

Reconstruction of Mandibular Contour Defect Using Patient-Specific Titanium Implant Manufactured by Selective Laser Melting Method

Hoon Joo Yang, DDS, PhD and Ji Hye Oh, BS

Abstract: The purpose of this study was to evaluate the surgical accuracy and postoperative stability of patient-specific titanium implants (PSTIs) manufactured by the selective laser melting method and applied for mandibular contour reconstruction. For 2 patients who showed asymmetry of the mandibular angle after mandibuloplasty, including angle reduction, reconstructive surgeries of the mandibular contour defects were performed using PSTI. Patient-specific titanium implant was three-dimensional designed using a mirror image similar to the shape of the contralateral side, and 3 screw holes were formed, avoiding the inferior alveolar nerve. Patient-specific titanium implant was applied intraorally, and screw fixation was performed via a transbuccal approach. Surgical accuracy and postoperative stability were evaluated by comparing preoperative three-dimensional design with immediate postoperative computed tomography (CT), and immediate postoperative CT with postoperative 6-month CT, respectively. Both patients were satisfied with the surgical results, and no complications were observed. Surgical accuracy was defined as a mean Hausdorff distance <0.4mm, and postoperative stability was defined as a mean Hausdorff distance <0.3mm. Our results suggest that PSTI by the selective laser melting method for augmentation of the mandibular border is useful as an additional cosmetic surgery.

Key Words: 3D printing, accuracy, mandible, patient-specific titanium implant, reconstruction

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Mandibular resection surgery is performed to treat tumors or infectious diseases, or to achieve aesthetic improvement in patients with a hyperplastic mandibular angle.^{1,2} If the lesion of the mandible includes the mandibular border, it inevitably develops an external defect after surgery. In addition, even when mandibuloplasty is performed for esthetic purposes, unsatisfactory results including non-esthetic mandibular defects may occur if the mandible is resected more than planned.^{1,2}

Grafting methods to restore mandibular defects can be broadly categorized into 2 groups: autogenous and alloplastic.³ However, autogenous bone grafts are not preferred because of complications such as postoperative infection, donor site morbidity, and unpredictable results due to bone resorption.^{4–6} In particular, when reconstructive surgery is needed for aesthetic outcomes to resolve asymmetry, not for functional purposes such as occlusion rehabilitation, the main purpose is to restore the mandibular border symmetrically similar to that of the contralateral side. It is better to use an alloplastic material to maintain the same shape continuously.

For alloplastic materials, stock-type materials, such as porous polyethylene (Medpor, Stryker, Kalamazoo, MI), polytetrafluoroethylene, silicone, etc, were used first.^{2,7} Although the shapes of these materials can be altered according to the mandibular defect during surgery, they have several disadvantages, such as the emergence of dead spaces due to the mismatch in shape with the underlying bone, risks of migration, and infection.^{8,9} As computed tomography (CT) has become more common, the fabrication of patient-specific implants has become possible, and either a handmade method or a method using computer-assisted design (CAD)/ computer-assisted manufacturing can be applied in manufacturing.^{2,7,10,11} The advantage of CAD is that mirroring is possible, which enables the fabrication of implants with the same shape as the contralateral side and improves symmetry.^{2,7,10}

Titanium (Ti) is one of the most biocompatible materials, and a patient-specific titanium implant (PSTI) can be manufactured by milling or three-dimensional (3D) printing methods. However, there are still relatively few clinical reports on the application of PSTI for mandibular contour restorations.^{2,7,12,13} This study thus aimed to evaluate the surgical accuracy and postoperative stability of PSTI manufactured by the selective laser melting (SLM) method and apply it to mandibular contour restorations.

MATERIALS AND METHODS

The study was conducted in accordance with the guidelines of the Declaration of Helsinki and was approved by the

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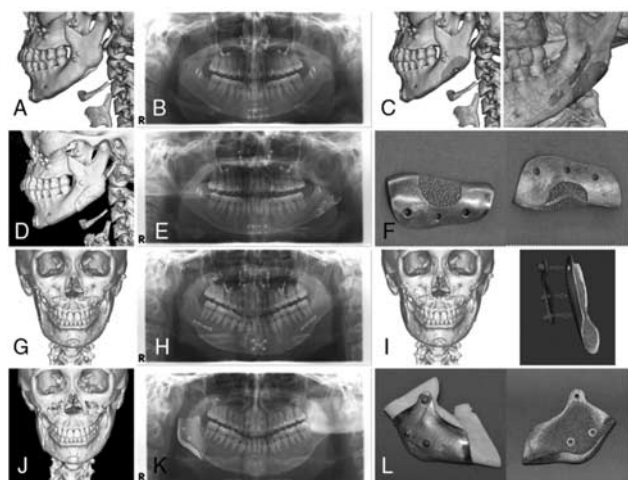


FIGURE 1. Patient 1 (A-F) and patient 2 (G-L): Preoperative CT (T0, A and G), preoperative orthopantomogram (T0, B and H), 3D designed PSTI on preoperative CT (C and I), postoperative CT (T1, D and J), postoperative orthopantomogram (T1, E and K), and 3D printed PSTI (F and L). 3D, three-dimensional; CT, computed tomography; PSTI, patient-specific titanium implant.

Institutional Review Board of the Seoul National University Dental Hospital (CDE19004, October 14, 2019). Informed consent was obtained from both patients involved in the study.

Patients

The first patient was a 47-year-old woman who visited the Department of Oral and Maxillofacial Surgery, Seoul National University Dental Hospital, with a request for reconstruction of mandibular angle depression. The patient had undergone Le Fort I osteotomy, bilateral sagittal split ramus osteotomy, genioplasty via T-osteotomy, mandibular angle reduction, and lateral osteotomy of the mandibular ramus at a private clinic 11 years prior. She showed asymmetry of the mandibular angle with severe depression of the left antegonial notch (Fig. 1A-B).

The second patient was a 26-year-old woman who had undergone Le Fort I osteotomy, bilateral sagittal split ramus osteotomy, genioplasty, bilateral malar reduction, and mandibular angle reduction at a private clinic 2 years prior. She visited the same center with the chief complaint of dissatisfaction, with the mandibular angle being cut too much. In the orthopantomogram, both mandibular angles showed a relatively normal shape. However, in three dimensions, the vertical length of the left ramus was short, so the left mandibular angle was higher than the right. Conversely, the right mandibular angle was located medially compared to the left side. Therefore, when viewed from the front, the right mandible was narrow (Fig. 1G-H).

Preparation of PSTIs

Three-dimensional facial CT was performed (T0) using a CT scanner (SOMATOM sensation 10, Siemens, Munich, Germany) with the following parameters: tube voltage, 120 kVp; tube current, 80 mAs; and slice thickness, 0.6 mm. Digital image files were exported in a Digital Imaging and Communications in Medicine format and imported into Dr Check (Cusmedi, Suwon, South Korea). The CT data were converted to stereolithography (STL) using the Aview Modeler Coreline (Seoul, South Korea). Each PSTI was designed using Materialise Magics (Materialise, Leuven, Belgium), and the surface was smoothed using a Meshmixer (Ver. 3.5, Autodesk, San Rafael, CA).

For the first patient, the PSTI was designed to restore the left mandibular angle by referring to the mirror image of the right mandibular angle. The dimensions of the PSTI were 33, 11, and 12 mm in anteroposterior length, buccolingual length, and height, respectively. The position of the screw holes was determined to avoid damage to the inferior alveolar nerve (IAN) during screw fixation via the trans-buccal approach (Fig. 1C). The central region was designed to have a reticular structure in both the inner and outer surfaces to increase the primary stability by friction. The size of the pores ranged from 750 to 950 μ m (Fig. 1F).

The second patient did not wish to correct the superior position of the left mandibular angle. Since she hoped that the volume of the right ramus and mandibular angle would be similar to that of the left and that the inwardly displaced mandible angle would come out, we decided to fabricate the PSTI only on the right mandibular angle. Because the soft tissue of the right buccal cheek and mandibular angle was thicker than that of the left, the volume of the PSTI was designed to be slightly smaller. The dimensions of the PSTI were 51, 10, and 37 mm in anteroposterior length, buccolingual length, and height, respectively. It was explained to the patient that the vertical height difference between the mandibular angles on both sides increased when the implant was applied. As in the first patient, 3 screw holes were identified by avoiding the IAN. Even if the holes were located by avoiding the IAN, there was a risk of nerve damage depending on the direction of the drill during surgery; therefore, a drill guide was additionally manufactured using the same 3D printing method. This involves the connection of 3 holes, protruding 2 mm from the outside, so that the direction of the drill could be maintained in the planned direction during surgery (Fig. 1I). Only the central region of the inner surface was designed to have a reticular structure (Fig. 1L).

The 3D model was sent to a 3D printer (MetalSys250, Winforsys, Yongin, South Korea) for 3D printing using the SLM method with Ti alloy (ASTM F136). The lateral surface was polished, with a surface roughness of less than 15 μ m. The fabricated PSTIs were autoclaved prior to surgery.

Surgical Procedure

In both patients, reconstructive surgeries using the PSTI were performed via an intraoral approach under general anesthesia. The defect site was exposed through the conventional vestibular incision and subperiosteal dissection, and the dissection was performed sufficiently to the lingual side so that the PSTI could be completely seated. The PSTI was applied and fixed with three 2.0 mm miniscrews (Jeil Medical Corp, Seoul, South Korea) using a transbuccal approach (Fig. 1D, E, J, K).

Analysis of Surgical Accuracy and Postoperative Stability

Three-dimensional facial CT was performed 2 days after surgery (T1) and 6 months after surgery (T2) in the same manner as before surgery (T0). Surgical accuracy was analyzed by comparing the 3D designed PSTI on T0 CT and the operated position of the PSTI on T1 CT. Postoperative stability was evaluated by comparing the PSTI position between the T1 and T2 CT images using 3DSlicer (Ver. 4.11, www.slicer.org). The STLs of T0, T1, and T2 were registered using voxel-based rigid registration, in which the cranial base, the stable anatomical structure, was used as reference.¹⁴ After reslicing each STL, the mean Hausdorff distance between the edge of the PSTI and the Dice similarity coefficient (DSC) were calculated.

RESULTS

Postoperative Progress

Both patients showed slightly decreased mouth opening at 2 weeks after surgery; however, mouth opening was fully recovered 1 month postoperatively. Neither patient complained of any particular discomfort, including additional numbness in the jaw and lower lip after surgery. The edges of the PSTI were indistinguishable on palpation. The patients were satisfied with the aesthetic improvements.

Surgical Accuracy and Postoperative Stability

The Hausdorff distances between the 3D designed PSTI and the surgical results of the 2 patients were 0.313 and 0.390 mm, respectively, indicating that the PSTI was accurately applied to the planned position. The Hausdorff distances between T1 and T2 were 0.271 and 0.297 mm, respectively, and were well maintained at the position where the PSTI was applied. However, when comparing the 3D model and T2, the Hausdorff distances were 0.279 and 0.338 mm, indicating that the PSTI had closer contact with the bone than immediately after surgery (Supplementary Digital Content, Table 1, <http://links.lww.com/SCS/D782>).

Similarly, the surgical accuracy evaluated by DSC of the 2 patients was 0.943 and 0.920, respectively, and the operations were performed as planned. Postoperative stability up to 6 months also showed a DSC of 0.948 and 0.935, respectively, and no positional change was observed until 6 months (Supplementary Digital Content, Table 2, <http://links.lww.com/SCS/D782>).

DISCUSSION

For patients with mandibular angle hypertrophy or facial asymmetry, mandibuloplasty to create a narrow and symmetrical face is a very common surgical method. Patients undergoing this surgery usually have a high desire for aesthetic improvement. Therefore, satisfaction with surgery can be high when the surgical result fits well with the aesthetic needs of the patient; however, if this is not achieved, excessive dissatisfaction may be expressed, and reoperation is sometimes requested. For surgical accuracy, a surgical guide can be made according to the level of mandibular resection and used for surgery.¹⁵ However, manufacturing a surgical guide is a very cumbersome process, so it is often not used. In addition, over-resection during mandibuloplasty may occur due to misplanning or inadequate surgical execution.²

These mandibular defects can be resolved with autogenous bone grafts or alloplastic materials such as Medpor, polytetrafluoroethylene, and silicone.^{3,6} Recently, patient-specific implants were manufactured using polyether ether ketone or Ti using the CAD/ computer-assisted manufacturing method.^{2,7,10,11,16} In this case report, we introduced 2 patients who resolved the asymmetry that occurred after mandibuloplasty with PSTI with 3D printing using the SLM method. Mommaerts et al⁷ also reported a case series of mandibular angle and border augmentation using PSTI manufactured in the same way and presented guidelines. Since there is a risk of mental nerve damage when inserting a voluminous implant, they introduced a method of fabricating 2 pieces of PSTI that interlock with a 3D puzzle connection, and the PSTI was fixed with at least 2 screws.⁷ In this case report, we analyzed and presented the surgical accuracy and postoperative stability of PSTI application.

It is very important to set the planned PSTI accurately. Because the inner surface of the PSTI is made according to the bone contour, maximum surface friction can be obtained, and is related to long-term stability.⁷ Furthermore, if the inferior border of the mandible is excessively cut in the previous surgery, the space between the IAN and the inferior border of the mandible may be narrow. If the PSTI is not positioned correctly, there is a risk that the screw may be fixed while damaging the IAN. In addition, there is a risk that the edge of the implant may be palpable.¹⁷ A submandibular approach may be used if the buccal vestibule has significant fibrosis or scars due to previous surgery.⁷ However, if surgery is performed for esthetic purposes, such as for the patients in this case report, extraoral scar may also be a problem, so the intraoral approach is usually preferred.^{2,16} To improve the surgical accuracy in the intraoral approach with limited field of view, sufficient dissection of the mandibular border must be performed anteriorly, posteriorly, and medially, beyond the application range of the PSTI.⁷ Furthermore, screw fixation should be performed, maintaining the PSTI as close to the bone as possible. The 2 patients in this case report showed high surgical accuracy, with a mean Hausdorff distance of 0.3 to 0.4 mm, but in both patients, it was observed that the anterior edge did not completely adhere to the bone in the postoperative ortho-pantomogram (Fig. 1E and K). This is thought to be due to the pulling of the PSTI in the superoanterior direction by inserting surgical instruments. If possible, it is recommended to be pulled using 2 instruments.

The postoperative stability of PSTI is primarily secured by mechanical fixation force with screws.¹⁸ The optimal number of screws to use has not yet been clearly determined, as this depends on the size of the implant, and clinical studies with a larger number of patients and analysis using finite element analysis are needed. In the 2 patients in this case report, PSTI applied using 3 screws was maintained without a change in position for up to 6 months. The reticular structure of PSTI, which could be formed because it was fabricated by the SLM method, has the effect of reducing weight and increasing proximity to the bone by increasing the overall elasticity.¹⁹ In addition, it was found that a porosity of more than 500 μ m promotes osteoinduction in Ti implants fabricated by the SLM method, which may help promote long-term stability.²⁰

In conclusion, the application of PSTI by the SLM method for the augmentation of the mandibular border is useful as an additional cosmetic surgery.

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