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Case Report

3D Printed Maxillofacial Trauma Plates as a Valuable Alternative to Conventional Miniplates: A Case Report

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Abstract

The principles in treating complex mandibular fractures have changed recently, although the objective of re-establishing the occlusion and masticatory function remains the same. Technological upgrades like 3D-printed customized plates and implants have replaced traditional stock plates by achieving safe and desirable anatomical and functional restoration with reduced operative time. In this case report, we aimed to design and employ customized 3D-printed titanium plates for mandibular reconstruction in a case with complex mandibular fracture. A preoperative CT scan of the patient was taken to evaluate the displacement between the fractured segments. Virtual surgical planning was done, and 3D-printed titanium plates were simulated, customized, fabricated, and placed following Champy's line of osteosynthesis for the approximation of fractured segments and to guide the occlusion during surgery. A postoperative CT scan was taken and overlapped with the preoperative virtual surgical plan scan to assess the interfragmentary gap after reduction and the amount of deviation. The result achieved was satisfactory, with no complications reported.

The use of customized 3D printed-Ti plates in the treatment of mandibular fracture had better accuracy and adaptability to the bone, avoided the need for plate bending, improved operator efficiency, and resulted in fracture reduction with satisfactory outcomes.

Keywords: ***Mandibular fractures, Patient specific plates, Virtual surgical planning, 3D titanium plates, Direct Metal Laser Sintering.***

Introduction

Mandibular fractures (MF) are the most diagnosed fractures of the maxillofacial region involving multiple sites with complex morphology, muscular attachments, or loss of occlusal relationships. As the mandible plays a complex role in the aesthetics of the face and functional occlusion, the loss of its continuity leads to compromised functional efficiency and cosmetic deformities thus requiring subsequent treatment modalities. [1,2]. The treatment for such cases require accurate bony consolidation in the correct anatomical position to facilitate standard mouth opening and restore the pre-traumatic occlusion for rehabilitation of patients, as even a mild discrepancy in the bony alignment can significantly change the occlusion [3,4].

Titanium trauma plates are one of the available treatment options and play a crucial role in the semi-rigid internal fixation of MF. However, the application of such plates requires frequent bending and shaping to gain perfect adaptation of the plate to the irregular bony contour of mandible and complex anatomical structures of the maxillofacial region. Any error in the fitting and adaptation of these trauma plates may hinder primary bone-fracture consolidation and affect treatment outcomes. Moreover, repeated shaping may result in local stress concentration and fracture of these plates [4,5].

To avoid such complications, patient-specific 3D-printed plates have been introduced in maxillofacial surgery. It has switched the surgeons' subjective evaluation to a more user-friendly interface for preoperative planning and simulation, intraoperative execution, and to foresee the challenges during the treatment procedures. As compared to traditional trauma plates, customized 3D printed plates are designed and fabricated according to structural details of the defect with acceptable accuracy and stability for an adequate fit to the bony segment of the mandible to achieve safe and desirable anatomical restoration [6,7,8]. Different studies have been documented frequently in recent years on the use of patient-specific, three-dimensional (3D) printed plates and implants in oral maxillofacial surgery. Li et al [9] in a study used customized 3D printed plates in maxillary and mandibular jaw reconstruction whereas Singare et al. [10] fabricated personalized 3D printed implants for repairing the mandible. Similarly, Jardini et al. [11] used a customized 3D-printed implant for surgical reconstruction of a large cranial defect.

With this knowledge, the present case report deployed a novel method of mandibular restoration using customized 3D-printed Ti-alloy (Ti6Al4V) plates in the management of mandibular fractures.

Case report

A 29-year-old male patient reported to the Department of oral and maxillofacial surgery (OMFS), Navodaya dental college (Karnataka, India), with a chief complaint of difficulty in opening the mouth and pain in the lower left front tooth region. Patient had a history of fall from the tractor the previous day. Extraoral inspection showed diffuse swelling in the left lower third of the face. Intraorally, an anterior open bite and right posterior crossbite were observed, along with a step deformity palpable between lower left lateral incisor and canine. Panoramic radiography (OPG) and 3-dimensional Computed tomography (CT) scan were taken for preoperative diagnosis, (**Fig 1**) which revealed displaced left parasymphysis and undisplaced right mandibular ramus fracture. Open reduction and internal fixation (ORIF) with 3D printed titanium plate for displaced left parasymphysis and close reduction for undisplaced right ramus fracture was the elected choice of treatment. Before initiation of treatment, the patient was explained about the procedure, and written informed consent was taken.

Preoperative surgical planning began with a CT scan of the patient's mandibular area and the construction of a 3D model. Patients were scanned using 128-slice CT (Ingenuity core 128-Philips Healthcare (Suzhou)co., Ltd) with a slice thickness of 1 mm and image matrix size of 512×512. The images were imported as data files in Digital Imaging and Communications in Medicine (DICOM) format using an online network. Virtual 3D volumetric reconstruction of fracture segment was done in 3D slicer 4.11.0 and converted to stereolithography Standard Tessellation Language (Stl) file format by the collaborated team of surgeons and biomedical engineers. The fracture areas were restored virtually based on the normal anatomy on the contralateral side, and optimal virtual reduction of the fractured segment was attained. The occlusion was also checked virtually to ensure entire anatomical and functional reduction of the mandibular fracture. A stock plate of 2mm was scanned and used as a preliminary sketch for a 3D printed plate. Next, a patient-specific 3D plate were designed (Autodesk meshmixer) and fabricated based on the profile of the virtually restored fracture segments. Holes were incorporated in this plate design to fix and maintain the restored mandible position. The fabrication of the 3D printed-Ti plate was done using Titanium- 6 aluminium- 4 vanadium (Ti6Al4V) alloy powder by direct metal laser sintering (DMLS) equipment (EOS M100, Germany). The fabricated plate was autoclaved in a steam sterilizer at the temperature of 121℃ and pressure of 15 psi for 15 minutes prior to its use in surgery. Before sterilization, plates were checked for accurate adaptation on FDM patient-specific 3D printed models, to ensure perfect adaptation so as to maintain the stability of restored fracture segments during the operative procedure. (**Fig 2**)

Under general anaesthesia, an intraoral vestibular incision was adopted on the anterior mandibular region, and a mucoperiosteal flap was reflected till the lower border. Mentalis muscle was incised, bilateral tunnelling of submucosa was done up to premolar region and periosteal layer was reflected to expose the fracture fragments. After gaining satisfactory approximation into their anatomical position, intermaxillary fixation (IMF) was done using two 1 mm thick 3D printed-Ti plates (2-hole and 4-hole plate with gap) and occlusion was assessed. These plates were adapted on the fractured segments according to Champy's line of osteosynthesis and fixed perpendicularly to the cortical bone using 2 mm monocortical screws. Adaptation of plates was satisfactory, and there was no need of plate bending. After IMF release, confirmed occlusion, and copious irrigation, incision closure was performed in layers using 3.0 vicryl (Ethicon) sutures. Medications were prescribed for five days, and dietary and oral hygiene instructions were given. (**Fig 3**)

The postoperative recovery was uneventful, and no major complications were observed. Postoperative CT scan was taken and overlapped with VSP to measure the interfragmentary gap between the fractured segment after reduction. The results were satisfactory with minimum deviations and displayed perfect continuity of the inferior border of the mandible, buccal and lingual cortices. (**Fig 4**)

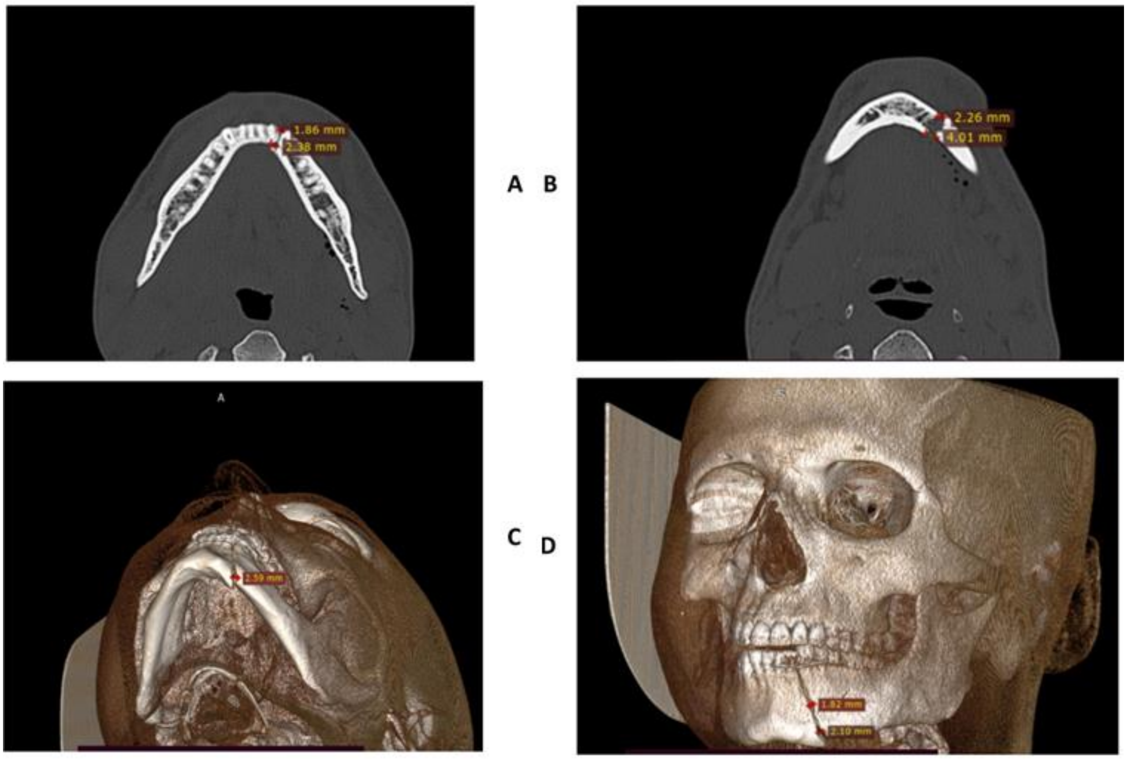

Figure 1: Preoperative CT of the patient showing displaced left parasymphsis fracture of the mandible between lateral incisor and canine. CT - Computed Tomography (a) axial section at alveolar bone level (b) axial section at inferior border (c & d) 3D reconstruction showing fracture with interfragmentary gap

Figure 2: (a) 4- hole and 2- hole fabricated customised 3D titanium plate. (b) 3D titanium plates placed and adapted on patient's 3D printed mandible model.

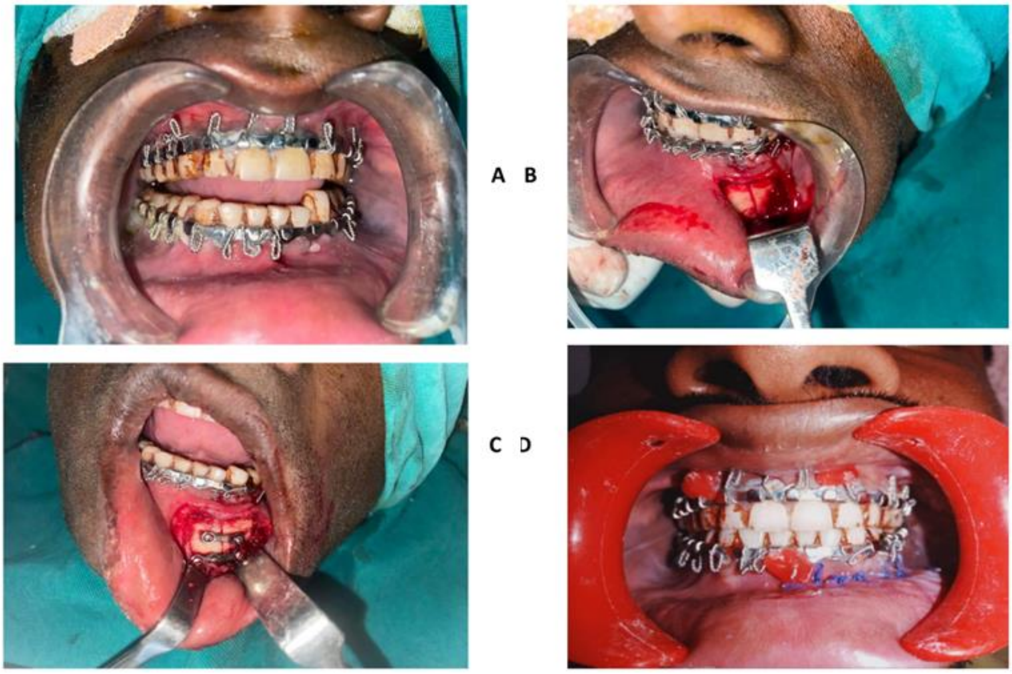

Figure 3: (a) Preoperative view showing a step deformity between lower left lateral incisor and canine with anterior open bite and right posterior crossbite. (b) Intraoperative view exposing the fracture segment. (c) Patient-specific 3D titanium plates adapted and fixed to the fractured segments using cortical screws. (d) Suturing done and confirmed stable postoperative occlusion.

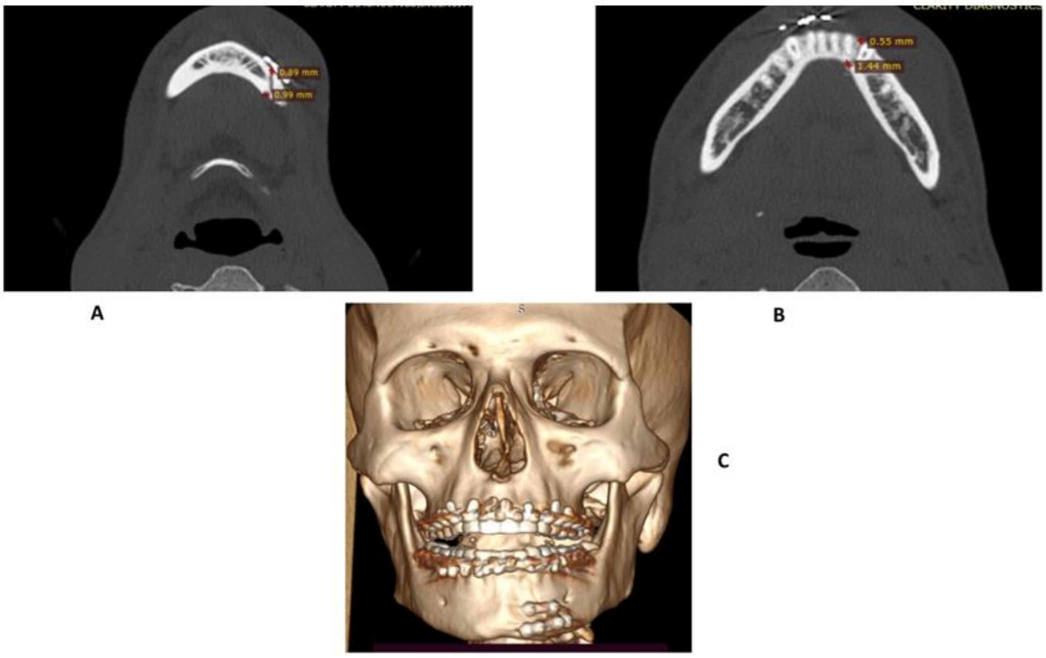

Figure 4: Postoperative CT scan of the patient revealing reduced interfragmentary gap between fractured segments and continuity in the (a)inferior border of the mandible (b) at alveolar bone level (c) and in 3D reconstruction

Discussion

The implementation of advanced technology like virtual surgical planning (VSP) and three-dimensional(3D) printing during the treatment of maxillofacial trauma provides a direct and clear 3D view of the fracture site, their displacement patterns in different angulations and its spatial relationship to surrounding components, thus giving adequacy of the required reduction process. Furthermore, it also aids in the fabrication of patient-specific surgical guides and plates for precise fracture reduction intraoperatively [12,13,20].

Currently, Titanium (Ti) & Ti-based alloys such as Ti6Al4V have broadly been applied in dentistry as guides, plates, or implants due to their excellent biomechanical properties and biocompatibility. Ti alloy plates are often used for robust internal fixation in reparative and reconstructive surgeries, playing a crucial role in OMFS. The biomechanical properties of Ti plates enable them to provide sufficient strength, rigidity, and stability during the internal fixation of fractured bone segments [14,15]. In the present case, we have used VSP and 3D printing to virtually manipulate and simulate the displaced bone fragments at any angle to achieve an adequate reduction process intraoperatively and to fabricate customized plates virtually. The virtual preoperative surgical planning enabled the operator to have a 3-dimensional visualization of the fracture segments and their spatial relationships to surrounding structures. At the same time, the 3D printed-Ti plates allowed for an accurate transfer of this preoperative virtual surgical plan to the actual procedure in the patient.

Due to the irregular bony architecture and complex anatomical structures of the maxillofacial region, plate shaping or bending is often done for trauma plates to obtain a precise adaptation to the bone surface for meticulous restoration of fractured segments. It was reported that the bone-plate contact rate of the standard Ti plate was only 53% which could be increased to 66% by pre-bending the plate [4,15]. However, attempts at plate shaping can generate micro fissures and brittle points, resulting in local stress concentration and premature fracture of plates, thereby affecting bone-fracture consolidation. The greater the bending angle of the Ti plate, the greater the stress and the more deviation from the design scheme [15,16].

Plate fracture in about 2.9-10.7% of mandibular injury cases has been reported in scientific literature [17]. This complication can be avoided with the use of a customized 3D printed plate due to its superlative accuracy and fit to the bony surface. Wang et al. [16] reported that the bone-plate contact rate of the 3D printed-Ti plate was 98.1% when used for a mandibular fracture model. Similarly, the present study also verified a perfect adaptation of patient-specific 3D printed-Ti plate to anatomical bone contour intraoperatively without requiring any further adjustments. The customised plate also acts as a guide to confirm accurate reduction of the mandible as visualised in the VSP. If the plate fits perfectly, it can be assumed that the reduction is as planned.

In this study, Ti plates were virtually designed, and customized based on a 3D CT scan image to fit perfectly and remain precisely in the designed position without slipping. It also provided adept consolidation of fracture segments and had the ability to reinforce native mandible. The 3D fabricated Ti plates used were of lower profile, about 1mm thick, and had decreased postoperative palpability. Different studies claimed that using a 1mm thick 3D printed-Ti plate for fracture fixation stabilized the maximum displacement and minimized the stress shielding, providing a secure environment for fracture healing. Also, when used, the mechanical properties of the 1 mm 3D printed-Ti plate were significantly better as compared to stock Ti plates of the same thickness [18,19].

The present report observed no postoperative complication, and the internal fixation with patient-specific 3D printed-Ti plates allowed for adequate intercondylar length restoration with reduced surgical duration and simplified the overall treatment procedure. The occlusion achieved was also stable and did not require any post operative maxillomandibular fixation. However, potential limitations were noticed with the use of 3D printed-Ti plates, like high cost and a prolonged phase for preparation with elaborate infrastructure requirements. Also, the software for 3D printing was technique-sensitive and required additional support from a proficient technician for precise segmentation and virtual 3D construction of both hard and soft tissues.

Conclusions

The present case report illustrates a more precise reduction and stabilization of the mandibular fracture using customized 3D printed-Ti plates with favourable aesthetic and functional outcomes and maximum patient satisfaction. Due to the superior biomechanical properties and accuracy, a 3D printed-Ti plate can be a credible alternative to the standard Ti plate and are more feasible to use for irregular shapes and complex anatomical structures in a clinical scenario. However, there is a need for further meticulously designed comparative studies and randomized clinical trials to evaluate the superior properties and long-term effects of 3D printed-Ti plates in the acute management of complex maxillofacial fractures.

Ethics approval and consent to participate

The study was approved by institutional ethics committee of navodaya dental college and hospital, Raichur provisionally registered by NECRBHR, DHR No.-2639

List of abbreviations

3D: 3Dimension
Ti: Titanium
CT: Computed Tomography
FDM: Fused Deposition Modelling
VSP: Virtual Surgical Planning

Data Availability

The clinical and radiographic images shown in the paper are already available in the manuscript.

Conflicts of Interest

"The author(s) declare(s) that there is no conflict of interest regarding the publication of this paper."

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Authors has no financial or other competing interest.

Authors' contributions

1.CC Substantial contributions to the conception or design of the work; or the acquisition, analysis, or interpretation of data for the work; AND drafting the work or reviewing it critically for important intellectual content; AND Final approval of the version to be published; AND Agreement to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. 2. KG Drafting the work or reviewing it critically for important intellectual content 3.SM Substantial contributions to the conception or design of the work; or the acquisition, analysis, or interpretation of data for the work 4. Substantial contributions to the conception or design of the work; or the acquisition, analysis, or interpretation of data for the work.5.MV Substantial contributions to the conception or design of the work; or the acquisition, analysis, or interpretation of data for the work.

All authors read and approved the final manuscript."

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