Reduction Malarplasty Using Customized Surgical Stent Based on 3D Virtual Surgery, CAD/CAM, and 3D Printing Technology: Case Series

Sung-Ho Ha, DDS, PhD, Sungyoung Jung, DDS, MSD,* and Jin-Young Choi, DDS, MD*[†]

Abstract: The zygomatic bone is a structure that protrudes symmetrically on both sides of the midface and plays an important role in the overall aesthetic appearance of the face. Unlike Caucasians, the mesocephalic facial shape is predominant in Asians, and therefore, many people have a relatively laterally developed zygomatic bone. In Asians, when the zygomatic bone is excessively developed, it gives a strong and stubborn image, and aesthetically, many people want to reduce the zygomatic bone because they prefer an oval and slim face.

To reduce the excessive zygomatic bone, a reduction malarplasty through an intraoral and preauricular approach has been performed. Although reducing the zygomatic bone is not a big problem in most cases of symmetric reduction malarplasty, it is not easy to produce surgical results as intended by the surgeon in asymmetric malar patients or patients requiring a three-dimensional (3D) change of zygoma. In addition, because of the mobility of the zygoma segment, it may be difficult to drill holes and fix plate after osteotomy. Moreover, these factors can increase the possibility of malunion or nonunion.

In this study, cutting guides made with the aid of 3D virtual surgery, 3D printing, and customized titanium plates manufactured with the computer-aided design/computer-aided manufacturing technology are used for 8 patients to maximize the recovery of 3D symmetry and minimize complications through accurate fixation after surgery. During the surgical procedures, screw hole drilling and osteotomy were performed using a cutting guide, and then, the malar segment was fixed by matching the premade customized plates with the predrilled holes. As a result of checking the accuracy of the surgery by superimposing the postoperative 3D cone beam computed tomography image and virtual surgery data based on the skull base, the 2 images almost overlapped and no significant differences were observed, so it was confirmed that the operation was performed exactly as planned.

When using the 3D technology, it is possible to perform a more accurate surgery in patients with asymmetry due to congenital anomalies or trauma as well as simple asymmetry, so it can be concluded that using the 3D technology can overcome the limitations and disadvantages of the conventional method as in the cases in this study. The accurate prediction of soft tissue is still insufficient, and further research is needed to overcome this limitation

Key Words: 3D virtual surgery, CAD/CAM, reduction malarplasty, surgical accuracy

(*J Craniofac Surg* 2022;33: 1578–1582)

The zygomatic bone and zygomatic arch are bony structures that protrude symmetrically anteriorly and laterally on both sides of the midface. It is recognized that having a soft oval shape at the frontal and lateral views is aesthetically pleasing. Different races have different face shapes. On the one hand, Caucasians mainly have a dolichocephalic skull shape, which has laterally depressed zygomatic bone and zygomatic arch in the frontal view. On the other hand, Asians have a lot of mesocephalies, so their faces are flat and wide, and there are many facial shapes with protruded zygoma area.[1,2] The standard of aesthetic appearance differs slightly based on the times and cultures, but in most cases, leftâ right symmetry, the ratio of the middle and lower face, and the ratio of protruding structures are considered.

When the zygomatic bone and zygomatic arch are excessively bulging anteriorly or laterally compared to the outline of the face or when right–left asymmetry exists, reduction malarplasty can be a solution to reduce the size of the zygomatic bone or restore lateral symmetry. However, when using the conventional malarplasty technique through an intraoral and preauricular approach, there is a possibility that asymmetry remains after the operation, and complications, such as malunion or nonunion, may occur if the fixation of the bone segment is unstable.[3]

To overcome these limitations, taking a three-dimensional (3D) facial cone beam computed tomography of patients in the surgical planning stage and then forming a 3D virtual skull image can be possible based on the CT data. Hereafter, a virtual surgery can be performed to restore the anteroposterior and horizontal symmetry as much as possible. Finally, producing and applying cutting guides and customized titanium plates containing information about the osteotomy lines and drill

From the *Department of Oral and Maxillofacial Surgery, Seoul National University Dental Hospital; and †Oral and Maxillofacial Surgery, School of Dentistry, Dental Research Institute, Seoul National University, Seoul, South Korea.
Received June 3, 2021.
Accepted for publication November 27, 2021.
Address correspondence and reprint requests to Jin-Young Choi, DDS, MD, Department of Oral and Maxillofacial Surgery, School of Dentistry and Dental Research Institute, Seoul National University, 101 Daehak-ro, Jongno-gu, Seoul 03080, South Korea; E-mail: jinychoi@snu.ac.kr
The authors report no conflicts of interest.
Supplemental digital contents are available for this article. Direct URL citations appear in the printed text and are provided in the HTML and PDF versions of this article on the journal's Web site (wwwjcraniofa- cialsurgery.com).

ISSN: 1049-2275
DOI: 10.1097/SCS.0000000000008430

holes of the bony segment after surgery using the computer-aided design/computer-aided manufacturing (CAD/CAM) and 3D printing technology can improve the accuracy of the surgery, shorten the operation time, and make the bone fragment fixation easier after the surgery. In addition, it is considered that the 3D technology is almost essential for facial plastic surgery for patients who are out of the normal anatomical structure due to trauma or congenital anomaly.

Therefore, in this study, we analyze the surgery accuracy by comparing the preoperative 3D virtual surgery data and postoperative CBCT of patients who underwent osteotomy using 3D virtual surgery, CAD/CAM, and 3D printing technologies. Furthermore, we would like to discuss the advantages and limitations of the 3D technology and consider the future development direction

MATERIALS AND METHODS

Preoperative 3D facial CBCT images of patients were taken for virtual surgery, then cutting guides designed by CAD that reflect osteotomy lines and drilling holes were produced by using the 3D printing technique, and finally, customized titanium plates were fabricated through the CAD/CAM technology. These surgical tools were used in the intraoperative process for reduction malarplasty in patients at the Seoul National University Dental Hospital included in this study.

Three-dimensional images of the skull bone through 3D facial CBCT were taken for all patients before surgery, and these images were re-orientated according to the patient's natural head position (NHP) with nasion as a reference point. Using this 3D skull image, virtual surgery was performed with FACEGIDE system (Megagen implant, South Korea). At first, the left and right sides were overlapped to analyze the degree of zygoma asymmetry for establishing the surgical plan. Next, appropriate osteotomy lines were set on a virtual skull image to separate the malar segment from the skull. After that, the malar segment was moved to the desired position according to the surgical plan. In this process, the amount of overlap can be shown and reflected in the cutting guides. In addition, at the final position of the malar segment, the step between the skull and malar segment can be shown and the plates are designed accordingly (Fig. 1). Cutting guides and customized plates were all designed with CAD, and cutting guides were produced with 3D printing technique (RAM500, RAY Inc., South Korea), and titanium plates were produced with CAM (ZX-55M, MANIX Co., South Korea).

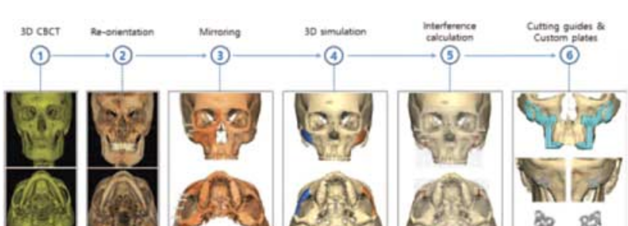


FIGURE 1. Work-flow of reduction malarplasty aided by 3D virtual surgery, CAD/CAM, and 3D printing technologies. Before surgery, 3D facial CBCT was taken, and reoriented according to patient's natural head position. Virtual skull image was produced and 3D asymmetry was measured by mirroring for determining surgical plan. By moving the malar segment to desired position, interference can be calculated. At final position of the malar segment was confirmed, cutting guides and customized titanium plates were designed and manufactured by CAD/CAM and 3D printing technologies. 3D, three-dimensional.

All operations were performed using an intraoral and sideburn combined approach. After exposing the anterior surface of the zygoma through an intraoral upper vestibular approach and adapting the cutting guides, zygomatic body resection was performed using a modified L-shaped osteotomy technique. Then, the root of the zygomatic arch was cut through a sideburn approach to displace the segment to the medial side.[4] The accuracies of virtual surgery, CAD/CAM technology, and 3D printing technology were confirmed by superimposing the 3D facial CBCT images taken after surgery with the virtual surgery data obtained before surgery. Superimposition between postoperative CBCT data and virtual surgery data was done with Geomagic Freeform Plus™ and Geomagic Control X software programs (3D Systems, Rock Hill, SC). The information on patients operated with the 3D technique method is presented in Supplementary Digital Content, Table 1, http:// links.lww.com/SCS/D621 and 3 cases are introduced. This retrospective study was reviewed and approved by the Institutional Review Board of the Seoul National University Dental Hospital, Seoul, Republic of Korea (IRB number ERI21011).

RESULTS

Clinical Presentation 1

An 18-year-old female patient with a chief complaint of facial asymmetry was presented to correct the mandibular asymmetry and reduce protruding zygoma (Fig. 2A). In the preoperative analysis of 3D facial CBCT images that were reoriented based on the NHP and nasion of the patient, the zygoma symmetry was evaluated with respect to the middle sagittal plane passing through the nasion (Fig. 2B). Surgical

FIGURE 2. A healthy 18-year-old female patient without systemic disease. She presented to our hospital with the desire of resolving facial asymmetry and reducing the prominent malar area. (A) Preoperative clinical photographs. (B) As a result of mirroring left and right through 3D virtual analysis, it was confirmed that the left zygoma protrudes more laterally than the right. (C) Images of virtual simulation after determining the amount of reduction. (D) Cutting guides and customized titanium plates, which include the osteotomy line and drill holes. (E) Postoperative clinical photographs. Both the prominent malar areas, which are the chief complaints of the patient, were reduced. (F) As a result of superimposing and comparing the virtual surgery image (brown color) with the postoperative 3D CBCT image (orange color), it can be confirmed that the actual surgery reliably reflects the virtual surgery due to the cutting guides and customized titanium plates. 3D, three-dimensional.

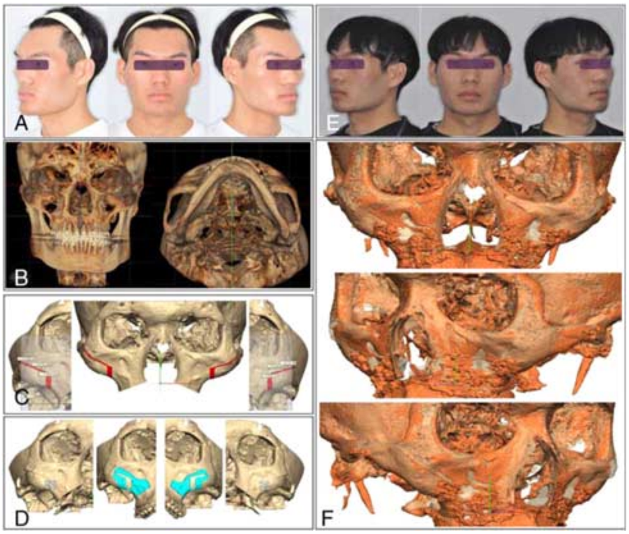


FIGURE 3. A 26-year-old male patient with acromegaly history presented to the hospital with a chief complaint of mandibular prognathism and prominent malar area. (A) Preoperative clinical photographs. (B) As a result of mirroring left and right through 3D virtual analysis, it was confirmed that the vertical location of the left and right zygoma is different. (C) Images of virtual simulation after determining the amount of reduction. (D) Cutting guides and customized titanium plates, which include the osteotomy line and drill holes. (E) Postoperative clinical photographs. Mandibular prognathism is resolved by orthognathic surgery and the prominent malar area is reduced with reduction malarplasty. (F) The result of superimposing and comparing the virtual surgery image (brown color) with the postoperative 3D CBCT image (orange color). 3D, three-dimensional.

planning was done through virtual surgery, and patient-specific cutting guides and customized plates were fabricated using the CAD/CAM and 3D printing techniques. In this case, since there is no tooth movement during surgery, accurate positioning of the cutting guides was achieved by designing a teeth-supportive type (Fig. 2C-D). To confirm the accuracy of the surgical prediction by virtual surgery, preoperative virtual surgery data and 3D facial CBCT taken after surgery were superimposed (Fig. 2E-F).

Clinical Presentation 2

A 26-year-old male patient who was diagnosed with acromegaly due to pituitary adenoma and underwent pituitary excision surgery was presented to resolve mandibular prognathism and reduce protruded zygoma (Fig. 3A). Comparing the size and position of both the zygomas by reorienting the 3D facial CBCT images taken before surgery, it was observed that the right zygomatic arch was located slightly superior, and asymmetry was observed (Fig. 3B). Virtual surgery was performed differently on each side to produce cutting guides and customized plates, and then the surgery was performed. In this patient, a simultaneous orthognathic surgery was planned to position the cutting guides by designing a plate-supported type (Fig. 3C-D). Postoperatively, the patient's zygomatic protrusion was significantly improved, resulting in improved aesthetics (Fig. 3E-F).

Clinical Presentation 3

A 19-year-old male patient was referred to the maxillofacial department for management of both condylar fractures after an open reduction and internal fixation of the maxilla and mandible at another hospital due to a pan facial fracture, including that of the left zygoma, caused by a road accident. In the primary surgery, open reduction and internal fixation of both

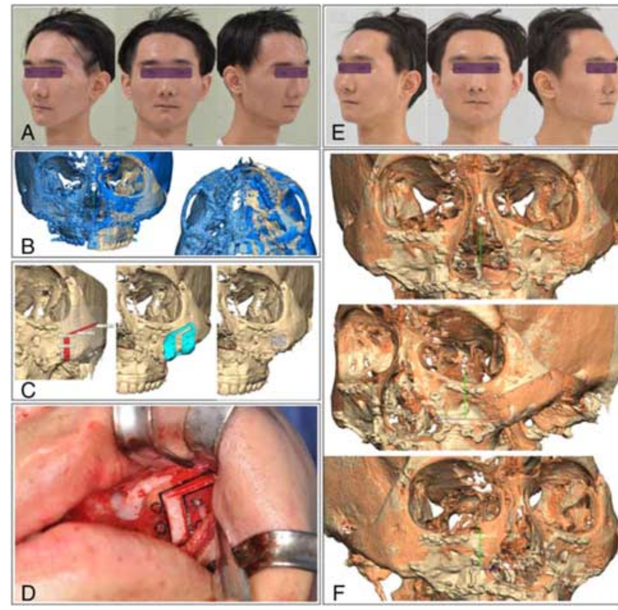


FIGURE 4. A 19-year-old male patientwith a history of panfacial fracture due to a road accident. Surgery was planned for the reduction of the left malar prominent area due to fracture. (A) Preoperative clinical photographs. (B) The surgery plan is established to restore the anteroposterior and left-right symmetries by mirroring left and right through 3D virtual analysis. (C) Images of virtual simulation after determining the amount of reduction. (D) Photographs of the actual surgery. The cutting guide produced through 3D printing is well placed on the bony surface so that the virtual surgery can be actually realized. (E) Postoperative clinical photographs. The left malar area is reduced compared with that before surgery, the left-right symmetry is improved, and the facial outline is smoothened. (F) The result of superimposing and comparing the virtual surgery image (brown color) with the postoperative 3D CBCT image (orange color). 3D, three-dimensional.

condyles and refixation of the maxilla and mandible were performed. During the follow-up period after surgery, the 3D facial CBCT images were taken and analyzed because the patient asked for the reduction of the enlarged left zygoma due to the lateral orbital wall and zygomatic arch fractures caused by the accident (Fig. 4A). Virtual surgery was performed to restore symmetry while avoiding setting an osteotomy line to the defect area caused by the accident. The cutting guides and customized plates were fabricated, and surgery was performed based on virtual surgery. In this case, the osteotomy line was set wide to restore the left-right symmetry, and the plate inserted in the previous surgery was removed. In addition, since the teeth could not be supported due to continuous orthodontic treatment after the accident, the cutting guide was designed to be placed on the widest bone surface as much as possible (Fig. 4B-C). Postoperatively, the patient's symmetry of zygoma was restored, and the postoperative 3D facial CBCT image was compared with the preoperative virtual surgery data (Fig. 4E-F).

In these cases, the optimal osteotomy line and the desired location of the malar segment for each patient were set by surgeons through virtual surgery before the operation. Producing cutting guides and using it for actual surgery can realize the osteotomy line and final position of the malar segment determined by virtual surgery. These cutting guides also contain the information of drill holes position, so screw holes were formed before the separation of the malar segment, so it can help accurate fixation of the segment. Customized titanium plates allowed the segment to be positioned at an exact angle and location set through virtual surgery. Additionally, customized plates and preformed screw holes allowed double checking of the final position of the malar segment. To check the accuracy of the operation, superimposing postoperative 3D facial CBCT and virtual surgical planning data was done by analyzing software programs. All results of superimposing images in this study showed that there were almost no errors, so it was confirmed that the virtual simulation was well reflected in the actual surgery. Aside from the aspect of accuracy, when 3D technologies were applied, the average operation time was shortened by about 1 hour compared to surgery using the classical method. Ultimately, these 3D technologies help improve the accuracy and convenience of the surgery.

DISCUSSION

In Asians, the mesocephalic facial shape is predominant, and a square-shaped face with a laterally prominent malar and mandibular angle implies a strong and stubborn image. On the contrary, oval and slender faces suggest feminine and mild impressions. Therefore, many patients hope to have a slim face through reduction malarplasty.[2]

There are intraoral, coronal, and temporal approaches to access the zygomatic body and zygomatic arch for performing malarplasty. Among them, the intraoral approach is the most commonly used approach because it does not leave any extraoral scars. The conventional method of reduction malarplasty to approach the zygomatic body was the intraoral upper vestibular approach. Unlike other approaches, since surgery is performed through an intraoral approach, there are no external skin scars and there is a less risk of facial nerve damage.[5,6] However, there are also many disadvantages. For example, since osteotomy and segment separation must be performed in the oral cavity with poor surgical vision, removing the exact amount of bone is challenging, and matching 3D symmetry is difficult. In addition, manipulating the instrument is tough, thereby making it difficult to establish an osteotomy line as planned. Moreover, it is possible to damage the prominence area of the zygoma, fracture the lateral orbital wall if the osteotomy line is directed upward, and make complications, such as malunion or nonunion, if the fixation of the segment is inaccurate.[3]

To overcome the limitations of these conventional methods, virtual surgery, CAD/CAM, and 3D printing technology can be used. Since a 3D change of the zygoma is possible through virtual surgery, the 3D symmetry can be restored almost completely, and accurate fixation is possible by forming a drill hole before osteotomy and using a customized plate. In addition, if orthognathic surgery is planned at the same time, the osteotomy line and drill holes position can be adjusted appropriately by virtual surgery. Therefore, 3D technologies can increase the accuracy and convenience of the operation, and consequently prevent malunion and nonunion, which frequently occur in conventional malarplasty.

Furthermore, operation time was significantly reduced by using these 3D technologies. When operating through the conventional method, it is very difficult and time consuming to set the exact position of the malar segment and fix the segment in a floating state. However, by using the 3D technology, the time and effort required for decision making can be excluded, and because it is only necessary to fit a custom plate to the screw holes made before osteotomy, fixation of the floating malar segment has become much easier. If 3D virtual surgery and CAD/CAM technologies were not used, a considerable amount of time would have been required for setting the left-right symmetrical osteotomy line, 3D positioning, and fixation of the floating zygoma segment after osteotomy. As a result of comparing the operation time required for reduction malarplasty, in our cases of this study with the help of 3D virtual technologies, the operation time was reduced by at least 1 hour compared to conventional reduction marlarplasty.

Many attempts have been made to overcome the shortcomings of conventional surgery, and many improvements have been made through the recent development of imaging technology, surgical techniques, and surgical materials. The introduction of the 3D CT technique and 3D virtual technology facilitates the prediction of surgical results by virtual surgery, thereby enabling a more accurate patient diagnosis and surgical planning.[7-9] The 3D printing and CAD/CAM technologies allow the production of customized surgical materials to reflect virtual surgery results in reality. In particular, customized titanium plates realize the accurate amount of segment movement and the angle between segments, while matching the superoinferior, anteroposterior, and leftright symmetries.[10,11] Internal rigid fixation with accurate contact between bone fragments minimizes the risk of malunion and nonunion. In addition, the latest surgical instruments, such as piezoelectric devices, can mark the osteotomy line on the bony structure without damaging the cutting guides, and osteotomy can be performed with minimal soft tissue detachment, enabling minimally invasive surgery.

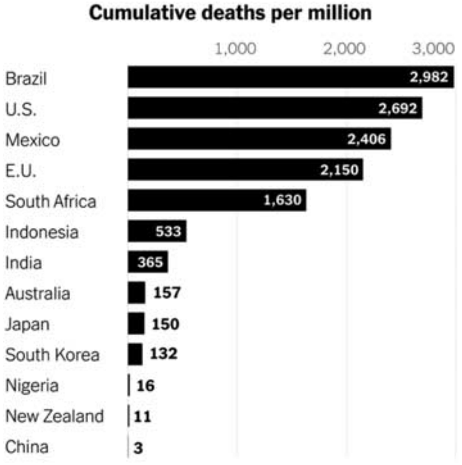
The development of a 3D virtual surgery software, 3D printing technology, and CAD/CAM technology has been applied to various fields of oral and maxillofacial surgery, improving the accuracy of the procedure and increasing the predictability of surgeries. They are especially applied to orthognathic surgery or hard tissue surgery for maxillofacial reconstruction, compensating for errors due to differences in the experience of the operator and finally leading to improvement in surgical accuracy.[12] Also, the use of 3D virtual surgery and CAD/CAM technology is very helpful for clinicians in the diagnosis and actual surgery of patients with trauma or congenital anomalies different from normal anatomical structures.[7-9] However, the application of 3D virtual surgery and CAD/CAM technology for facial aesthetic surgery such as malarplasty has not yet been commercialized. As in this study, if 3D technologies are used, it is possible not only to establish an appropriate surgical plan but also to match the 3D symmetry almost perfectly through virtual simulation. In addition, virtual simulation can be reflected in actual surgery through cutting guides made through the CAD/CAM technology. Finally, it is possible to minimize the time required for decision making during surgery because it undergoes an analysis process through a 3D skull image before surgery. Especially, the cases of asymmetry due to acquired hormonal effect as in case 2 of this study and facial asymmetry due to accidents as in case 3, it would have been difficult to restore the patient's 3D symmetry and improve facial aesthetics without the help of virtual surgery.

In this study, we examined how 3D virtual surgery, 3D printing technology, and CAD/CAM technology could be applied to actual aesthetic surgery through presented cases. There is no doubt that these latest technologies are applied to surgery in the oral and maxillofacial area to increase the predictability of surgery and ensure better results. Although there is a disadvantage that the predictability of the amount of change in soft tissue followed by changes in hard tissue is inaccurate, it can be expected that there will be significant developments in this area through further research in the future.[13] Therefore, if the limitation of soft tissue prediction is overcome, these will be applied to various fields, contributing to the establishment of a surgical plan and improvement of postoperative aesthetics.

REFERENCES

1. Uhm KI, Lew JM. Prominent zygoma in orientals: classification and treatment. *Ann Plast Surg* 1991;26:164–170
2. Kim YH, Cho BC, Lo LJ. Facial contouring surgery for Asians. *Semin Plast Surg* 2009;23:22–31

3. Myung Y, Kwon H, Lee SW, et al. Postoperative complications associated with reduction malarplasty via intraoral approach: a meta analysis. *Ann Plast Surg* 2017;78:371–378
4. Ma YQ, Zhu SS, Li JH, et al. Reduction malarplasty using an L-shaped osteotomy through intraoral and sideburns incisions. *Aesthet Plast Surg* 2011;35:237–241
5. Sumiya N, Kondo S, Ito Y, et al. Reduction malarplasty. *Plast Reconstr Surg* 1997;100:461–467
6. Kim YH, Seul JH. Reduction malarplasty through an intraoral incision: a new method. *Plast Reconstr Surg* 2000;106:1514–1519
7. Baek RM, Kim J, Kim BK. Three-dimensional assessment of zygomatic malunion using computed tomography in patients with cheek ptosis caused by reduction malarplasty. *J Plast Reconstr Aesthet Surg* 2012;65:448–455
8. Tao Q, Min H, Yangyang L, et al. Digital simulation of osteotomy reduction of a prominent zygomatic arch. *J Craniofac Surg* 2021;32:2553–2556
9. Lassausaie A, Sesque A, Barthelemy I, et al. Virtual surgery planning and three-dimensional printing template for osteotomy of the zygoma to correct untreated zygomaticomaxillary complex fracture. *J Craniofac Surg* 2020;31:1142–1145
10. Cho J, Kwon JS, Lee UL. Occlusion-fit three-dimensional-printed zygoma repositioner. *J Craniofac Surg* 2018;29:731–732
11. Feng F, Wang H, Guan X, et al. Mirror imaging and preshaped titanium plates in the treatment of unilateral malar and zygomatic arch fractures. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 2011;112:188–194
12. Tonin RH, Iwaki L, Yamashita AL, et al. Answer to the authors: 3D virtual surgical planning for positioning and orientation of the maxilla in orthognathic surgery: methodological issues on accuracy and agreement. *Orthod Craniofac Res* 2020;24:301–303
13. Holzinger D, Juergens P, Shahim K, et al. Accuracy of soft tissue prediction in surgery-first treatment concept in orthognathic surgery: a prospective study. *J Craniomaxillofac Surg* 2018;46:1455–1460



Gone forever.