Clinical Case Report

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The use of 3D-printed titanium mesh tray in treating complex comminuted mandibular fractures

A case report

Junli Ma, PhD[a], Limin Ma, PhD[b], Zhifa Wang, PhD[a], Xiongjie Zhu, MD[a], Weijian Wang, MD[a,*]

Abstract

Rationale: Precise bony reduction and reconstruction of optimal contour in treating comminuted mandibular fractures is very difficult using traditional techniques and devices. The aim of this report is to introduce our experiences in using virtual surgery and three-dimensional (3D) printing technique in treating this clinical challenge.

Patient concerns: A 26-year-old man presented with severe trauma in the maxillofacial area due to fall from height.

Diagnosis: Computed tomography images revealed middle face fractures and comminuted mandibular fracture including bilateral condyles.

Interventions and outcomes: The computed tomography data was used to construct the 3D cranio-maxillofacial models; then the displaced bone fragments were virtually reduced. On the basis of the finalized model, a customized titanium mesh tray was designed and fabricated using selective laser melting technology. During the surgery, a submandibular approach was adopted to repair the mandibular fracture. The reduction and fixation were performed according to preoperative plan, the bone defects in the mental area were reconstructed with iliac bone graft. The 3D-printed mesh tray served as an intraoperative template and carrier of bone graft. The healing process was uneventful, and the patient was satisfied with the mandible contour.

Lessons: Virtual surgical planning combined with 3D printing technology enables surgeon to visualize the reduction process preoperatively and guide intraoperative reduction, making the reduction less time consuming and more precise. 3D-printed titanium mesh tray can provide more satisfactory esthetic outcomes in treating complex comminuted mandibular fractures.

Abbreviations: 3D = three-dimensional, CMFs = comminuted mandibular fractures, DICOM = Digital Imaging and Communications in Medicine, SLM = selective laser melting.

Keywords: 3D printing, comminuted mandibular fractures, titanium mesh tray, virtual surgery

1. Introduction

The treatment of comminuted mandibular fractures (CMFs) still remains a challenge for surgeons. One of the major intraoperative difficulties is how to restore the contour of fractured sites, considering many cases of CMFs present severe bone displacement and bone loss that make anatomic reduction almost impossible. In addition, bending commonly used reconstruction plate is time consuming and mostly depends on surgeon's experiences.[1] Another challenge is how to fix multiple bony fragments reliably. Unreliable fixation is considered the leading factor for postoperative infection. The infection rates as high as 14.3% with reconstruction plate and 30% with miniplates have been reported.[2]

Compared with traditional reconstruction plate, customized titanium mesh tray could provide more satisfying three-dimensional (3D) morphology and stability as it could be shaped to fit the contour of the segment of mandible and fix bony fragments and grafts.[3,4] However, manipulating a titanium mesh to achieve a suitable contour is difficult and less precise. Moreover, repeated bending also decreases mechanical strength of mesh.[5]

Vast advances in virtual surgery and 3D printing technique have greatly improved surgical accuracy and efficiency.[6,7] Some researchers also use a 3D-printed mandible model to produce a customized mesh tray by handy manipulation of commercial titanium sheet.[8] In our report, we would like to introduce our experiences in using virtual surgery and 3D printing technique to directly print a customized titanium mesh tray, which have been successfully applied in treating complex CMF.

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JM and LM contributed equally to this work.

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[a] Department of Stomatology, [b] Department of Orthopedics, Guangdong Key Laboratory of Orthopedic Technology and Implant Materials, Guangzhou General Hospital of Guangzhou Military Command, Guangzhou, China.

[*] Correspondence: Weijian Wang, Department of Stomatology, Guangzhou General Hospital of Guangzhou Military Command, the liuhua road 111#, Guangzhou, Guangdong 510010, China (e-mail: wweijian_dr@126.com).

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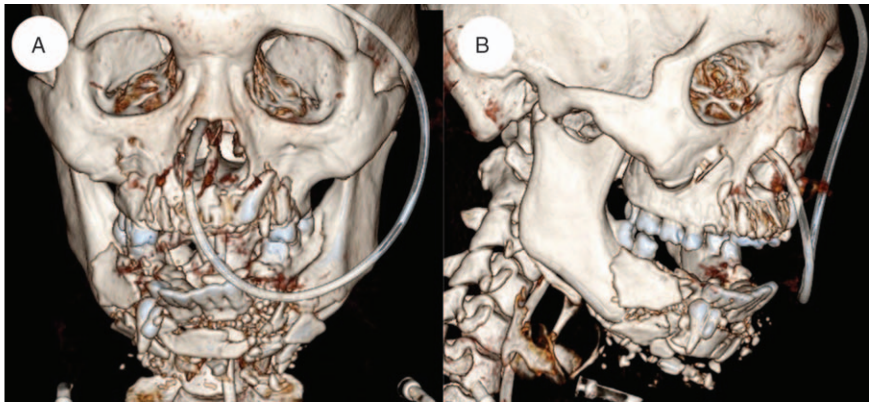

Figure 1. Preoperative CT of the patient. A, Front view, and B, lateral view, showing severe comminuted mandible fractures. CT = computed tomography.

2. Case report

A 26-year-old man was transferred to our department with severe maxillofacial trauma due to fall from height after 1 month's treatment in intensive-care unit. Physical examination showed extensive swelling of maxillofacial area. Both the upper and lower dentitions were severely impaired, leading to loss of normal occlusal contacts. The patient had severe difficulty opening and closing the mouth. He relied on nasogastric tube for feeding. His past medical history was nonsignificant. Computed tomography (CT) scan revealed middle face fractures and extensive CMF extending from ramus to ramus including bilateral condyles. The mental area was the most heavily traumatized region with multiple displaced bone fragments of varying size (Fig. 1).

The surgery planning phase began with the construction of the 3D model. The patient was scanned using dual-source, 64-slice spiral CT (SOMATOM Definition CT, Siemens Healthcare, Forchheim, Germany) with a slice thickness of 0.7 mm and an image matrix size of 512×512. The images were processed as data files in the Digital Imaging and Communications in Medicine (DICOM) format using an online workstation. The cranio-maxillofacial models were constructed using the ScanIP v.5.0 of the Simpleware. Virtual reduction of bony fragments was performed through the collaboration between surgical team and biomedical engineers. By trial movements of the comminuted segments, optimal "virtual" reduction was achieved. The fractured or defected area was restored by mirroring the contralateral side or based on the normal anatomy of the region. Then a mesh tray was designed based on the contour of restored site. Slots were reserved on both sides for entrance of the mental nerve (Fig. 2). The cranio-maxillofacial model and mesh tray designed were then exported in the "StereoLithography" format.

The manufacturing of Ti6AI4 V cellular mesh tray was carried out in a selective laser melting (SLM) commercial equipment (Concept Laser M2, Upper Franconia, Germany). The machine is equipped with an Yb-Faser-Laser and a focus beam diameter of 50 μm. The processing occurs under an Ar/N2 atmosphere. The SLM processing parameters used in this study were as follows: a

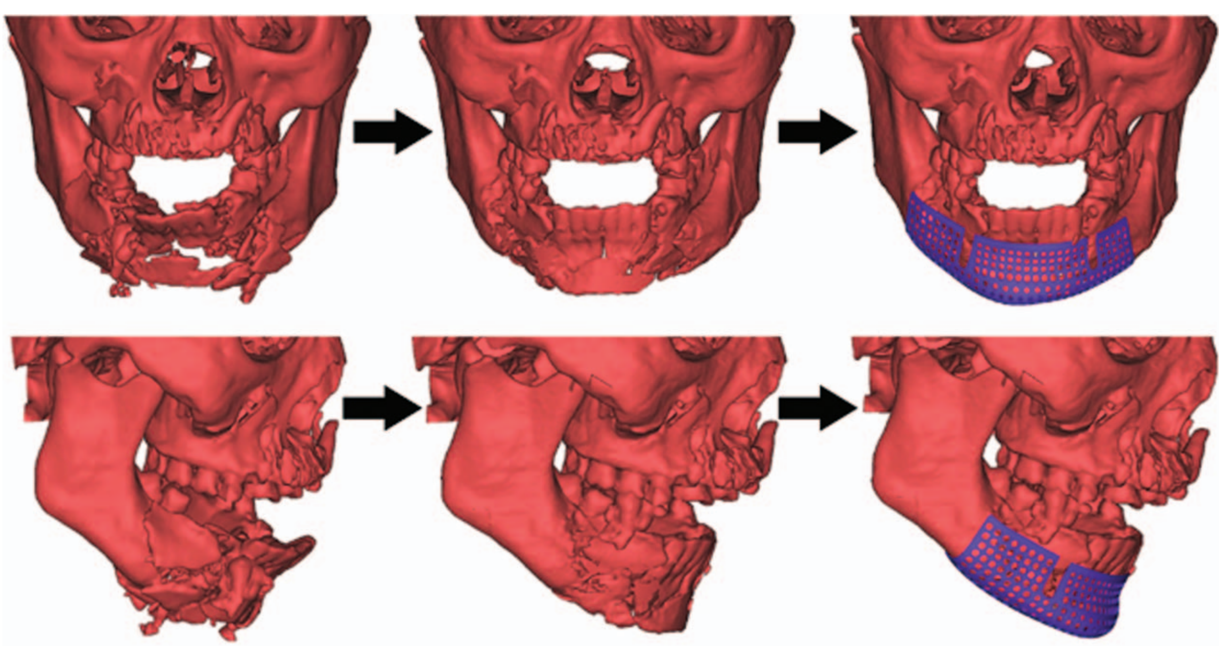

Figure 2. The process of virtual reduction and design of titanium mesh tray.

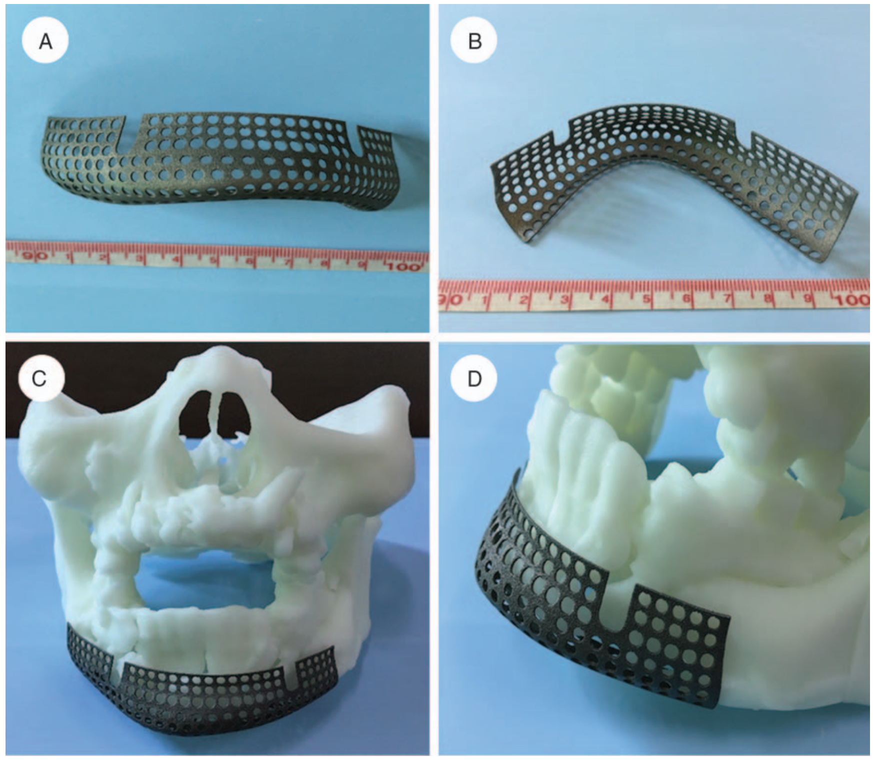

Figure 3. The front view (A) and back view (B) of the 3D-printed customized titanium mesh tray. C and D, The mesh tray inserted on 3D-printed scull model. 3D = three-dimensional.

laser power of 100 W, a scan speed of 650 mm/s, a scan spacing of 70 μm. The mesh tray was built on a platform and once produced, the tray was cut from the platform and then the building supports were removed. Then, the tray was immersed in an ultrasonic bath containing isopropyl alcohol for 10 minutes to remove residual powders during the process (Fig. 3).

The surgery was performed under general anesthesia. Bilateral condyle fractures were first treated by open reduction and fixation via traditional preauricular approach. Then an extraoral submandibular incision on both the sides was adopted. Some bone fragments smaller than 1 cm were discarded; the mesh tray was then positioned according to the planed site. The remaining bone fragments were subsequently reduced under the guide of mesh tray. Once reduced, the bone fragments were fixed to the tray using commercial titanium screws. A bone defect in size of 5 cm presented in the lower half of the central mental area. The bone graft harvested from left anterior iliac was shaped according to the geometry of titanium mesh tray and then was fixed with titanium screws (Fig. 4A and B). The wound was closed after plentiful irrigation. Postoperative maxillomandibular fixation was performed for 2 weeks.

The postoperative recovery was uneventful, and the patient was discharged at the 3rd postoperative week. He was followed up at 2 months later and underwent CT scan. There were no obvious clinical signs of inflammation, and the patient was satisfied with the appearance of mandible. The CT images revealed favorable morphology of mandible without signs of bone resorption, and the mesh tray was covered in partial by bone callus (Fig. 4C and D). The removal of mesh tray was scheduled 1 year after surgery. This study was approved by the ethics committee board of the Guangzhou General Hospital of Guangzhou Military Command. Informed consent was given by the patient.

3. Discussion

Treating CMFs is difficult even for experienced surgeons mainly due to the difficulties in accurate reduction and fixation of comminuted bone fragments, especially for cases involving loss of anatomic references or occlusal relationship. In addition, CMFs are often accompanied with bone defect, and how to restore bone defect and achieve satisfying appearance is another aspect that must be taken into preoperative consideration.

In the present case, severely displaced bone fragments, bone defect, and loss of normal occlusal relationship all make the reduction and restoration extremely difficult. Especially, the most severe fracture lies in the mental area of mandible, an area with complex geometry. Numerous tiny bone fragments are nearly impossible to be anatomically reduced to restore the natural curve in this area. Moreover, there are only limited occlusal contacts in the posterior molars, which is not enough to guide accurate alignment of alveolar bone bearing anterior lower teeth in the anteroposterior direction. In the past, reduction of such a complicated fracture was usually achieved by repeated tries and modifications according to surgeons' experiences, making the process time-consuming and the results highly variable.[1,9]

Great advances in virtual surgery, computer-aided design, and manufacturing have greatly improved the surgical accuracy and efficiency. Virtual surgery enables surgeons to simulate reduction preoperatively by virtually manipulating bone fragments at any angle and determine the optimal position for fragments. With 3D printing technology, various surgical templates can be easily fabricated to guide precise reduction intraoperatively.[8,10] With the assistances of these technologies, the therapeutic outcomes have become more reliable and predictable. Currently, these technologies have been attempted in multiple maxillofacial

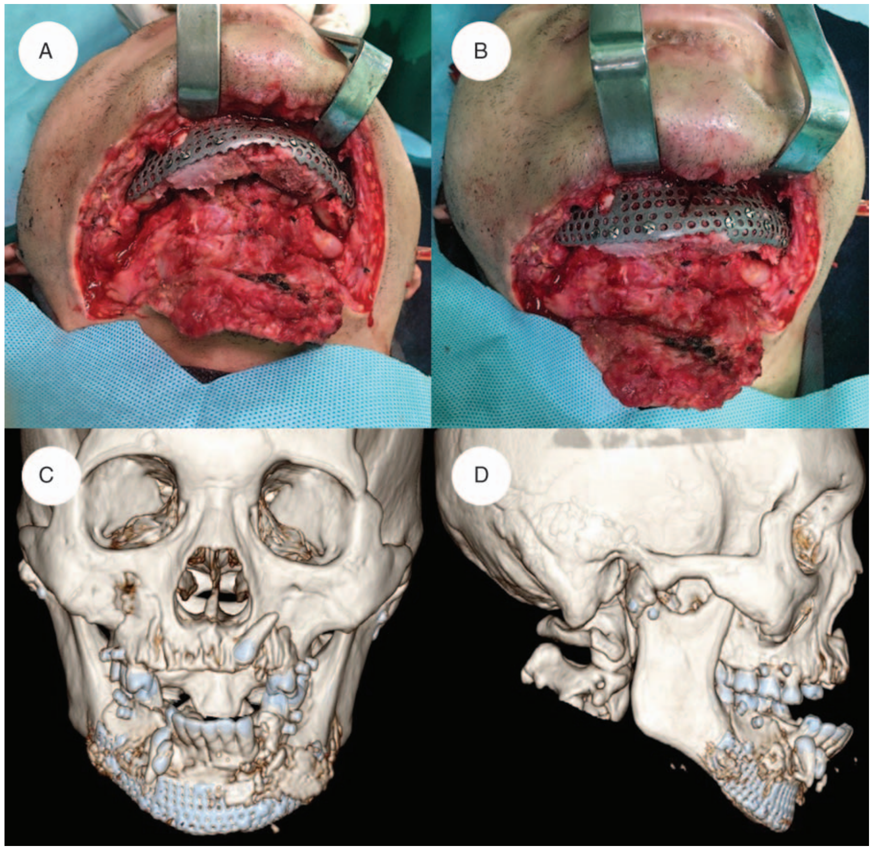

Figure 4. A and B, Intraoperative view of 3D-printed titanium mesh tray and iliac bone graft after bone reduction. Front view (C) and lateral view (D) of 3D CT images of mandible 2 months after surgery. 3D = three-dimensional, CT = computed tomography.

surgery areas, including head and neck reconstruction,[11,12] orthognathic surgery,[7] and maxillofacial trauma.[13,14]

In the present case, we used virtual surgery to simulate the reduction process. With close collaboration between surgery team and engineers, the optimal sites of displaced fragments could be determined preoperatively. The surgeons could have a direct and clear view about the morphology of fractured sites to be reduced. More importantly, the mesh tray fabricated by 3D printing technology based on finalized model could guide the intraoperative manipulation. All these factors led to reduced surgery time and better outcomes.

The major improvement of the present study is the use of 3D-printed mesh tray to restore the morphology of mandible. In fact, the usage of mesh tray has been advocated in the treatment of mandibular comminuted fractures and discontinuity defects for a long time, as it could provide more satisfying 3D morphology and stability than traditional miniplates and reconstruction plates.[3,4] There are several commercially available mesh trays, like Dacron urethane tray,[15] Dumbach Titan Mesh-System,[16] and KLS Martin Mandible Mesh Tray. They are in nature a simulation of partial mandible and need to be adapted by hand intraoperatively to fit the contour of mandible. Then, with the advances of computer-assisted design and rapid prototyping technologies, precise model of individual patient's mandible could be easily fabricated preoperatively, and titanium mesh could be manually adapted to make more precise trays.[1,8] But, in general, these customized mesh trays are still hand-fabricated utilizing prefabricated commercial titanium mesh. It is time-consuming to achieve a precise contour. Moreover, repeated manipulation also decreases mechanical strength of mesh.[5,8]

In the present study, the customized titanium mesh tray was directly printed by rapid prototyping machine after virtual surgery and design, which greatly improved accuracy of tray, sparing the need of hand manipulation. Besides, surgeons can easily change the design of tray to meet the specific needs of varying patients, resulting in a truly customized tray. In the present case, the printed titanium tray possessed the normal contour of mental area, and this geometry is difficult to acquire by manipulating commercial mesh by hand. As a carrier of iliac bone graft, the customized tray could provide sufficient support for overlying soft tissues and reliable fixation of bone fragments. The perforations of tray also allow for rapid revascularization of the bone graft site.

The main limitations of the 3D-printed titanium mesh tray are the higher cost and relative long preparing phase from design to fabrication. In addition, there are 2 aspects that need to be improved regarding the 3D-printed titanium mesh tray. The first one is the design of mesh trays. The balance between the mechanic strength and permeability has to be achieved by changing the shape and structure of tray, allowing enough strength to withstand the masticatory load and rapid revascularization of the bone graft site.[16] Preventing stress shielding is also a consideration in the design of tray.[17] Because of limited cases, the long-term effects of 3D-printed titanium mesh tray still need to be evaluated. Another aspect is related to the materials of tray. Currently, titanium and its alloys are the most frequently used material, and the mesh tray needs to be removed after bone healing. Recently, biodegradable materials, like hydroxyapatite/poly-L-lactide, have been used in the fabrication of customized mesh tray.[18] The advances in material science and 3D printing technology will produce integratable implants for specific individuals in the near future.[9]

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