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Original Article

Computer Assisted Design and Analysis of Customized Porous Plate for Mandibular Reconstruction

K. Moiduddin [a,b,*] S. Anwar [b] N. Ahmed [a,b] M. Ashfaq [a,b] A. Al-Ahmari [a,b]

[a] *Princess Fatima Alnijiris's Research Chair for Advanced Manufacturing Technology (FARCAMT Chair), Advanced Manufacturing Institute, King Saud University, Riyadh, Saudi Arabia*

[b] *Industrial Engineering Department, College of Engineering, King Saud University, Riyadh, Saudi Arabia*

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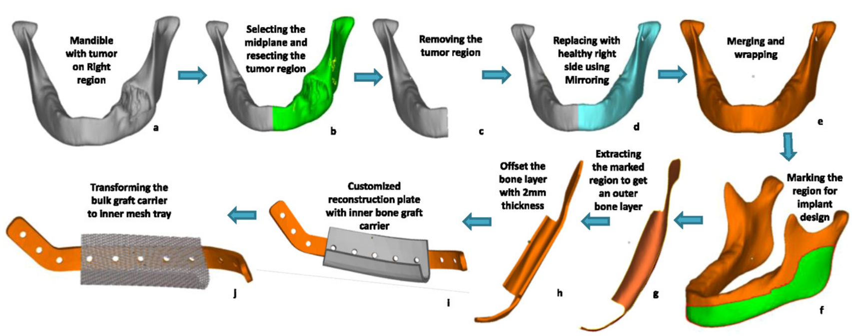
Graphical abstract



Abstract

Background: The reconstruction of large mandibular defects using commercial available reconstruction plates often leads to complications. The application of computer aided design technologies together with advanced medical imaging (CT/MRI) is gaining increased attention in reconstructive surgeries. Studies have proved that implants with porous structures can effectively enhances the biological fixation of the bone. However, no study has been reported on the design and analysis of the customized porous mandibular reconstruction.

Objective: The objective of this study is to present an integrated framework model for the design and analysis of customized porous reconstruction plate based on the selection of implant design techniques.

Method: In this study two customized implant design techniques (mirroring/anatomical) are compared and the best design is selected based on the surface deviation. A 3D finite element analysis was performed on the selected implant design model to evaluate its biomechanical response under chewing conditions.

Results: The finite element simulated results reveal that the designed porous plate can withstand the chewing load conditions and provides good stability. The maximum stresses developed on the reconstruction plate (360 MPa) and screws (122.90 MPa) are significantly less and within the failure limit of implant material.

* Corresponding author at: Advanced Manufacturing Institute (AMI), College of Engineering, King Saud University, Riyadh, Saudi Arabia.
E-mail addresses: kmoiduddin@gmail.com (K. Moiduddin), sanwar@ksu.edu.sa (S. Anwar), anaveed@ksu.edu.sa (N. Ahmed), mashfaq@ksu.edu.sa (M. Ashfaq), alahmari@ksu.edu.sa (A. Al-Ahmari).

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Conclusion: Based on the results, it is recommended to use mirror design reconstruction technique in repair of mandibular bone which can effectively improve the stability and flexibility of mandibular reconstruction under chewing conditions.

Keywords: Mandible reconstruction plate; Porous implant; Implant design selection; Deviation analysis; Finite element analysis; Stress distribution

1. Introduction

Due to educational awareness, rising incidence of surgeries and efforts by the industry players among medical doctors and patients, the adoption of novel technologies in the medical field is gaining momentum. The mandible plays an important role in the facial symmetry, mastication, occlusion and speech functions [1,2]. The chin, lip position, and appearance of the smile are all related to the mandible. Large and continuity mandibular defects are frequently caused by trauma and tumor related issues. Immediate reconstruction of the mandible segmental defects provides the best functional and aesthetic results. Vascularized bone graft with titanium reconstruction plate is the gold standard with primary donor sites, including fibula, iliac crest, radial forearm and scapula [3]. Delayed reconstruction of mandibular defects results in fibrosis and scarring of the hard and soft tissue, making the placement of the reconstructed bone rather difficult and complex [4]. Mandibular reconstruction is a challenging task for maxillofacial surgeons due to the compact and deeply hidden structures.

Commercial available reconstruction plates do not provide a precise reconstruction due to their standard shape and size. Moreover, the surgeons spend a considerable amount of time, bending and shaping the reconstruction plate to match the patient's jaw contours. The over-bending and lack of passive fitting of the reconstruction plate lead to fatigue fracture [5,6]. Fatigue wear and fracture has been reported as one of the major problems associated with the implant loosening, failure and stress-shielding [7]. Continuous over bending is also harmful to material distraction and are susceptible to fractures. Screw loosening, plate exposure and fractures are the most frequent complications faced by the traditional reconstruction plates [8]. In contrast, to match the facial contours and provide better cosmetic results, it is essential to use the concept of customized implant design using medical modeling software. In addition, new and improved reconstruction implants with mesh structures are needed which can accelerate the healing process. Implants with porous structures have effectively shown long term biological fixation due to bone tissue ingrowth through the pores [9,10].

Designing a customized implant beforehand improves the precision and shortens the surgery time as well. With the advancement of medical technology, specifically the information technology in the last quarter of the 20th century, virtual surgical planning (VSP) and simulation have gained increased attention in reconstructive surgeries. The progress of medical modeling software and its integration with the medical imaging techniques such as computed tomography and magnetic resonance imaging (CT/MRI) provides an opportunity for clinicians to diagnose and perform virtual assessment, simulate and conduct preoperative surgery planning for the entire surgery on the computer itself. Accurate and careful preoperative planning and simulation of the surgeries can increase the predictability of favorable outcomes such as accurate fixation, lower surgical risk and reduction of surgery time.

The present study outlines the computer aided workflow in the design and finite element analysis of the customized porous reconstruction plate starting from the patient CT scan. Finite element analysis (FEA) is a numerical simulation process, allowing simulation of structures that approximates to reality. FEA plays a crucial role in the design of reconstruction plates [11,12] and is widely employed in biomechanical studies to analyze the mechanical behavior of mandibular implants [13,14]. The purpose of this study is to develop an integrated framework model for the design of customized porous reconstruction plate based on the selection of reconstruction design techniques and computing the stresses and strains generated during chewing conditions. These developments are unique in mandibular reconstruction as not many researchers attempted to design and analyze the porous reconstruction plate due to its complexity.

2. Methodology for customized porous reconstruction plate

The flowchart shown in Fig. 1, illustrates the major steps involved in the design and analysis of customized porous reconstruction plate for mandibular reconstruction. These steps are explained as follows.

2.1. Patient with defective tumor

A patient underwent an incisional biopsy procedure in a hospital, which showed a solid, plexiform predominant ameloblastoma. A GE Light Speed VCT XTe 64-row spiral CT was used to scan the patient's facial bones with 3D reconstruction and showed a multicystic lesion with expanded buccal and lingual plates and some cortical perforations. Each slice was composed of 512 × 512 pixels, with slice thickness of 1.25 mm and pixel size was 0.49 mm × 0.49 mm. The obtained DICOM (digital imaging and communication in medicine) images from a CT scan are stored in a database for further study.

2.2. Mandible 3D model preparation

The obtained DICOM files are in 2D format, providing a surgical view of front, side and back end of the patient anatomical structures. The DICOM data (Fig. 2(a)) is processed by stacking the 2D image data to form a 3D surface model (Fig. 2(b)) using medical modeling software "Mimics 17.0®". Mimics® is an image processing software for 3D design and modeling developed by Materialise NV, Belgium. A custom thresholding