Using mixed reality and CAD/CAM technology for treatment of maxillary non-union after Le Fort I osteotomy: a case description

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Introduction

Le Fort I osteotomy (LF-I) is the most frequently performed surgical procedure in the maxilla and has a wide range of applications. LF-I is now performed more frequently because safer surgical protocols with more stable outcomes have become available, and the demand by orthodontists to improve occlusion, facial features, and postsurgical stability is increasing (1).

LF-I was used by Wassmund in 1927 when he repositioned the maxilla without separating the pterygoid process for an open bite caused by a Guerin-type fracture. Obwegeser developed the modern LF-I, in which he completely immobilized the maxilla with pterygomaxillary disjunction (2).

Although complications, such as bleeding and sensory disturbances have been reported, LF-I has a relatively stable outcome (3,4). However, blindness (5) and non-union of the maxilla (6-8) have rarely been reported; therefore, adequate preoperative evaluation and planning before, during, and after surgery are important.

Recently, mixed reality (MR) technology has been applied to medicine and medical education (9). Microsoft® HoloLens comprises a head-mounted sensor camera, and spatial mapping of the surrounding environment helps position the holographic images, enabling MR with speech and/or gesture control. However, no studies have reported its use in the treatment of non-union.

Here, we report the case of a patient with significant resorption of the maxilla due to non-union after bimaxillary surgery (LF-I and sagittal split ramus osteotomy) and metal plate removal at another hospital. The patient was managed using computer-aided designing and computer-aided manufacturing (CAD/CAM), MR, and iliac block bone grafting.

Case presentation

A 47-year-old woman with malocclusion and nasal obstruction was examined at the Department of Oral and Maxillofacial Surgery of Tokyo Dental College Suidobashi Hospital in August 2020. In September 2013, she underwent bimaxillary surgery (LF-I and sagittal split ramus osteotomy) at another university hospital. After the bimaxillary surgery, the maxillary and mandibular segments were fixed with titanium plates, and follow-up examinations were scheduled. Owing to the acceptable progress, the maxillary and mandibular plates were removed at the same

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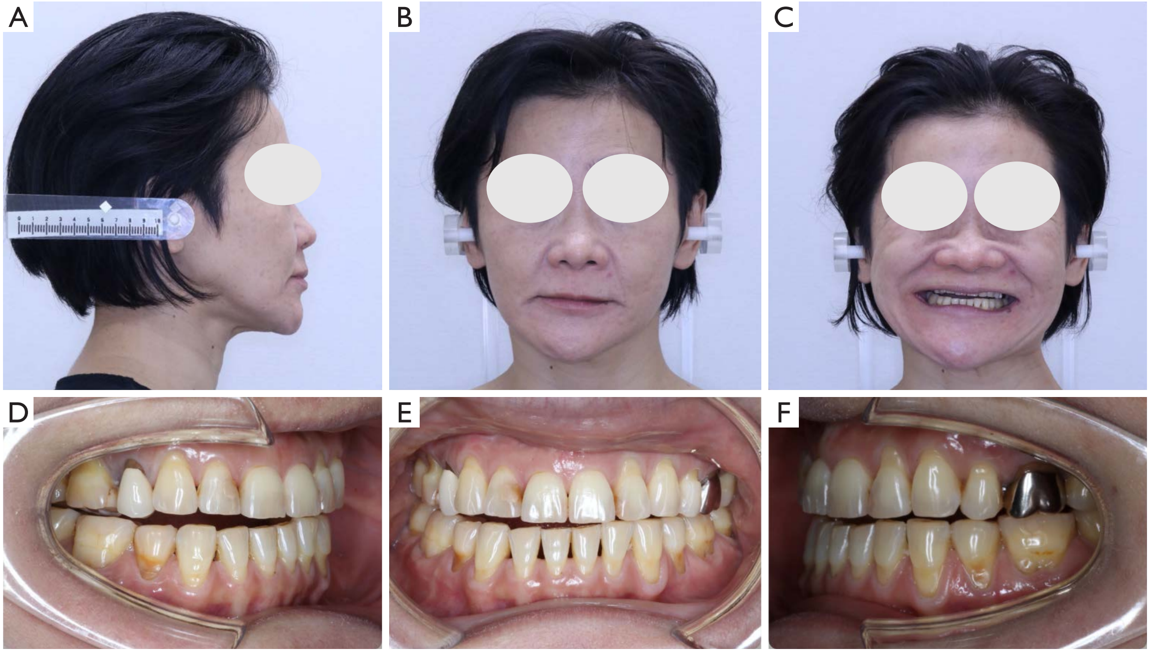

Figure 1 Preoperative evaluation. (A-C) Facial photographs at initial examination. (D-F) Intraoral photographs at initial examination. These images are published with the patient's consent.

hospital in April 2015. She noticed symptoms of a "floating maxilla" after the second surgery. The patient was left untreated for a long duration and referred to our hospital in August 2020 because of worsening symptoms of the floating maxilla.

Clinical examination revealed prognathism, facial asymmetry, and deviation of the dental midline to the right. In addition, the maxilla exhibited 6 mm of vertical movement (*Figure 1A-1F*). Intraoral examination revealed an anterior open bite. The patient complained of nasal obstruction but had no spontaneous pain. Maxillary teeth, except those treated endodontically, showed a positive reaction in electric pulp tests. The patient was not under treatment for other conditions.

Cephalometric analysis revealed a shortening of the midface and a rightward deviation of the mental region (*Figure 2A-2D*). Computed tomography (CT) showed an absence of bone in the region of the maxilla where osteotomy was performed (*Figure 3A*). When the occlusion was checked on the diagnostic and virtual models, no discrepancy between the width of the maxillary and mandibular arches was evident, and a harmonious occlusal relationship could be obtained by moving the maxilla downwards (*Figure 3B-3D*). The floating maxilla and rightward deviation of the mental region could be managed by approximately one and a half years of orthodontic treatment. We prioritized the complications of LF-I and performed a two-stage genioplasty. Preoperative orthodontic treatment and maxillofacial osteotomy were considered, but only maxillofacial osteotomy was performed to prevent any further deterioration in the patient's quality of life and maxillary resorption. Based on the cephalometric analysis and CT data, the extent and direction of maxillary repositioning were determined. Since several bone grafts were needed, we decided to harvest an iliac bone block graft (*Figure 4A*). Due to the complexity of the operation, we performed a virtual operation with three-dimensional (3D) models and devices. In addition, the MR technology was applied to confirm intraoperatively the movement of the maxilla to the planned position.

Preoperative preparation (virtual operation and Microsoft® HoloLens application)

Preoperative CT was performed using SOMATOM Definition AS (Siemens, Forchheim, Germany); a virtual operation was performed using Mimics (Materialise, Leuven, Belgium), and the position of the maxilla was determined by simulating maximum intercuspation of teeth and harmonious facial length. The mandible was rotated

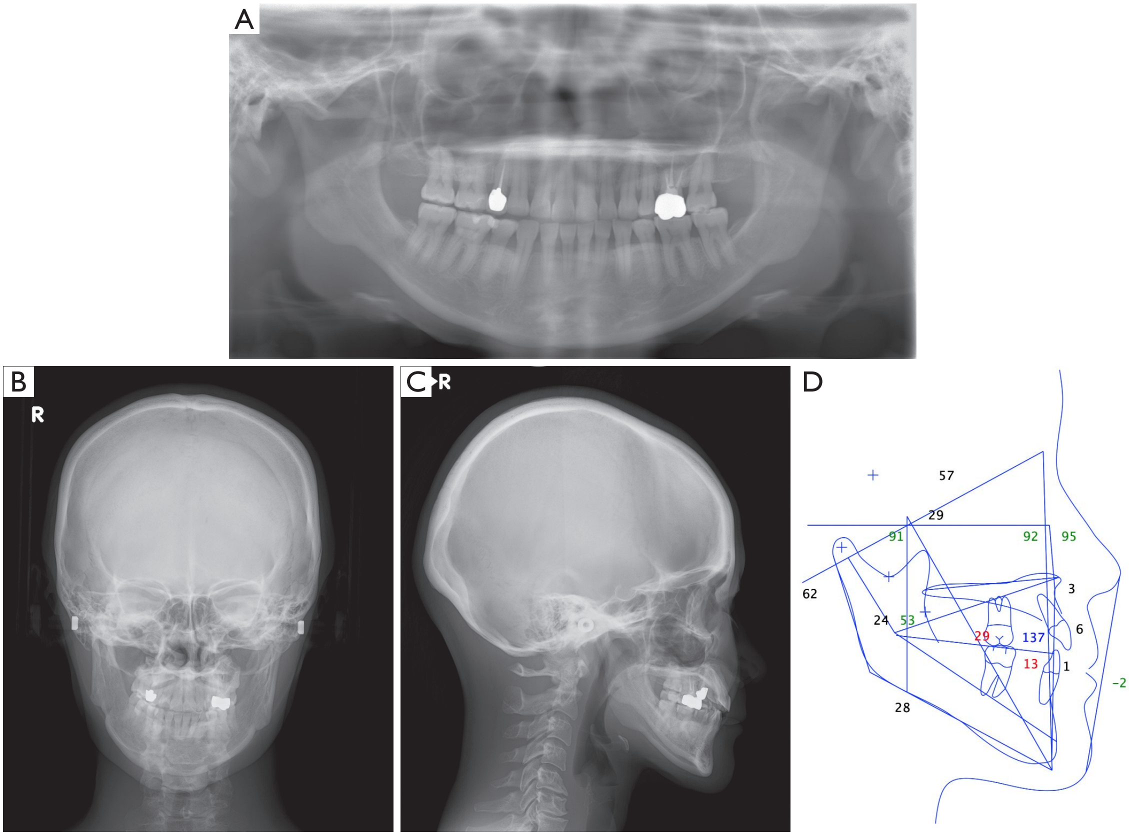

Figure 2 Preoperative radiographic evaluation. (A-C) Preoperative radiographs. (D) Cephalometric analysis.

depending on the position of the temporomandibular joint. After determining the desired position of the maxilla, the iliac bone block graft was shaped according to the shape of the created gap. The CT data pertaining to the maxillary jaw and iliac bone were segmented and obtained in Standard Triangle Language format using the Mimics software, which was used to prepare a Microsoft® HoloLens application with UNITY (April 17, 2017 flavor) and Visual Studio Community (2017/Version 15.9.4).

Preoperative preparation (fabrication of 3D models and pre-bending of metal plate)

Using a 3D printer (Objet 260 Connex, Stratasys, Ltd., Minnesota, USA), a 3D model detailing the images of the repositioned maxilla with the iliac bone graft was prepared, which was shared preoperatively among all surgeons. In addition, the 3D model was used to pre-bend a titanium plate. The maxillary right molar region exhibited significant bone resorption, which limited the positioning of the titanium plate. In addition, a cutting guide for iliac bone grafting was fabricated using the 3D printer.

Surgical procedure (LF-I, iliac bone grafting)

LF-I and iliac block bone grafting were performed under general anesthesia in April 2021 (*Figure 4B-4D*). An incision was made in the maxillary anterior gingiva along the previous surgical scar for debridement. The gingiva partially adhered to the maxillary sinus mucosa and the nasal mucosa. After separating the gingiva, the maxilla exhibited a vertical movement of approximately 15 mm. Separating the lesion from the mucosal periosteal flap was difficult. Intermaxillary fixation was performed, and the iliac block bone was inserted in the gaps on both sides and fixed using the pre-bent metal plate. The nasal septum was ligated to the maxillary bone (*Figure 5A-5D*). Through the operation, the three surgeons wore Microsoft® HoloLens, and the surgery was performed using virtual reality (VR) to ascertain the positions of the iliac bone graft and repositioned maxillary

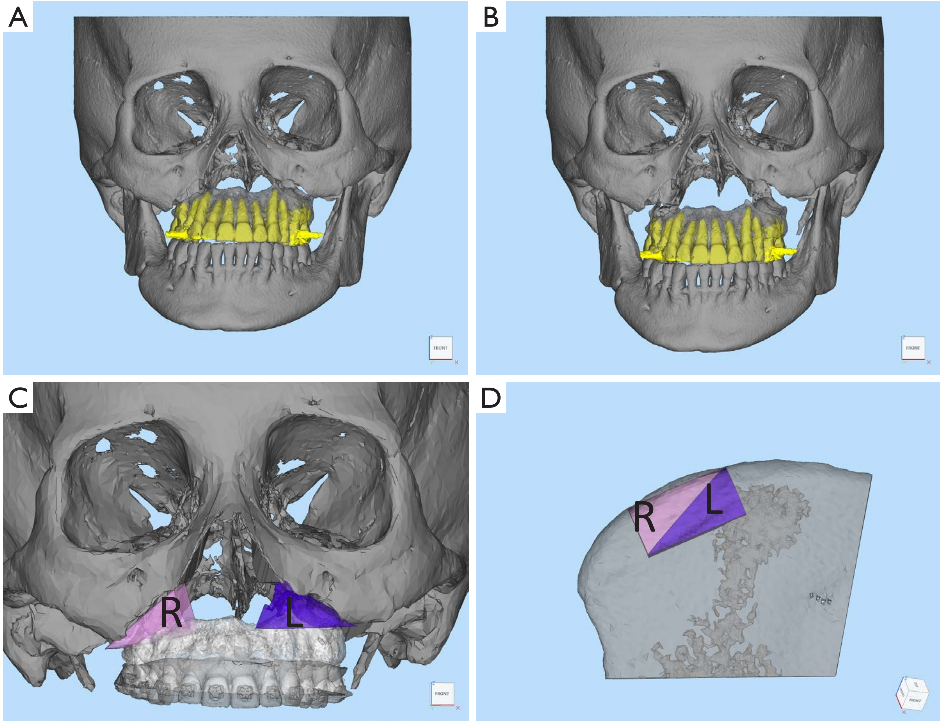

Figure 3 Three-dimensional reconstruction. (A,B) Determination of the maximum contact between the maxillary and mandibular occlusal surfaces of teeth and the correct position of the maxilla based on facial proportions. (C) The gap created fitted with the data of the iliac bone block graft. (D) A cutting guide designed to harvest an iliac bone block of the required size.

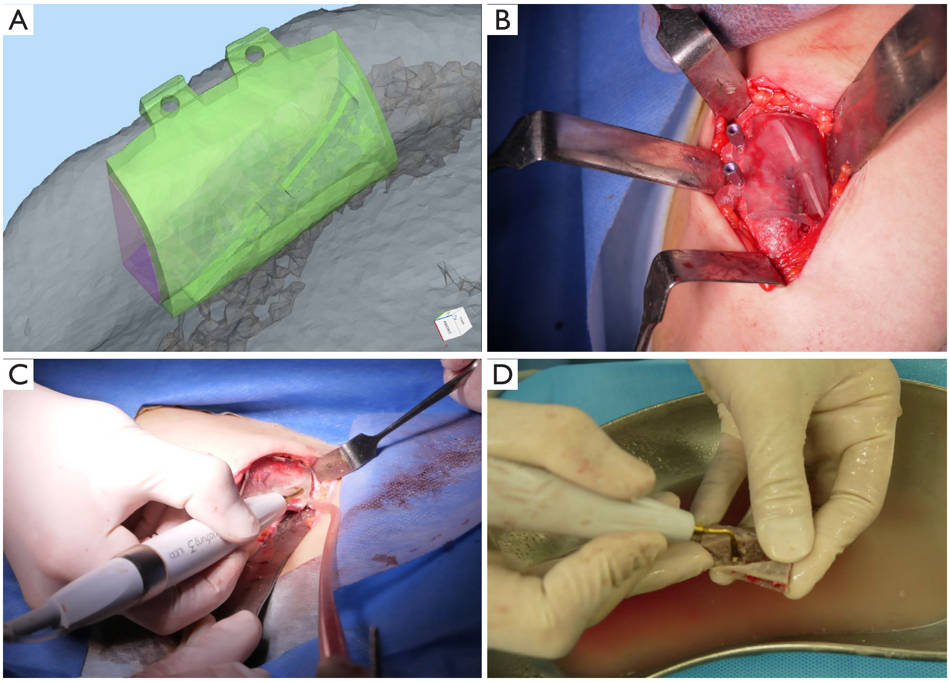

Figure 4 Harvesting of the iliac bone graft. (A-D) Gap created in the maxilla to be fitted with the iliac bone block. Fabrication of a 3D device. Intraoperative findings. Extracted iliac bone. After harvesting, the 3D device is used to shape the bone.

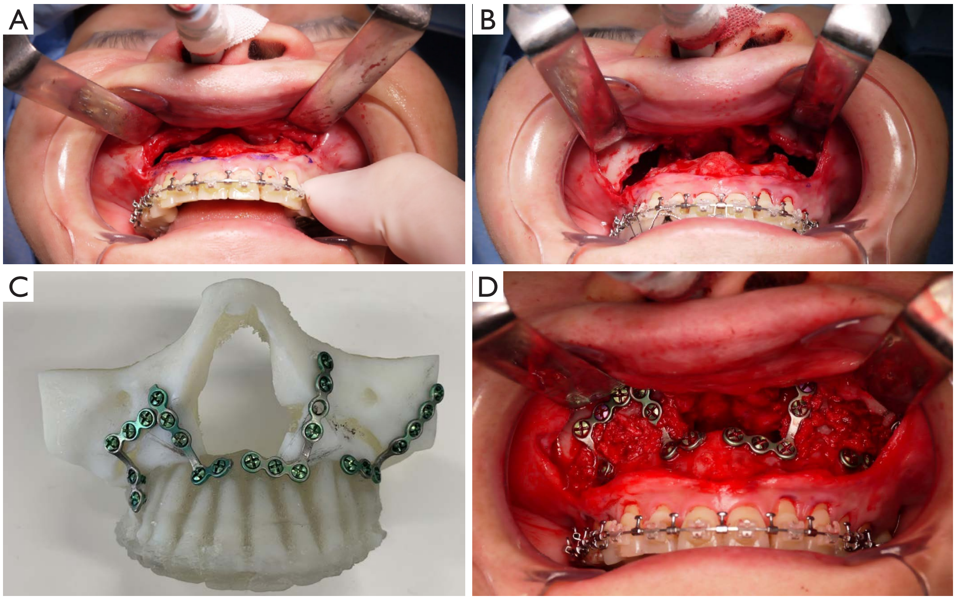

Figure 5 Intraoperative view. (A) Gingiva partially adherent to the maxillary sinus mucosa and the nasal mucosa. (B) Vertical movement of the maxilla of 15 mm. (C,D) Intermaxillary fixation, insertion of the iliac block bone in the gaps on the right and left sides, and fixation with a pre-bent metal plate.

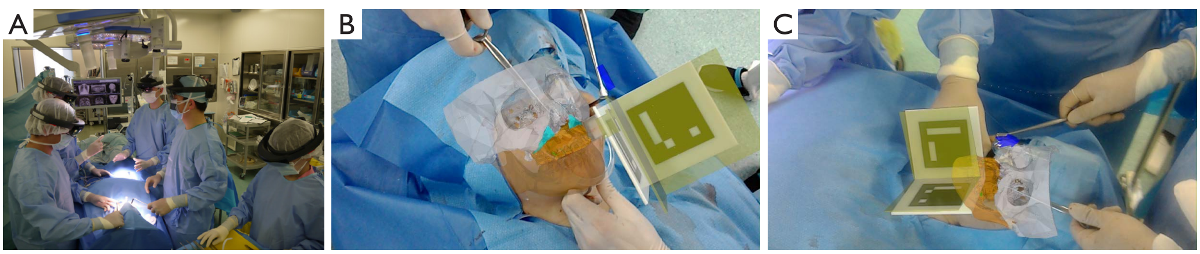

Figure 6 Intraoperative view using Microsoft® HoloLens. (A) Surgeons wearing Microsoft® HoloLens can share the hologram and manipulate using gestures and voice. (B,C) The operating field and the application automatically aligned by fabricating the registration markers, and the markers recognized by Microsoft® HoloLens.

bone (*Figure 6A-6C*). The patient's head position was in a movable position. The registration markers were connected to the occlusal plate. VR application enabled 3D sharing of the same VR among all surgeons using the registration marker, which further enabled performing the surgery with the superimposition of the VR on the patient. The left side of the maxilla was fixed with two holes fewer than planned to prevent wound expansion. After fixation, the intermaxillary fixation was released, and the 3D position of the maxilla was confirmed with polygons using registration markers. The obtained position and fixation of the maxilla were similar to those planned preoperatively. The operative time was 3 h 9 min, and the amount of blood loss was 16 mL. The preparation of Microsoft® HoloLens before surgery required approximately 10 min. The soft tissue present in the osteotomy area was pathologically diagnosed as a traumatic neuroma.

One-year postoperatively, the facial height and occlusion improved, but a slight rightward deviation of the mental region persisted (*Figure 7A-7E*). Imaging analysis revealed good osteosynthesis and no plate or screw fracture (*Figure 8*). The patient did not have any problems pertaining to the surgery while performing routine activities 1 year 6 months after the surgery. In addition, nasal obstruction, which was caused by the pressure exerted by the maxillary bone during occlusion, completely disappeared, and the

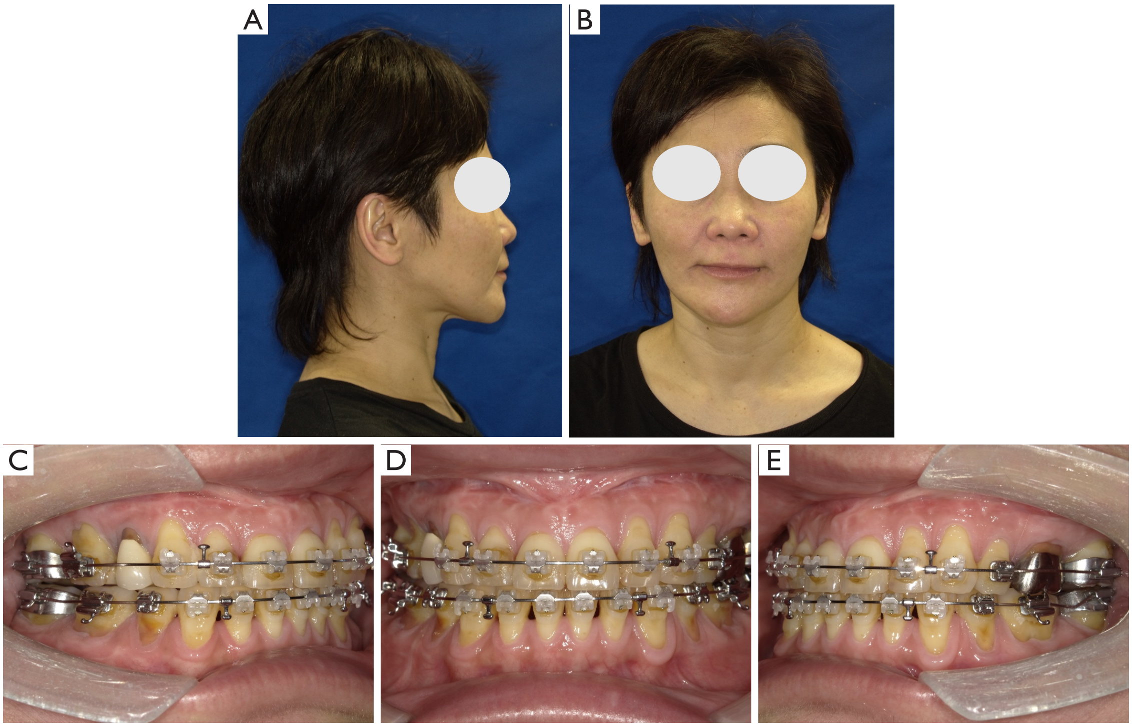

Figure 7 Postoperative photographs. (A,B) Facial photographs. (C-E) Intraoral photographs. Facial view: Persistent slight rightward deviation of the mental region. These images are published with the patient's consent.

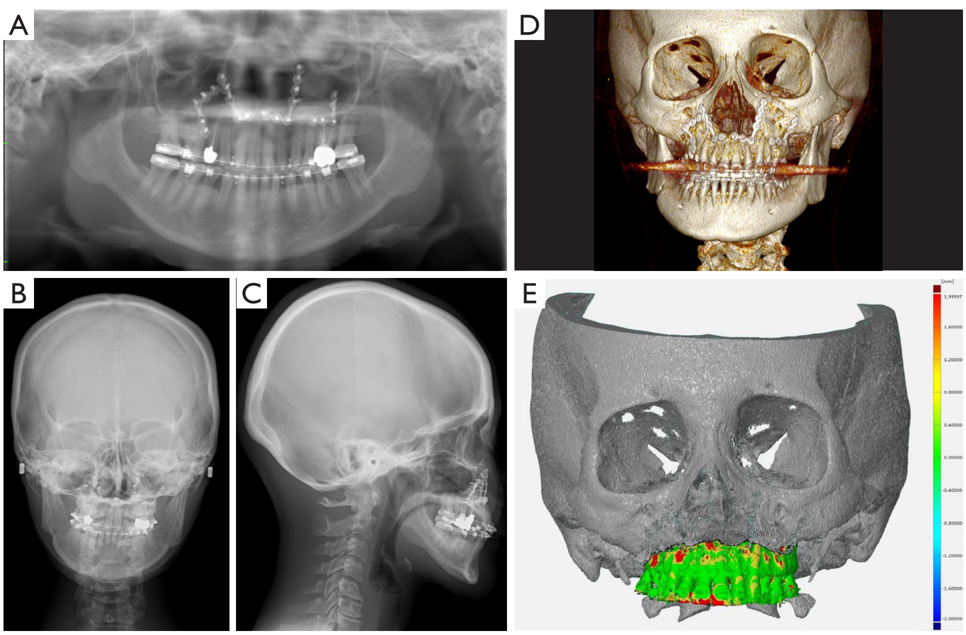

Figure 8 Postoperative evaluation. (A) Orthopantomogram. (B,C) Cephalograms. (D) Computed tomography scan. (E) 3D surface analysis. The percentage of bone measurement error <2 mm between the Tv and T1 image is 80.9%. Tv, preoperative virtual operation 3D image; T1, one-month postoperative CT image.

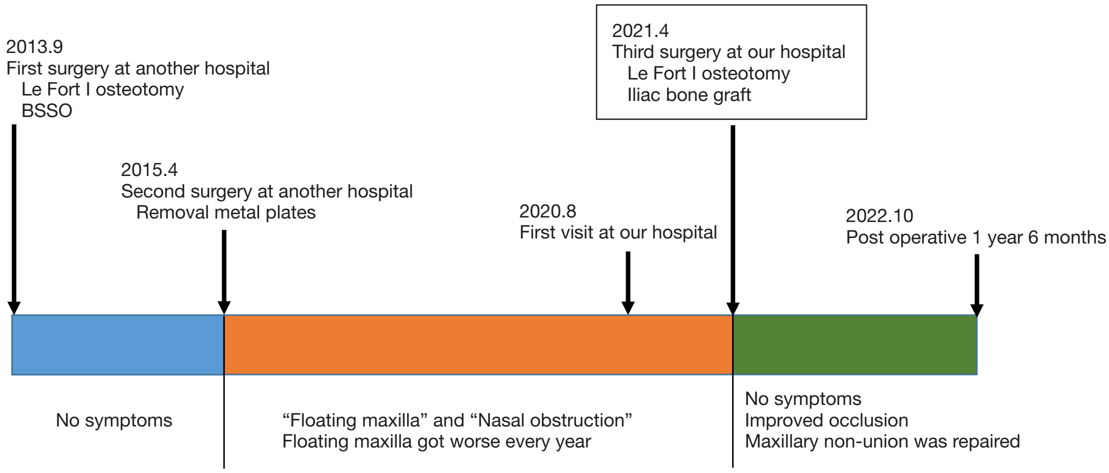

Figure 9 The treatment timeline of the patient. BSSO, bilateral sagittal split osteotomy.

maxillary non-union was repaired (*Figure 9*).

Evaluation

Postoperative evaluations were conducted by comparing the preoperative virtual operation 3D image (Tv) and the one-month postoperative CT image (T1) using Mimics and 3-matic (Materialise, Leuven, Belgium). We used GOM Inspect (GOM, Braunschweig, Germany) and as a reference for image overlaying, and three arbitrary points were automatically selected following setup (10). The reference plane was established using the methods described by Badiali *et al.* and Park *et al.* (11,12). Since only the bone surfaces were compared, the parts with the metallic plate in the postoperative CT scan were removed using the method outlined by Badiali *et al.* (11). A 3D surface analysis and a point-based analysis were used as evaluation methods.

3D surface analysis

The deviation between the bony surfaces in Tv and T1 was measured. Based on previous reports, the threshold value was defined as <2 mm, and its fraction was calculated (13).

The percentage of bone measurement errors <2 mm between the Tv and T1 images was 80.9% (*Figure 8E*).

All procedures performed in this study were in accordance with the ethical standards of the institutional committee and the Helsinki Declaration (as revised in 2013). Written informed consent was obtained from the patient for publication of this case report and accompanying images. A copy of the written consent is available for review by the editorial office of this journal. The study was approved by the Ethics Committee of Tokyo Dental College, Tokyo, Japan (No. 794 844).

Discussion

The complications of LF-I include upper lip dysesthesia, massive bleeding, blindness, osteonecrosis, and rarely, a floating maxilla. According to Zaroni *et al.* (4), non-union is rare and occurs in 0.2% of cases. Nonetheless, maxillary movement, infection, and maxillary sinusitis have been reported as risk factors for non-union. In this case, the possibility of postoperative infection and maxillary sinusitis was considered because the maxillary osteoplasty performed at the other clinic had not resulted in a large gap.

Several treatments for a floating maxilla have been reported. Improved outcomes can be obtained by early treatment with a small amount of bone grafting and fixation of an absorbable plate, as reported by Kurohara *et al.* (8). In this case, since the floating maxilla persisted for a long duration, maxillary bone resorption had advanced markedly and the area for screw placement was limited, rendering fixation of the mesh plate difficult. The use of freeze-dried bone (7) or artificial biomaterials (14) as grafts has been reported, but the use of fresh autogenous bone is safer. In addition, fresh autogenous bone can be obtained from the molar region and mandibular ramus area, which does not create an extraoral wound. Extraorally, fresh autogenous bone can be obtained from the iliac bones (15) or ribs. However, these procedures lead to an extraoral wound.

Since a gap of approximately 10 mm was determined in the virtual operation, a metal plate was bent using a 3D model that was fabricated preoperatively, and an iliac bone block was harvested and implanted using an intraoperative cutting device. In addition, MR surgical assistance helped in confirming that the maxilla was fixed in the ideal position. In Japan, custom-made metal plates cannot be used for jaw deformities and can only be used for jaw reconstruction patients.

We have applied CAD/CAM and MR (16,17) in various oral surgeries including orthognathic surgery and obtained good results. In addition, the application of MR technology enables the evaluation and confirmation of the 3D position of the maxilla during surgery (17). The use of a 3D model allows us to perform realistic simulations before surgery, which not only allows us to perform accurate surgery in a shorter time, but also to determine the extent of necessary bone movement and optimal occlusion. In this case, the titanium plate was pre-bent on a 3D model to reduce the operation time and accurately position the maxilla.

Microsoft® HoloLens has a head-mounted sensor camera, and spatial mapping of the surrounding environment enables positioning the holographic images and using MR with speech and/or gesture control (18,19). MR surgical assistance, which superimposes holographic images on the patient, enables the confirmation of the 3D position and anatomical morphology of the maxillary bone, which can enhance surgical safety and reduce postoperative complications (17).

In this case, MR surgical assistance using Microsoft® HoloLens and a 3D model was used in the treatment of a maxillary non-union. This technique enabled performing of the surgery safely in accordance with the preoperative plan. Patient-specific implants should be used in conjunction with MR technology to reproduce virtual operations more accurately.

Moreta-Martinez *et al.* reported the use of a 3D printer for the fabrication of a single unit surgical guide and tracking marker for sarcoma resection by registering the patient and using VR with higher accuracy and an error of only 2 to 3 mm (20).

A limitation of MR surgery is the difficulty in the manual superimposition of the VR onto the patient. We developed a method that recognizes the specific registration marker with Microsoft® HoloLens and uses it to automatically superimpose the VR onto the patient.

Other areas where this technology can be useful include the imaging of blood vessels during orthognathic surgery and intraoperative confirmation by superimposing virtual-operation data on actual-operation data at the time of jaw movement. This technology could have a number of applications in oral and maxillofacial surgery and other fields in the near future. However, this technique is not yet perfect, and further development of the hardware is essential to make the superimposition more accurate.

In conclusion, a patient with maxillary non-union was re-operated using CAD/CAM and MR. Iliac bone grafting was performed, which is a predictable treatment option for bone healing, especially in cases of prolonged non-union after the initial osteotomy. The patient was able to eat all types of food without difficulty 2 months after surgery and was satisfied with the stability of the occlusion, improvement of facial appearance, and disappearance of nasal obstruction. In the present report, the incorporation of Microsoft® HoloLens in preoperative planning and intraoperative visualization of the oral and maxillofacial region enabled precise and safe surgery.

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Footnote

Conflicts of Interest: All authors have completed the ICMJE uniform disclosure form (available at https://qims.amegroups.com/article/view/10.21037/qims-22-414/coif). The authors have no conflicts of interest to declare.

Ethical Statement: The authors are 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. All procedures performed in this study were in accordance with the ethical standards of the institutional committee and the Helsinki Declaration (as revised in 2013). Written informed consent was obtained from the patient for publication of this case report and accompanying images. A copy of the written consent is available for review by the editorial office of this journal. The study was approved by the Ethics Committee of Tokyo Dental College, Tokyo, Japan (No. 794 844).

References

1. Hamada Y, Sugahara K, Yoshida S, Watanabe A, Bessho H, Kasahara K, Takano M, Saito C, Shibahara T, Katakura A. A 27-year retrospective clinical analysis of 2640 orthognathic surgery cases in the Tokyo Dental College. J Oral Maxillofac Surg Med Pathol 2019;31:305-10.
2. Buchanan EP, Hyman CH. LeFort I Osteotomy. Semin Plast Surg 2013;27:149-54.
3. Eshghpour M, Mianbandi V, Samieirad S. Intra- and Postoperative Complications of Le Fort I Maxillary Osteotomy. J Craniofac Surg 2018;29:e797-803.
4. Zaroni FM, Cavalcante RC, João da Costa D, Kluppel LE, Scariot R, Rebellato NLB. Complications associated with orthognathic surgery: A retrospective study of 485 cases. J Craniomaxillofac Surg 2019;47:1855-60.
5. Cruz AA, dos Santos AC. Blindness after Le Fort I osteotomy: a possible complication associated with pterygomaxillary separation. J Craniomaxillofac Surg 2006;34:210-6.
6. Imholz B, Richter M, Dojcinovic I, Hugentobler M. Non-union of the maxilla: a rare complication after Le Fort I osteotomy. Rev Stomatol Chir Maxillofac 2010;111:270-5.
7. De Backer T, Neyt L, De Clercq C, Mommaerts M, Abeloos J, Van Butsele B. Non-union of a preprosthetic Le Fort I osteotomy with freeze-dried bone as an interpositional graft. Acta Stomatol Belg 1994;91:133-42.
8. Kurohara K, Tomomatsu N, Nakakuki K, Sakuma T, Arai N, Yoda T. Treatment of refractory non-union after maxillary osteotomy: A case report. J Stomatol Oral Maxillofac Surg 2019;120:493-6.
9. Gerup J, Soerensen CB, Dieckmann P. Augmented reality and mixed reality for healthcare education beyond surgery: an integrative review. Int J Med Educ 2020;11:1-18.
10. Xia JJ, Gateno J, Teichgraeber JF, Christensen AM, Lasky RE, Lemoine JJ, Liebschner MA. Accuracy of the computer-aided surgical simulation (CASS) system in the treatment of patients with complex craniomaxillofacial deformity: A pilot study. J Oral Maxillofac Surg 2007;65:248-54.
11. Badiali G, Roncari A, Bianchi A, Taddei F, Marchetti C, Schileo E. Navigation in Orthognathic Surgery: 3D Accuracy. Facial Plast Surg 2015;31:463-73.
12. Park SH, Yu HS, Kim KD, Lee KJ, Baik HS. A proposal for a new analysis of craniofacial morphology by 3-dimensional computed tomography. Am J Orthod Dentofacial Orthop 2006;129:600.e23-34.
13. Mazzoni S, Badiali G, Lancellotti L, Babbi L, Bianchi A, Marchetti C. Simulation-guided navigation: a new approach to improve intraoperative three-dimensional reproducibility during orthognathic surgery. J Craniofac Surg 2010;21:1698-705.
14. Wardrop RW, Wolford LM. Maxillary stability following downgraft and/or advancement procedures with stabilization using rigid fixation and porous block hydroxyapatite implants. J Oral Maxillofac Surg 1989;47:336-42.
15. Persson G, Hellem S, Nord PG. Bone-plates for stabilizing Le Fort I osteotomies. J Maxillofac Surg 1986;14:69-73.
16. Sugahara K, Koyachi M, Koyama Y, Sugimoto M, Matsunaga S, Odaka K, Abe S, Katakura A. Mixed reality and three dimensional printed models for resection of maxillary tumor: a case report. Quant Imaging Med Surg 2021;11:2187-94.
17. Koyachi M, Sugahara K, Odaka K, Matsunaga S, Abe S, Sugimoto M, Katakura A. Accuracy of Le Fort I osteotomy with combined computer-aided design/computer-aided manufacturing technology and mixed reality. Int J Oral Maxillofac Surg 2021;50:782-90.
18. Saito Y, Sugimoto M, Imura S, Morine Y, Ikemoto T, Iwahashi S, Yamada S, Shimada M. Intraoperative 3D Hologram Support With Mixed Reality Techniques in Liver Surgery. Ann Surg 2020;271:e4-7.

19. Johnson PB, Jackson A, Saki M, Feldman E, Bradley J. Patient posture correction and alignment using mixed reality visualization and the HoloLens 2. Med Phys 2022;49:15-22.
20. Moreta-Martinez R, García-Mato D, García-Sevilla M, Pérez-Mañanes R, Calvo-Haro J, Pascau J. Augmented reality in computer-assisted interventions based on patient-specific 3D printed reference. Healthc Technol Lett 2018;5:162-6.

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