# Functional Reconstruction in Mandibular Avulsion Injuries

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**Abstract:** The present report describes the planning and surgery as well as pitfalls and management of a patient with a near total mandibular avulsion injury that was rehabilitated using three-dimensional (3D) laser printing of a titanium lower jaw. Laser-sintering involves zapping layers of powdered metal to recreate a 3D implantable skeletal defect. The process involves using either mirror imaging of the unaffected side or using archival image database of healthy individuals. A 25-year-old man presented with a gunshot injury that left him with a near total avulsed mandible. The patient received state-of-the-art treatment using a laser 3D printed mandible which was connected to the muscles of mastication for functionality. The inner side of the titanium jaw was filled with the patient's comminuted fractured bones in addition to harvested iliac crest bone graft that was covered with the patient's remaining periosteal tissue. The implantation of a near total mandible using 3D laser printing is a fast and predictable process that in selected patients can result in aesthetically as well as functionally excellent results. The authors believe that the future of craniofacial reconstruction will employ these methods for facial bony reconstruction.

**Key Words:** Facial reconstruction, laser printing, mandible, patient-specific implant, PSI

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Historically, three-dimensional (3D) printing was known as Stereolithography or "SLA" printing. The method was invented with the intent of allowing engineers to create prototypes of their designs in a more time-effective manner. The term "stereolithography" was coined in 1986 by Chuck Hull who patented stereolithography as a method of creating 3D objects by successively "printing" thin layers of an object using a medium curable by ultraviolet light, starting from the bottom layer to the top layer. Variations of this process were used by many others ever since.[1] There are quite a few reports on using a stereolithography model as a template or guides as described by Kernan and Wimsatt[2] to preoperatively bend a reconstruction plate that is functional and results were with acceptable precision.[3]

Laser-sintering involves zapping layers of powdered plastic or metal with a laser to harden the powder in specific areas. When an area of bone is missing in the craniofacial region this could have both aesthetic and functional effects. Until recently to reconstruct these voids either bone grafting or alloplastic materials such as bone plates and titanium mesh's were used. Sometimes, alloplastic materials such as reconstruction plates are used alone and a second, late, bony reconstruction following a time interval is performed to reconstruct these voids in the patient's skeleton. In other patients, reconstruction using primary microvascular free bone flaps, such as fibula or iliac crest flaps, in combination with reconstruction plates or miniplates is performed for primary and secondary reconstruction.

Computer-assisted virtual planning of craniofacial reconstructions with bone flaps and the use of resection and cutting guides that are manufactured via computer-aided design and computer aided manufacturing techniques have gained popularity in recent years and are used routinely in clinical practice.[4–7] Patient-specific implants (PSI) are manufactured and designed to help in the reconstruction of skeletal voids due to loss of craniofacial bone. The main benefit in using PSI is superior anatomical matching as compared with conventional reconstruction methods (titanium plating, microvascular free flaps, etc.).

The most popular materials used to date are polyether ether ketone (PEEK) that is used for large defects in the mid and upper thirds of the craniofacial domain and commercially pure titanium that has a higher modulus of elasticity from that of cortical bone and is chosen in load-bearing areas such as mandible reconstruction.

In the present article, we describe the reconstruction of a large post traumatic avulsed mandible using a patient specific implant.

## METHODS

A 25-year-old man was urgently transported by helicopter to the emergency department at our medical center due to a severe maxillofacial trauma in the lower third of the face, from what seemed to be a rifle wound injury. Upon admission the patient was conscious (Glasgow coma scale = 13). The patient was bleeding severely from his submental area. Physical examination revealed a penetrating wound at his left mandibular angle area, comminution and partial avulsion of the mandible and an exit wound at the mid mandibular-mental area (Fig. 1A and B). The patient underwent emergency intubation and was taken to the imaging department for angio-computerized-tomography. His imaging findings revealed a subtotal comminuted mandibular injury with severe bone avulsion. The temporomandibular joints and the ascending ramous on both sides were intact. There was a total avulsion of the mandibular dentition except for the third molars (Fig. 2). Following the initial stabilization and airway securing the patient was rushed to the operating theater and the oral intubation was converted to a tracheostomy. A surgical incision of the neck from mastoid to mastoid was performed to gain access to the mandible. Following exploration and bleeding control, primary mandibular stabilization was established using a 2.4 reconstruction plate (Synthes, Solothurn, Switzerland) with an attempt to salvage the remnant mandibular bone and create separation of the intraoral compartment from the neck. Unfortunately due to the extensive defects and loss of 3D facial relations and proportions, the reconstructed relations were in-proper sagittaly (posterior-anteriorly), vertically, and transversely (Fig. 3A and B). This caused the patient disability and improper

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FIGURE 1. A 25-year-old patient suffering from severe comminution and partial avulsion of the mandible and soft tissue resulting from a rifle injury. (A, B) Soft and hard tissue avulsion is observed on arrival.

function manifested by difficulty in opening and closing the mouth (Fig. 3C). This condition required a secondary lower face reconstruction. For the second stage of reconstruction, based on 3D computed tomography (CT) imaging, a titanium PSI was fabricated using pure titanium and laser sintering (AB Dental, Ashdod, Israel). It was designed between the two angles of the mandible with an inner cradle to accommodate the remnant mandibular bone together with iliac crest free bone graft. The implant was designed with specific areas of exposed bone to allow the reattachment of the muscles of mastication; masseter, medial pterygoid, and the anterior bellies of the digastric muscles, thus allowing the mandible to function following the surgery.

The size and shape of the mandible was designed based on an estimation of the shape of the original mandible in reference to the remaining maxilla and using archival images of mandibular CT scans of other patients. A final mandible with similar projection and arch form was embedded into the patient's CT (Fig. 4).

Three weeks following the first surgery the patient was reanesthetized and using the initial extra-oral approach the former reconstruction plate was removed and replaced by the new well fitting PSI that was fixed to the remaining mandibular ramus bilaterally. Careful attention was paid to preserve the oral mucosa intact. The remnant vital comminuted mandibular bones were placed in the cradle of the PSI with addition of iliac crest bone graft in the bony voids. Small areas of discontinuity in the harvested bone graft were filled using xenograft bone substitute (Bio-oss, Geistlisch, Switzerland) and the entire bony reconstruction was covered using collagen membranes (Biogide, Geistlisch, Switzerland) to serve as barrier for complete bony regeneration (Fig. 5A). The surgical incision in the neck was closed (Fig. 5B). Postoperative management included antibiotic treatment (Amoxicillin calvulonic acid, 1grX3/d I.V.) and soft diet.

## RESULTS

Postoperative functional and 3D facial reconstruction results were satisfactory (Figs. 6 and 7) and following physiotherapy, a mouth

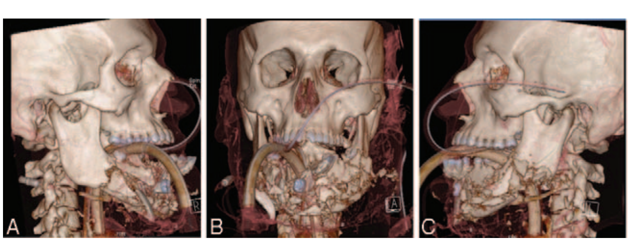


FIGURE 2. Three-dimensional computed tomography performed with arrival demonstrates the severely comminuted mandible from the right to the left angle. (A) Right lateral aspect. (B) Anterior aspect. (C) Left lateral aspect.

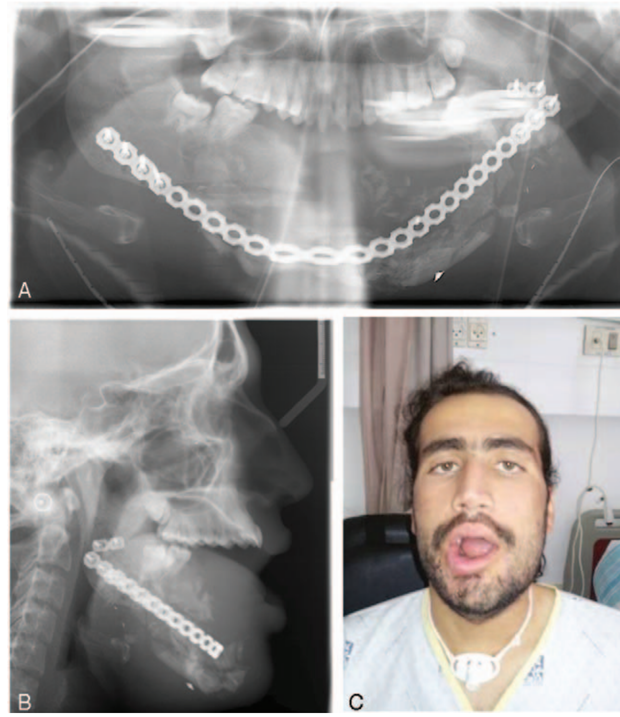


FIGURE 3. Following the first surgery. (A, B) Pantomogram and lateral cephalometric x-ray accordingly showing the reconstruction using a 2.4 reconstruction plate. The increase in the lower facial height and improper intermaxillary relations and countering of the mandible can be observed. (C) The patient had difficulty in mobilization of the mandible.

opening of 40 mm and complete antero-posterior and lateral mandibular movements were achieved.

Proper fixation of the PSI was observed and the condyles are in place.

Surgical incisions underwent proper healing with no secondary infection.

The patient had follow-ups of 6 months showing good incorporation of the PSI and bone graft with good functional and aesthetic results. Proper lower facial height was achieved.

In the near future our patient will return for the final dental reconstruction using dental implants that will be inserted to the newly generated mandibular bone and final fixed prosthetic teeth will be manufactured.

## DISCUSSION

In craniomaxillofacial surgery, reconstruction of congenital or acquired defects of the skull and facial regions is extremely

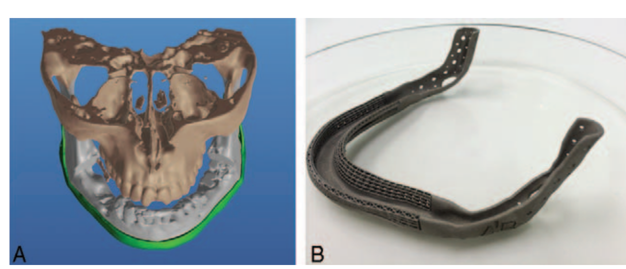


FIGURE 4. The designed PSI. (A) Virtual mandibular reconstruction. (B) The produced titanium PSI. PSI, patient-specific implants.

 

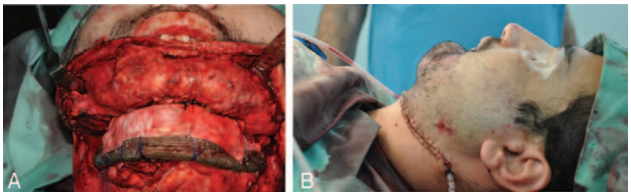


**FIGURE 5.** Intraoperative photographs. (A) Following fixation of the patient-specific implant and insertion of the vital comminuted remnants of the mandible together with iliac crest bone graft and xenograft covered with collagen membranes. (B) Clinical photograph following closure of the surgical incision.

challenging mainly due to the complex anatomy, sensitivity of the involved systems, and aesthetics.[8]

Autologus bone grafts are considered the gold standard for craniofacial skeletal reconstruction. Yet, their use is limited by many factors including the availability of a suitable donor site, especially for large defects, additional costly surgeries with added morbidity, tissue harvesting problems, donor site morbidity with an additional patient discomfort, probability of infection at both the recipient and donor sites, increased surgical time, and in many patients resorption of the graft that requires secondary surgeries. All of the above have led surgeons to the search of alloplastic materials that would be suitable without the inherent problems.[9–11]

Due to advancements in new technologies computer-based treatment planning systems are available (computer-aided design and computer-aided manufacturing), and have greatly facilitated reconstructive surgery that is more precise and predictable.[12] The overall goals are to increase precision and aesthetics and to decrease morbidity and operation time, thereby reducing costs, hospitalization, and improving the quality of our patient's lives. This can be achieved preoperatively by a virtual plan and design in an advanced 3D environment that is then transferred to the operation theater.[3,12] Lack of soft tissue coverage in the surgical bed continues to be the major pitfall in every craniofacial reconstruction, yet a light in the end of the tunnel in the form of 3D tissue printing using the patient's stem cells as building blocks may be the ultimate solution for biological reconstruction of large defects in the future.

The use of laser 3D printing in the presented report resulted in a fast and effective treatment with minimal complications.

Patient-specific implants' main advantage is reconstruction of facial projections anatomically by using a mirror image of the unaffected side (when applicable) and superimposing it on the effected/damaged area. In the present patient in whom there is a bilateral avulsion of the lower facial bony segments the 3D planning of the vertical, sagittal, and transverse defects was performed using

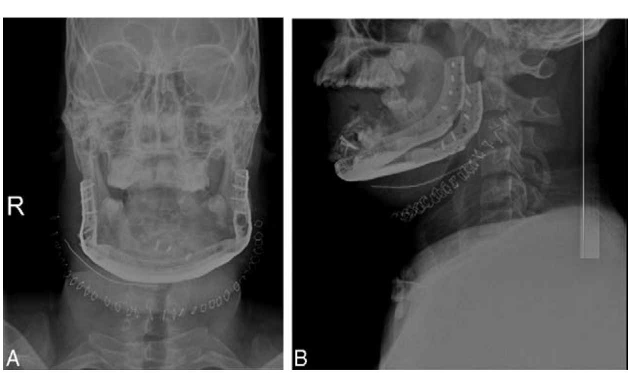


**FIGURE 6.** Postoperative radiographs demonstrating the fixed patient-specific implants in proper facial relations. (A) Anterior-posterior cephalometric radiograph. (B) Lateral cephalometric radiograph.


**FIGURE 7.** Two-month postinsertion of patient-specific implants. (A) Anterior view. (B) Lateral view. Proper facial proportions can be observed.

the unaffected maxilla and facial bones in combination with predicted cephalometric measurements.

As described in the Introduction, the main materials used for PSI construction are PEEK and titanium. The main advantage of using PEEK as the material for reconstruction is its similar modulus of elasticity as cortical bone and in case modifications of a PEEK implant are required they can be easily performed in the operating room with standard bores.

The PSI made from titanium is ideal to load-bearing areas such as mandible reconstruction; however, it requires excellent precision in manufacturing since alterations in shape or size during the operation is nearly impossible. Both materials are biocompatible and autoclavable.

Computer-assisted mandibular reconstruction with patient-specific implants appears to be a promising approach for reconstructing mandibular defects in patients of primary reconstruction in elective resections or in second-stage reconstruction of trauma patients as is seen in the presented patient. Careful attention should be paid to preserve the oral mucosa intact to prevent exposure and infection of the bone graft and thus extra-oral approach is preferred.

In the future, higher quality of reconstructions, especially in terms of form and function, can be expected with the advancement and popularization of the method. Future large-scale clinical trials are needed to determine whether these promising results can be translated into successful practice and what further developments are needed in the future.

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