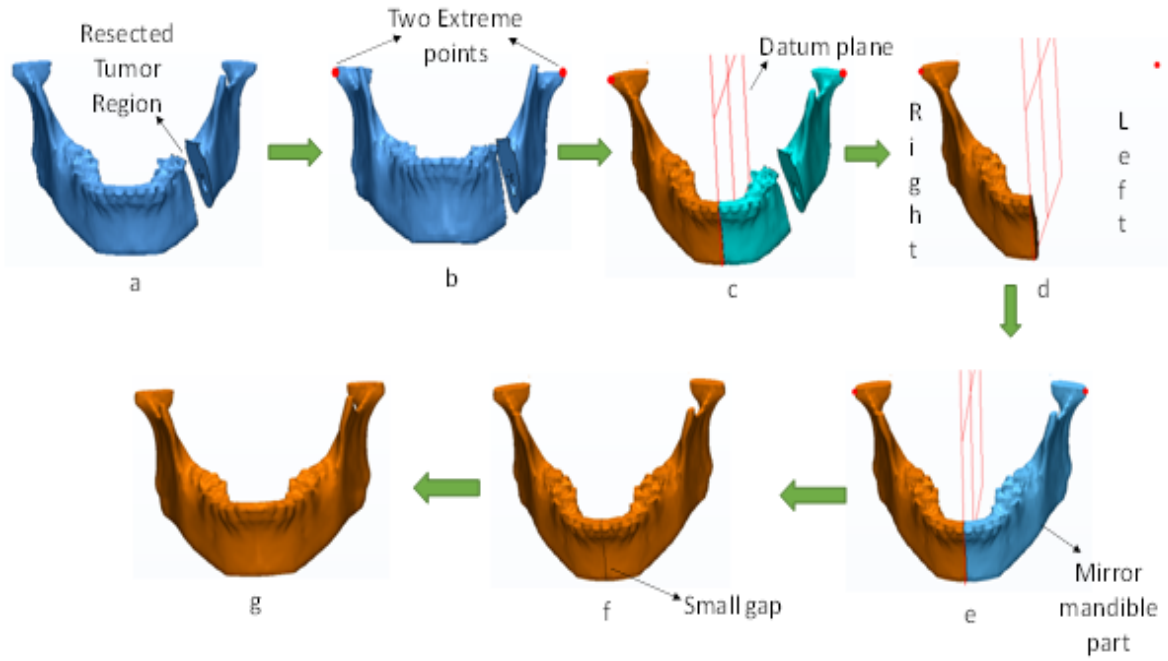

Fig: 3. Mirroring reconstruction design steps from the tumor region to the clean mandible.

plane to cut the mandible from the central region (Fig. 3 (c)). The left tumor mandible is removed (Fig. 3 (d)) and replaced by the mirror image of the right side of the mandible (Fig. 3 (e)).

The left and right mandible regions are then merged and wrapped to cover the gaps (Fig. 2 (f)) to get the final reconstructed mirroring mandible model. The reconstructed mirroring mandible model is then used for the design of the reconstruction implant or plate (steps Fig. 2 (i-l).

The mirror reconstruction technique is only used in the symmetrical nature of bone. A small amount of asymmetry is always present in the human body parts. In the facial skeleton, the more asymmetry it is, the harder to determine the midsaggital plane and less reliable the mirroring reconstruction technique [12].

2.1.2 Anatomical reconstruction Technique

The anatomical reconstruction is a new technique which is widely used nowadays. In case of tumor occurring at the asymmetry region such as the center region of the chin, the mirroring technique fails and anatomical reconstruction technique is used. The Anatomical reconstruction technique is also known as free form surface or lofting technique in the CAD software's such as CATIA, Solidworks etc.

The anatomical reconstruction technique can be used in both symmetrical and asymmetrical regions, but needs more technical expertise when compared to mirroring techniques. Bartolo et al. [13] used three points to construct the defective part of the nose using reverse engineering.

Joel et al. [14] developed new custom made craniofacial implant using CAD software which by adjusting the points to get the desired shape. Jayanthi [15] used the defective cranium region as a template for building the actual region of interest (implant) by adjusting and depicting the precise defect.

- **Steps involved in Anatomical reconstruction Technique using 3-Matic**

The same 3-matic® design software is used in the anatomical reconstruction technique.

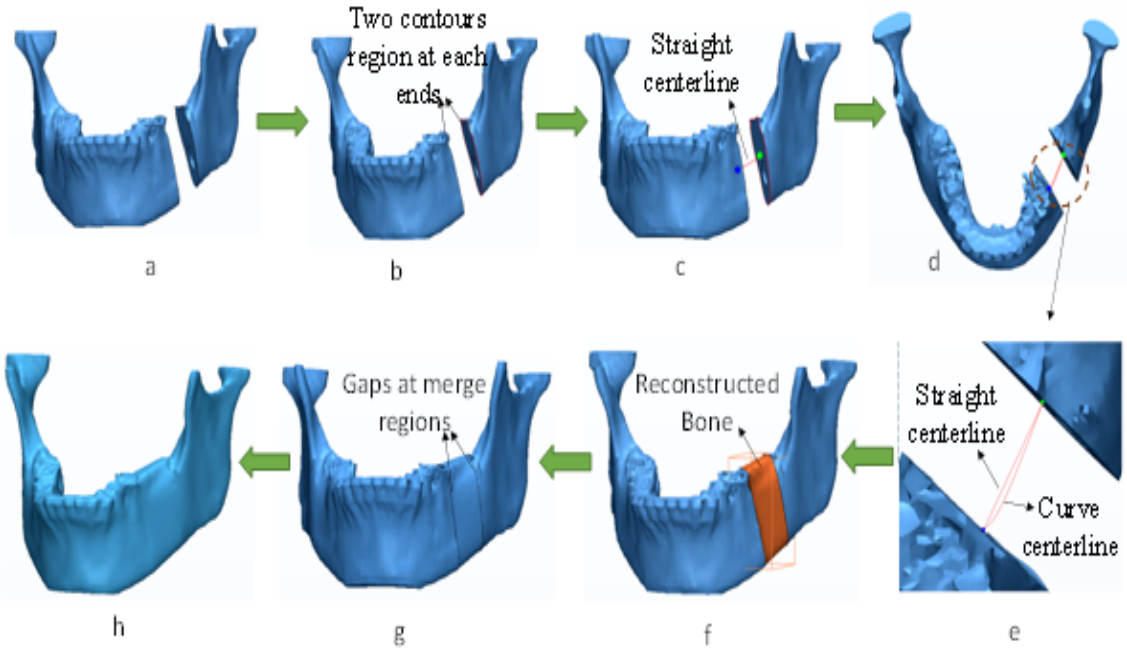

Fig: 4. Steps involved in the anatomical reconstruction design model from the tumor region to the clean mandible.

Two contours of the resected ends are selected (Fig. 4 (b)) in 3-matic® to create a straight center line (Fig. 4 (c)) for the anatomical reconstruction design. The straight centerline is edited from straight to curve to adjust the contours of the mandible (Fig. 4 (e)).

The curve center line creates the new reconstructed bone, thus filling the resection area of the tumor region (Fig. 4 (f)). The gaps (Fig. 4 (g)) attained after the merge operation is removed using wrapping operation to get the final anatomical reconstructed mandible model as shown in Fig. 4 (h)). The anatomical reconstructed mandible model is used in the design of the mandible implant with similar steps as shown in Fig. 2 (i-l).

2.2 Reference mandible using Mimics®

The reference mandible is the mandible without any defects and is used as a reference model for comparing the anatomical and mirror reconstruction techniques.

The reference mandible model is obtained from the same patient CT scan using Mimics® after replacing the tumor region as shown in Fig. 5.

An edit mask tool with draw features is used to add the pixels (blue) at the tumor region (green) of the mask (Fig. 5 (b)).

This is to replace the tumor part with active bone as illustrated in Fig. 5 (b). The obtained reference mandible (Fig. 5 (c)) is separated from the whole face by segmentation and used as the reference model (Fig. 5 (d)) for comparison and inspection of mirroring and anatomical design technique.

3. DEVIATION ANALYSIS FOR CUSTOMIZED MANDIBLE DESIGN TECHNIQUES

Geomagics qualify® is used to quantify and inspect the difference between the two implant design reconstruction techniques (Mirroring and Anatomical design models) with respect to the reference mandible model.

The clean mandible test models obtained from mirroring (Fig. 3 (g))

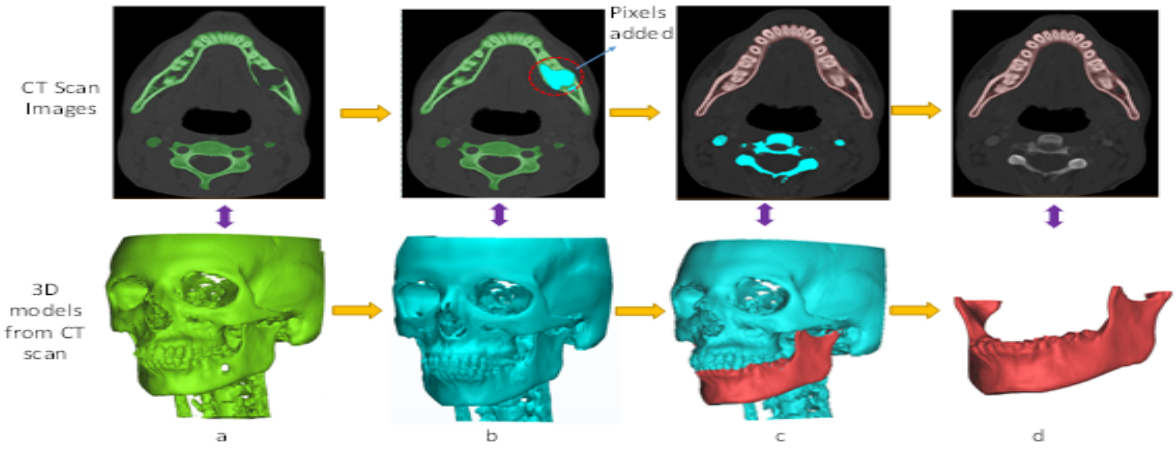

Fig: 5. Steps involved in obtaining the reference mandible model from the defective mandible using Mimics®.

and anatomical reconstruction technique (Fig. 4 (h)) are compared to the reference mandible model (Fig. 5 (d)) using Geomagic qualify® to select the best implant design technique. 3D and 2D comparison is done using geomagics qualify® to determine the surface deviation between the reference and the test models.

3.1 3D Comparison using Geomagic qualify®

Geomagic qualify® is the industry's most comprehensive, robust and accurate 3D inspection software that enables fast, accurate and graphical comparison between the as built test objects and reference CAD models. In 3D comparison as shown in Fig. 6, the test mandible produced through mirroring and anatomical reconstruction techniques are aligned with the reference mandible model with a series of analyses to determine the surface deviation in millimetres (mm). The maximum and minimum colour spectrum are defined as the deviation of mandible test models from the reference model. The Fig. 6 also provides the average deviation, standard deviation and root mean square value of the mandible test models from the reference model. The negative values on the colour spectrum (light blue to dark blue) indicates the test surface moving inside the reference surface and the positive value (green to yellowish red) indicates the test surface moving away (outside) from the mandible reference surface.

3.2 2D Comparison using Geomagic qualify®

The 2D comparison of the mirror and anatomical reconstruction test models with the mandible reference model is illustrated in Fig. 7. In 2D comparison, a cross-sectional plane is created on the reference and test mandible models, providing the whisker plot showing the difference between

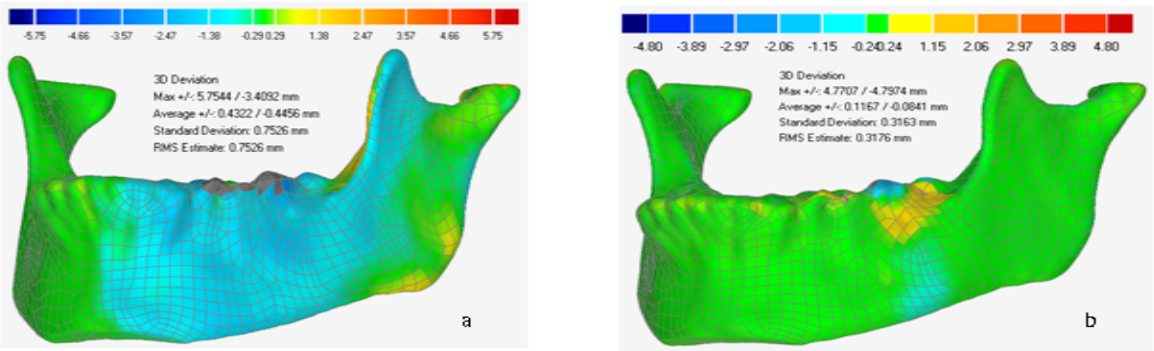

Fig: 6. 3D comparison of the reference mandible model with (a) mirror reconstruction and (b) anatomical reconstruction model.

the particular cross section as illustrated in Fig. 7. The Colour spectrum of both the design models (Fig. 7) represents the deviation of the mandible test model from the mandible reference model. The cross-sectional YZ plane on both the test design mandibles (Fig. 7) is used to acquire the whisker plot of the graphical area.

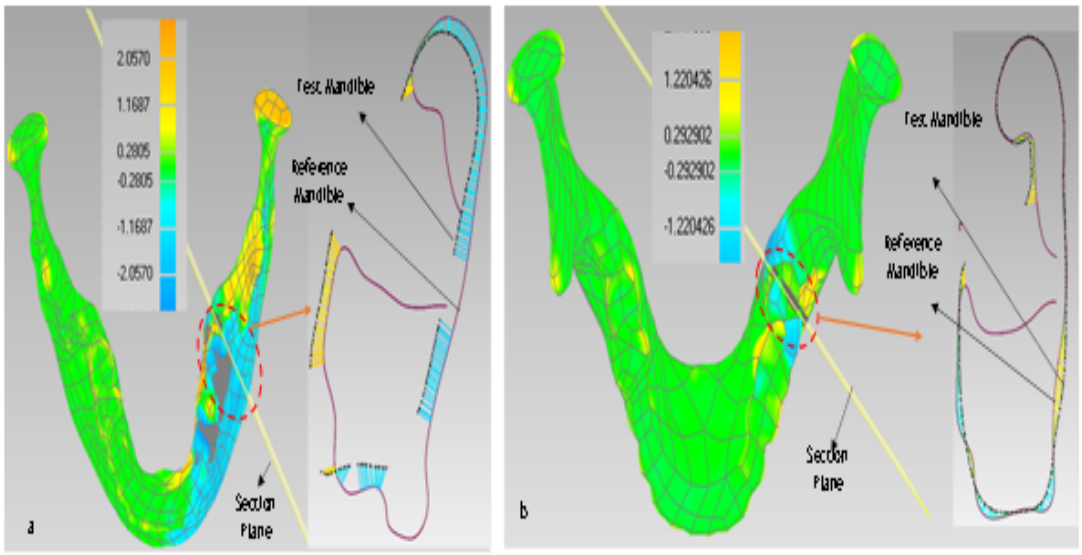

Fig: 7. 2D comparison illustrating the deviation of the (a) mirror test model and (b) anatomical test model from the reference mandible model.

4 RESULTS

Through this study, we presented a comparison of two commonly used mirroring and anatomical implant design reconstruction techniques.

The 3D comparison results from Table 1, shows that the anatomical design reconstruction technique provides lesser average surface deviation with a range of 0.1167/-0.0841 mm when compare to the mirroring design reconstruction technique with a range of 0.4322/-0.4456 mm.

In Comparison, the standard deviation and Root mean square value of the reconstructed anatomical design model is 0.3163 and 0.3176 which is half than that of mirror reconstruction model of 0.7526.

In 2D comparison of the cross section area of the tumor part, we found that the mirroring technique has a surface deviation of approximately 2 mm when compared to 1.2 mm of anatomical design model with the reference mandible.

Table-1. Comparison results for mirror and anatomic reconstruction models

Implant design reconstruction technique	Avg Deviation Max/Min (mm)	Standard Deviation (mm)	Root mean Square Estimate
Mirror Reconstruction Technique	0.4322 / -0.4456	0.7526	0.7526
Anatomical Reconstruction Technique	0.1167 / -0.0841	0.3163	0.3176

5 CONCLUSION

The development and design of customized implants is important to reduce the implant failure and mismatch between the implant and bone interface. There are various methods for designing customized implant, but focus should be given on the implant design technique which provides more accurate and best results with minimum deviation from bone-implant interface.

Comparing the 3D and 2D results of the mirror and anatomical design reconstruction techniques, it was observed that the anatomical design technique has less surface deviation from the reference mandible when compared to the mirror reconstruction technique. The average surface deviation of the anatomical design model is in the range of -0.0841 to 0.1167 mm which is less compared to mirroring technique model with a range of -0.4456 to 0.4322 mm. Based on this research study, we conclude that the anatomical reconstruction design technique is more appropriate technique than mirroring technique in the design of customized mandible implants thus providing an improvement in the accuracy of bone reconstruction. This research study may help the bio-medical engineers in selecting the anatomical design technique in place of mirroring technique as the anatomical design technique is closer to reference mandible model.

ACKNOWLEDGEMENT

This Project was funded by The National Plan for Science, Technology and Innovation (MARRIFAH), King Abdul-Aziz City for Science and Technology, Kingdom of Saudi Arabia, Award Number (12-INF2685-02)

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