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Rehabilitation of Mandibulectomy with Patient-Specific Instrument: A Case Report

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ABSTRACT

We present a treatment option for extensive mandibular resection using CAD/CAM technology. This option allows for the patient's immediate and complete rehabilitation and has advantages over autografts. A 73-year-old female patient was diagnosed with Central Giant Cell Granuloma (CGCG). The proposed treatment plan involved an angle-to-angle resection of the mandible along with free flap surgery using an autologous iliac graft; however, the patient declined this option. As a final treatment plan, the possibility of utilizing a customized titanium prosthesis as a patient-specific implant (PSI) was considered. The patient was discharged in good general condition, and remarkably, full function was recovered within 24 hours. Additionally, the patient was able to speak and eat after just 5 hours, a testament to the swift recovery this treatment option offers. The primary benefits of this method are immediate results and swift, accurate surgical procedures, which provide reassurance of its efficiency.

Keywords: Mandibular reconstruction; Patient-specific implant; 3D-printing; Oral surgery; Head and neck cancer.

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Introduction

The incidence of orofacial tumors is on the rise, with surgical resections often being the preferred treatment to eliminate neoplasia and prevent recurrence. Given that malignancies usually lead to the destruction of surrounding tissues, wide excision is necessary. However, this approach can result in facial deformities as it may involve the removal of muscles, soft tissues, articular discs, and the mandibular condyle [1]. Losing structures affects patients' essential functions, including nutrition, speech, and self-esteem [2,3]. The resection technique, as well as the extent and location of the removal, influence the level of functional disability and loss of aesthetic appearance [2]. These elements play a crucial role in determining each patient's rehabilitation requirements. Rehabilitation may encompass secondary surgical interventions, prosthetic solutions, speech therapy, and psychological support, all aimed at restoring the patient's functionality, appearance, and self-esteem [3].

Preferably, the vertical and horizontal bone loss should be replaced with a vascularized bone graft or alloplastic material, which may require additional surgery. To recover patients' quality of life with extensive defects, mandibular reconstruction with free flap surgery is the treatment of choice because it provides a decent shape and good implant acceptance [2]. However, compromised dental foundation areas with scar tissue, reduced vestibular depth, and insufficient bone volume make oral rehabilitation with removable prostheses difficult [2,3]. Considering the disadvantages and complications of these treatment plans, technological progress has revealed novel alternatives for clinicians, offering a glimmer of hope. This report aimed to demonstrate an alternative for patients who are challenged by complications of allograft surgeries and for surgeons to achieve ultimate clinical outcomes without the need for additional surgeries.

Case Report

A 73-year-old female patient was referred to the Department of Oral and Maxillofacial Surgery at Sina General Hospital in Tehran, Iran, with the chief complaint of swelling on the left anterior aspect of the mandible. Paraclinical examinations and radiographic images demonstrated left mandibular expansion. The sonographic survey revealed edema and linear liquid accumulation in the lesion. After clinical and paraclinical observations, a biopsy revealed the lesion's histological features. The histopathology report of the specimen demonstrates a spindle cell background containing numerous multinucleated giant cells, pigmented histocytes, hemorrhage, and osteoid material. The report indicates Central Giant Cell Granuloma (CGCG) as the final diagnosis. Considering the patient's age and the expansion of the lesion, a conservative treatment plan was implemented, consisting of six intra-lesion injections of Triamcinolone (Triamcinolone Hexacetonide 40mg/ml, Triamhexal, hexal co., Germany), administered in six separate sessions every other week. Unfortunately, the patient rejected follow-ups for one year. After the patient's return, examination revealed no change in the lesion, and surgical resection of the lesion was planned. Due to the expansion of the lesion, one-third of the mandibular bone had to be resected.

As the patient was edentulous, surgical treatment was planned with free flap surgery and an iliac graft. The patient did not accept this treatment plan and rejected follow-up for more than one year. The patient returned once more, and the lesion had expanded to the other side and devastated the mandible's whole body. The patient's CBCT revealed a well-defined multilocular expansile lesion extending from the right molar area to the left molar region of the mandible. The internal septa inside the lesion were visible (Figure 1). The treatment plan involved an angle-to-angle resection of the mandible and free flap surgery with an autologous iliac graft. As the patient again rejected the treatment plan, the option of customized titanium prostheses as a patient-specific implant (PSI) was discussed. The patient approved this option, which became the final treatment plan.

Design and manufacturing of PSI

The patient's anatomical models were created based on DICOM data from Cone-beam computed tomography with a slice thickness of 0.5mm. The 3D model, generated by MIMICS software (Materialise, Belgium), was used to design a custom-made mandibular implant. Under the surgeon's supervision, we determined the location and angle of the osteotomy cuts to achieve proper fixation. The standard form of the mandible was simulated, scaled, and designed to fit the surface of the remaining mandible parts, ensuring the implant was fixed properly. The STP file format version was edited in SOLIDWORKS 2019 (Dassault Systèmes, Vélizy-Villacoublay, France). The weight optimization was performed by removing geometric holes from the implant. Freehand modeling was done using Geomagic Studio 2012 software (3D Systems, USA) to modify the implant in correlation with the upper jaw and soft tissue. Furthermore, to facilitate the application of overdentures for the patient in the future, we designed a dental implant fixture form based on the standard dimensions of an actual implant fixture (Figure 2). Before metal printing, the design was manufactured using ABS (Acrylonitrile Butadiene Styrene) material and FDM (Fused Deposition Modeling) printing to evaluate the provided model. Minor revisions were made to the model, and then we moved on to the final fabrication process. Then, the full model was printed using SLM (Selective Laser Melting) with medical-grade titanium (Ti-6Al-4V). The annealing process was performed by maintaining the implant at a temperature of 600°C for 180 minutes. The decontamination process involved cleaning, disinfection, inspection, packaging, and gamma sterilization.

Surgical process and PSI placement

Written informed consent was obtained from the patient. All procedures were explained to the patient and conducted in accordance with the Declaration of Helsinki, which outlines the ethical principles in medical research. The incision was performed under general anesthesia and after local anesthesia with an extraoral approach. Bilateral dissection of the facial artery, vein, and sub-mandibular gland to the mandible was performed, and bilateral access was facilitated. The osteotomy was performed using a pre-fabricated cutting guide and mandibular resection (Figure 3). Titanium fabricated patient-specified implant (PSI) fixed with ten screws with 12mm diameter (Figure 4). All of the muscles were sutured to the PSI, and a 3-layer suture was applied for the incision (Figure 5). The patient was discharged with a favorable general status, and the patient's full function recovered within 24 hours. Also, the patient was available to speak and nourish after 5 hours (Figure 6).

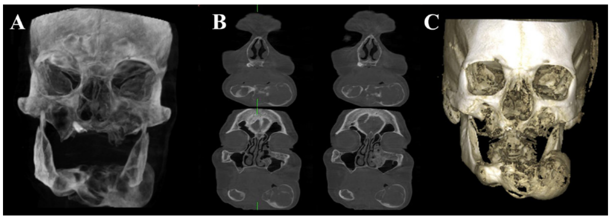

Figure 1. A. Frontal radiographic view of the patient. B. Selected slices of frontal CBCT of the patient. C. Patient three-dimensional rendered CBCT.

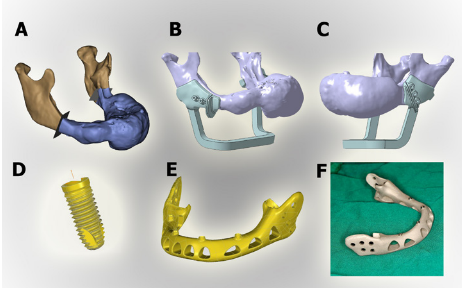

Figure 2. A. Cutting guide points decided by surgeon considering conservative, feasibility, and critical safety margin B & C. 3D-designed surgical guide. D. The simulated fixture is to be placed in the final PSI model. E. Final simulated PSI. F. Final fabricated PSI.

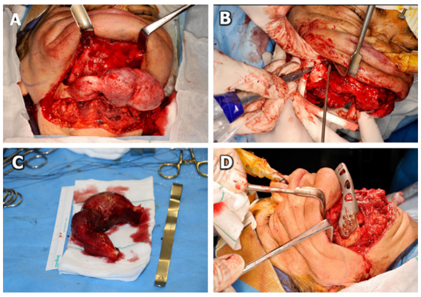

Figure 3. A. Extra-oral approach. The dimension of the lesion affects the body of the mandible. B. Application of a pre-fabricated surgical guide designed by CAD technology. C. Resected lesion. D. Titanium fabricated PSI precise placement with five 12mm-screws on each side.

Figure 4. Final fabricated Patient-Specific Implant. The geometrically shaped holes have been removed from the implant to adjust the weight and utilize it as a muscle anchorage.

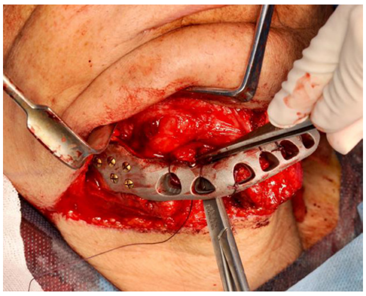

Figure 5. The PSI was fixed with ten screws with a 12mm diameter. All of the muscles were sutured to the implant.

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Figure 6. The final result of the surgery. The patient was available to speak and nourish after 5 hours.

Discussion

In cases where microvascular bone flaps cannot be used due to the patient's medical status or history, mandibular reconstruction alternatives using non-irradiated tissue pose a significant challenge for the surgeon. Attempts have been made with various materials, mostly metal or plastics, combined with multiple regional and microvascular soft tissue flaps [2,4]. The osseointegration system has been used for over three decades to manage craniofacial deformities, but challenges arise in areas with inadequate bone volume for solitary screw implants [5-7]. Advancements led to the development of plate-like titanium implants with multiple percutaneous abutments, secured subperiostally with bone screws to distribute loading forces. Notable innovations include the Epitec system, introduced by Farmand and Leibinger GmbH in 1991, which features a titanium grid with tapped holes, and the Epiplating system, developed by Federspil P., Federspil P.A., and Schneider M. in 2000, adapted for craniofacial trauma with standardized plates for various anatomical regions [8-10]. While plate-like implants are valuable for prosthetic retention, they do have limitations.

Adjusting and bending standardized plates to fit individual anatomies can be time-consuming and technically challenging, as repeated modifications risk compromising metal integrity and leading to early fatigue and failure. Precise trimming and careful processing of sharp edges are essential. Additionally, the plates' limited dimensions can hinder optimal positioning. Accurate placement is crucial for integrating with the prosthesis contours without obstruction while ensuring sufficient retention to prevent displacement. In anatomically complex regions, achieving the proper adjustments becomes even more difficult. Improper positioning may result in poorly crafted prostheses, leading to unsatisfactory aesthetic and functional outcomes or even complete failure [5]. The rapidly advancing field of computer-assisted innovations is set to revolutionize various medical applications. In the field of prosthetic facial reconstruction, significant progress has already been made through the use of CT-based planning for craniofacial implant placement and digital modeling for the manufacture of silicone prostheses. Furthermore, the use of a pre-shaped Epitec system employing stereolithographic techniques, along with the computer-aided generation of a copy-milled bar for prosthetic reconstruction, has also been documented [11-13]. There is no widely accepted consensus regarding the optimal alloplastic reconstruction material, and currently, no single choice is universally considered perfect [14-16]. Publications typically highlight the advantages and disadvantages of titanium and PEEK as the two primary options for digital reconstruction. The biocompatibility of titanium is well-documented, and its capacity for osseointegration serves as a significant advantage for certain applications [17,18].

Additionally, research into adjusting the mechanical properties of additive manufactured (AM) implants through internal structural manipulation has gained attention. Medical grade Ti6Al4V is utilized across the selective laser melting (SLM) spectrum of AM techniques as well as in electron beam melting (EBM) processes (such as those developed by Arcam, Sweden) [14]. The EBM method, which involves pre-heating each layer of powder before full fusion, generally encounters fewer issues arising from residual heat stresses. Moreover, the reduced temperature gradient in EBM leads to faster processing times. In contrast, SLM processes can achieve finer resolution and smoother surface finishes. Fundamentally, the use of additive manufacturing (AM) to produce titanium implants enables greater design flexibility compared to traditional machining, as AM can replicate virtually any geometry with intricate internal and external features, whereas computer-aided manufacturing (CAM) is limited by the accessibility of the cutting tool.

However, design for AM necessitates expert input, particularly to optimize build orientations, support structures, surface finishing, and hole reaming [14]. Current published digital workflow case series exhibit a slight preference for PEEK, as this material aligns more closely with bone's mechanical properties, such as strength, stiffness, and elasticity, thereby minimizing stress shielding. Furthermore, PEEK may enhance patient comfort due to its lower thermal conductivity, reduced density, and lighter weight. Its radiolucency is frequently cited as a significant advantage for enhanced postoperative imaging, particularly in oncological applications. PEEK is also amenable to intra-operative adjustments using burrs, which have been reported to be necessary on a sporadic to moderate basis. However, detailed insights into the underlying reasons for these adjustments, particularly in the context of early design decision-making, remain underexplored [14,16,19]. The number of case reports and series utilizing Patient-Specific Implants (PSIs) is on the rise, driven by advancements in technology and a significant decrease in the costs associated with designing and manufacturing these implants. The number of studies involving titanium patient-specific implants (PSIs) is limited. The study conducted by Alasseri and Alasraj addresses the challenges associated with reconstructing maxillofacial defects, primarily due to the intricate anatomy and the potential complications arising from traditional implants. It highlights the benefits of utilizing computer technology to create PSIs. In the study, six patients were fitted with ten PSIs, consisting of eight implants made from PEEK and two from titanium, with no immediate or follow-up complications reported. All patients reported high satisfaction with both the functional and aesthetic outcomes. The main drawback identified is the significant cost associated with PSIs [20].

The study conducted by Kreutzer et al. evaluated the feasibility and clinical outcomes of utilizing patient-specific 3D-printed miniplates for mandibular reconstruction with fibula free flaps in a cohort of 8 patients. Following virtual planning, titanium miniplates were produced using selective laser melting, and 3D-printed guides assisted with the surgical procedures. All flap fixations were successfully carried out, demonstrating a high accuracy of 3.64±1.18 mm between the planned and actual results. Osseous union was achieved in all intersegmental gaps, with one partial and 18 complete unions, after an average period of 10 months. There were no intraoperative complications or postoperative issues related to the plates. The study concludes that this technique is feasible and yields promising outcomes for mandibular reconstruction [21]. Joshi et al. discussed the challenges of resection following mucormycosis, including occlusal function, aesthetics, and facial asymmetry. A patient with Aramany class 1 and Cordeiro type II subtotal maxillectomy underwent surgery for mucormycosis and received reconstruction with a patient-specific implant. The outcome was positive, with immediate teeth replacement and improved facial symmetry, function, and psychological well-being. The case highlights the benefits of using patient-specific implants facilitated by 3D printing and CAD-CAM technology for complex maxillofacial defects [22].

Most previous studies focused on the calvaria [23,24], orbital floor [25-27], maxilla [28,29], and alveolar bone30, where the functional load was minimal. Few reports exist on custom titanium implants designed for areas with increased functional loads, such as the zygoma and mandible. In a case series, Lim et al. evaluated the effectiveness and safety of patient-specific titanium implants in maxillofacial reconstruction, with an average follow-up period of 36.7 months. Of 16 patients, only one implant failed, with no cases of osteolysis or subsidence. Patient satisfaction was high, with a mean VAS score of 9. The findings support the use of titanium implants as an effective alternative to autogenous bone for oral and maxillofacial defects, thereby avoiding donor site issues [31]. Titanium is a highly biocompatible material but has also presented severe complications when used as bridging plates [32]. There is precedent for the replacement of the mandible by three-dimensional reconstruction with titanium [33]. Soft tissue tolerance is a common disadvantage of all facial implants, independent of material chemistry. The implant used here had a macroscopically smooth surface with pre-fabricated holes on the lateral aspect, allowing for mechanical attachment of the soft tissue flap to the implant.

Today, customized, patient- and site-specific forms of titanium can be obtained through combinations of clinical, imaging, and fabrication techniques [34]. The PSI used in the present patient showed an excellent fit, achieving an abundant and more convenient surgical intervention. The surgical time was also significantly decreased. The fixation extent also needs to be carefully planned since the quality of the surrounding bone and force transmission vary widely. The possibility of designing the final 3D volume resulted in a more aesthetic outcome, as care could be taken with the bulk volume of the free flaps. Although alternative treatment modules are not available for some patients, there is still limited information on the long-term stability of soft tissue adjacent to PSIs. Long-term follow-up is necessary to evaluate PSIs and reveal precise comparison results in contrast with free-flap surgeries.

Conclusion

Despite some technical challenges, this method offers significant advantages, including immediate results and rapid, precise surgical procedures that enhance patient recovery times and promote the surgeon's comfort. CAD/CAM technology and 3D printing are becoming vital components in the therapeutic arsenal of maxillofacial surgery. Ongoing advancements and

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enhancements continually mitigate various drawbacks, making this approach to reconstruction a swift, efficient, and dependable option.

Conflict of Interest

There is no conflict of interest to declare.

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