Outcomes of Zygomatic Complex Reconstruction With Patient-Specific Titanium Mesh Using Computer-Assisted Techniques

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Purpose: Zygomatic complex defects after extensive maxillectomy can cause severe esthetic and functional deformities. Patient-specific titanium mesh fabricated using a computer-assisted technique is a promising method for such midface reconstruction. The aim of this study was to evaluate the application and clinical outcomes of this technique.

Patients and Methods: This was a retrospective study that included 9 patients with zygomatic complex defects after extensive maxillectomy from 2015 through 2017 at the authors' institution. A 3-dimensional stereo model was obtained based on mirror images of the unaffected side to fabricate a patient-specific titanium mesh using computer-assisted design and manufacturing. Titanium mesh was used to restore the contour of the zygomatic complex with free flap reconstruction after tumor resection. Anterolateral thigh flaps were used in 8 cases and a myocutaneous fibula flap was used in 1 case. Symmetry of the zygomatic complex was evaluated by measuring the zygomatic eminence on the postoperative computed tomogram, and complications were recorded during follow-up visits. Facial symmetry was self-evaluated and scored.

Results: Mean duration for follow-up was 27.3 months (range, 15 to 39 months). Mean deviation of the zygomatic eminence between the reconstructed and unaffected sides was 1.4 ± 0.5 mm. No significant difference was noted in the zygomatic eminence between the reconstructed and unaffected sides (P = .591). Titanium mesh exposure occurred in only 1 patient after radiotherapy. There were no other remarkable complications. All patients were satisfied with their postoperative facial symmetry.

Conclusion: Patient-specific titanium mesh fabricated using a computer-assisted technique was an alternative option for extensive zygomatic complex reconstruction, resulting in acceptable clinical outcomes. A study with a larger sample and long-term follow-up is needed for the observation of long-term outcomes and risk of titanium mesh-related complications.

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The zygomatic complex is the major bony support of the midface, providing support to the globe, dominating the prominence of the midface, and maintaining facial symmetry. Ablation of midface tumors with extensive maxillectomy is one of the most common causes for destruction of the zygomatic complex. Defects of the zygomatic complex can cause severe functional and esthetic deformities. Special considerations should be taken when performing zygomatic complex reconstruction, which include rehabilitating the prominence of the midface and restoring facial symmetry; providing a framework to support soft tissue; supporting the orbital content; and separating the oronasal communication.[1] During the past few decades, several materials and methods have been used for midface reconstruction, including free flap transfer, autogenous bone grafts, and alloplastic materials.[2,3] Nevertheless, reconstruction of zygomatic complex deformities remains one of the most challenging procedures owing to the complex geometry of this area even for experienced surgeons. Failure to restore the anatomy of this area can cause complications, such as diplopia, ocular dysfunction, decreased visual acuity, and severe cosmetic deformities.

Currently, titanium implants, which are flexible and can easily simulate the bony structure, are well accepted as the primary choice for cranial and midface fracture repair.[2] In a previous study, the authors achieved satisfactory outcomes with individualized titanium mesh for orbital floor reconstruction after tumor resection.[4] Therefore, the authors investigated the applicability of this method for zygomatic complex defect reconstruction. To the authors' knowledge, there are only a few studies reporting on the use of titanium mesh in the reconstruction of zygomatic complex defects. The aim of the present study was to evaluate the clinical procedure and outcomes of zygomatic complex reconstruction with patient-specific titanium mesh using a computer-assisted technique.

Patients and Methods

PATIENT DEMOGRAPHICS

This was a retrospective study that included 9 consecutive patients (4 men and 5 women) with a mean age of 43.7 years (range, 16 to 70 yr) treated at the authors' institution from April 2015 through April 2017. The study protocol followed the Declaration of Helsinki and was approved by the institutional ethics committee and review board (number PKUSSIRB-2013058). The inclusion criteria were *1)* patients diagnosed with unilateral midface tumors; *2)* extensive maxillectomy involving the zygoma and orbital rim; and *3)* extensive zygomatic, orbital, and maxillary defects requiring simultaneous reconstruction. The exclusion criteria included *1)* a history of radiotherapy or chemotherapy; *2)* patients who were medically unfit for general anesthesia; and *3)* metal allergy. The histopathologic diagnosis of each patient was confirmed by preoperative biopsy examination. The geometry of defects of each case was evaluated. Options for reconstruction included the anterolateral thigh flap (ALTF) and the free fibula flap (Table 1).

Information on postoperative adjuvant therapy and prognosis of the disease were recorded during the follow-up period (Table 2). To evaluate the outcome, postoperative complications, such as diplopia, ocular dysfunction, infection, and mesh exposure, were recorded. The zygomatic eminence and facial symmetry also were assessed (Tables 3,4).

In this study, primary predictor variables included the geometry of defects, pathologic diagnosis, method of reconstruction, and postoperative adjuvant therapy. Primary outcome variables included the zygomatic eminence and facial symmetry, complications, and prognosis during the follow-up period.

VIRTUAL SURGICAL PLANNING

All patients underwent spiral computed tomographic (CT) scanning of the head and neck region preoperatively (field of view, 20 cm; pitch, 1.0; slice, 0.75 mm; 120Y280 mA), and the data were imported into iPlan CMF (BrainLAB AG, Feldkirchen, Germany) in Digital Imaging and Communications in Medicine (DICOM) format. In the software, precise tumor mapping was performed, producing a direct 3-dimensional (3D) model showing the tumor and its relation to important adjacent structures (Fig 1). The resection margin could be determined based on 3D views of tumors and pathologic results. Subsequently, tumor resection and maxillectomy were simulated virtually using ProPlan CMF (Materalise, Leuven, Belgium) according to clinical and 3D radiographic findings (Fig 2). Because the normal contour of the zygomatic complex was destroyed, images of the unaffected side were mirrored to simulate and recover anatomic characteristics on the affected side (Fig 3). Thereafter, a 3D resin stereolithographic model was printed based on the mirror image using rapid prototyping techniques. This model was used to pre-bend a patient-specific titanium mesh (0.6 mm; AO CMF, Synthes, Switzerland) that would be individually used to rehabilitate the contour of the zygomatic complex (Fig 4).

SURGICAL PROCEDURE

A Weber-Ferguson incision was used to expose the tumor. Tumor resection with maxillectomy that included the zygomatic complex was performed according to the virtual plan. Each osteotomy line was confirmed under the guidance of a computerized navigation system (BrainLAB AG; Fig 5). The patient-

Table 1. PATIENT CHARACTERISTICS (N = 9)

Patients	Gender	Age (yr)	Affected Side	Primary Diagnosis	Reconstruction Option	Geometry of Defects			
						Zygomaticomaxillary Suture	Zygomatic Arch	Inferior Orbital Rim	Alveolar Bone
1	M	41	Right	Odontoblastoma	ALTF	Yes	No	Yes	Yes
2	M	66	Right	Squamous cell carcinoma	ALTF	Yes	No	Yes	Yes
3	F	45	Left	Squamous cell carcinoma	ALTF	Yes	No	Yes	Yes
4	F	36	Right	Osteofibroma	ALTF	Yes	Yes	Yes	No
5	F	70	Left	Squamous cell carcinoma	ALTF	Yes	No	Yes	Yes
6	F	36	Right	Ameloblastoma with local metastasis	ALTF	Yes	No	Yes	Yes
7	F	19	Right	Osteosarcoma	ALTF	Yes	Yes	Yes	Yes
8	M	16	Left	Osteofibroma	FFF	Yes	No	Yes	Yes
9	M	64	Left	Odontoblastoma	ALTF	Yes	No	Yes	Yes

Abbreviations: ALTF, anterior lateral thigh flap; F, female; FFF, free fibula flap; M, male.

Zhang et al. Computer-Assisted Zygomatic Complex Recontruction. J Oral Maxillofac Surg 2019.

specific titanium mesh was adjusted and adapted intraoperatively. Subsequently, the mesh was fixed to the residual bone with 4- to 5-mm microscrews (Fig 6). Thereafter, surgical defects were reconstructed with bony or soft tissue free flaps and the dead space deep to the mesh was filled by subcutaneous tissue or the muscle layer of the flap. The surface of the mesh also was covered by the flap tissue, particularly in the nasal and inner canthus area and the lateral region of the zygoma (Fig 7).

OUTCOME EVALUATION

All patients were followed for at least 12 months. Postoperative complications, including diplopia, ocular dysfunction, local infection, and titanium mesh exposure, were evaluated by clinical examination. Facial symmetry was self-evaluated and scored by patients, and results were classified as satisfactory (8 to 10), fair (4 to 7), or poor (0 to 3). All patients underwent CT scanning 2 weeks postoperatively. Data in DICOM format were uploaded into iPlan CMF (BrainLAB AG), and the symmetry of the zygomatic complex was evaluated objectively with the following method on the postoperative CT scan. The zygomatic eminence was measured on an axial slice with a coordinate system by an experienced examiner. The method of measurement was introduced and validated by He et al[5] for post-traumatic zygomatic reconstruction. The distance from the most prominent point of the bilateral zygomatic complex contours to the

Table 2. PATIENTS' FOLLOW-UP INFORMATION (N = 9)

Patients	Age (yr)	Primary Diagnosis	Adjuvant Treatment	Local Recurrence	Follow-Up (mo)	Outcome
1	41	Odontoblastoma	None	No	15	ANED
2	66	Squamous cell carcinoma	Rad	No	17	ANED
3	45	Squamous cell carcinoma	Rad	No	22	ANED
4	36	Osteofibroma	None	No	19	ANED
5	70	Squamous cell carcinoma	Rad	No	29	ANED
6	36	Ameloblastoma with local metastasis	None	No	31	ANED
7	19	Osteosarcoma	Chem	Yes	35	DOD
8	16	Osteofibroma	None	No	39	ANED
9	64	Odontoblastoma	None	No	39	ANED

Abbreviations: ANED, alive without evidence of disease; chem, chemotherapy; DOD, dead of disease; rad, radiotherapy.

Zhang et al. Computer-Assisted Zygomatic Complex Recontruction. J Oral Maxillofac Surg 2019.

Table 3. OUTCOMES OF ZYGOMATIC COMPLEX RECONSTRUCTION USING INDIVIDUALIZED TITANIUM MESH

		Postoperative Complications				Facial Symmetry	
Patients	Primary Diagnosis	Diplopia	Ocular Dysfunction	Infection	Titanium Mesh Exposure	Self-Evaluation Point	Evaluation Outcome
1	Odontoblastoma	No	Normal	No	No	8	Satisfied
2	Squamous cell carcinoma	No	Normal	No	No	8	Satisfied
3	Squamous cell carcinoma	No	Normal	No	Yes	7	Fair
4	Osteofibroma	No	Normal	No	No	7	Fair
5	Squamous cell carcinoma	No	Normal	No	No	8	Satisfied
6	Ameloblastoma with local metastasis	No	Normal	No	No	9	Satisfied
7	Osteosarcoma	Yes	Normal	No	No	8	Satisfied
8	Osteofibroma	No	Normal	No	No	9	Satisfied
9	Odontoblastoma	No	Normal	No	No	7	Fair

Zhang et al. Computer-Assisted Zygomatic Complex Recontruction. J Oral Maxillofac Surg 2019.

intersection point between the midline and the border of the skull base were measured (Fig 8A). Deviation of the distance between the affected and unaffected sides was calculated and compared to evaluate surgical outcomes (Fig 8B). Differences in the zygomatic eminence between the unaffected and reconstructed sides were calculated using paired-sample *t* tests with SPSS 17.0 (SPSS Inc, Chicago, IL). A *P* value less than .05 was considered statistically significant.

Results

Of the 9 patients, 4 were diagnosed with benign tumors and 5 were diagnosed with malignant tumors. In all cases, zygomaticomaxillary sutures were involved. Thus, all defects included the main block of the malar and maxilla. Total or partial inferior orbital rims also were involved in all cases. Furthermore, in 2 cases, the defects were more extensive and involved the zygomatic arch. The alveolar bone was resected in 8 cases. Although the contour of the zygomatic complex was reconstructed with patient-specific titanium mesh using computer-assisted techniques, ALTFs were the preferred option (8 of 9 cases) for reconstruction of extensive defects, and the free fibula flap was used in only 1 case.

Table 4. POSTOPERATIVE EVALUATION OF ZYGOMATIC EMINENCE

	Zygomatic Eminence Evaluation		
Patients	Reconstructed Side (mm)	Unaffected Side (mm)	Deviation (mm)
1	80.8	81.8	1.0
2	76.7	76.0	0.7
3	70.8	68.9	1.9
4	79.3	81.2	1.9
5	77.8	77.1	0.7
6	60.5	59.2	1.3
7	66.8	65.5	1.3
8	86.8	85.1	1.7
9	86.3	88.4	2.1
Mean	76.2 ± 8.2	75.9 ± 9.1	1.4 ± 0.5*

* $P = .591$.

Zhang et al. Computer-Assisted Zygomatic Complex Recontruction. J Oral Maxillofac Surg 2019.

Mean follow-up duration was 27.3 months (range, 15 to 39 months). During the follow-up period, none of the 4 patients with benign tumors presented with local recurrence. Of the 5 patients with malignant tumors, 3 patients received radiotherapy, another patient underwent postoperative chemotherapy, and the remaining patient was followed for pathologic results, confirmed as ameloblastoma with local malignancy. Of the malignant cases, only 1 patient developed local recurrence of osteosarcoma with distant metastasis and died of disease during the follow-up period (Table 2).

All free flaps were successful, and titanium mesh exposure occurred in only 1 patient with squamous cell carcinoma (SCC) after radiotherapy in the lateral region on the zygoma; a secondary surgery was performed with a local advancement flap to cover the exposed titanium mesh. No specific complications (eg, diplopia or ocular dysfunction) or infection, anaphylactic reaction, or anaphylaxis were reported in this patient series (Table 3).

Dimensions of the zygomatic eminence on the reconstructed and unaffected sides are presented in Table 3. Mean deviation of the facial eminence was 1.4 ± 0.5 mm, and no significant difference was observed between the affected and unaffected sides ($P = .591$; Table 4).

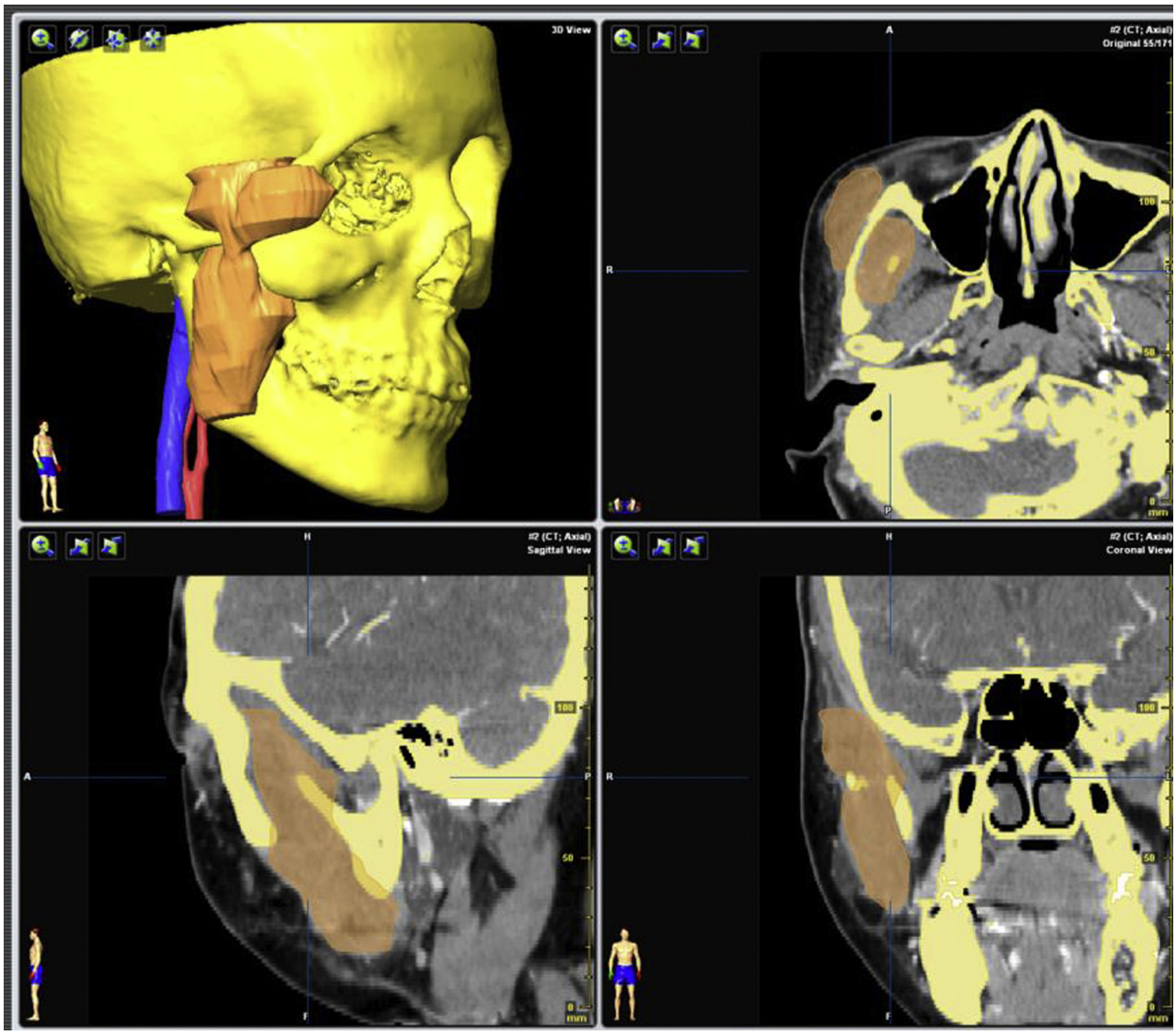

FIGURE 1. Three-dimensional mapping of tumor and adjacent structures.

Zhang et al. Computer-Assisted Zygomatic Complex Recontruction. J Oral Maxillofac Surg 2019.

The patient self-evaluation scores of facial symmetry showed that 6 patients were quite satisfied with their appearance, and the other 3 patients reported acceptable facial symmetry (Table 3). Postoperative CT scans were taken 2 weeks after surgery, and 3D reconstructed images showed excellent outcomes for anatomic restoration of the zygomatic complex with titanium mesh (Fig 9). Facial symmetry was satisfactory. Figure 10 presents a representative case.

Discussion

The zygomatic complex is the most important bony structure of the midface. Zygomatic complex defects resulting from tumor resection can cause severe functional and esthetic deformities.[1] In recent decades, several options have been reported for midface reconstruction.[2,3,6-9] However, the unique and irregular shape and characteristics of this anatomic area cannot be restored completely even by experienced surgeons. In recent years, prefabricated titanium implants have been well accepted as the primary choice for cranial and midface fracture repair,[2-5] and the authors' group performed a previous study using fabricated titanium mesh for orbital floor reconstruction after maxillectomy.[4] Based on the satisfactory result of that research, the authors investigated this technique for reconstruction of a more extensive defect, namely zygomatic complex defects. As far as the authors are aware, there has not been a study reviewing titanium mesh for zygomatic complex reconstruction. Therefore, the aim of the present study was to evaluate the clinical procedure and outcomes of zygomatic

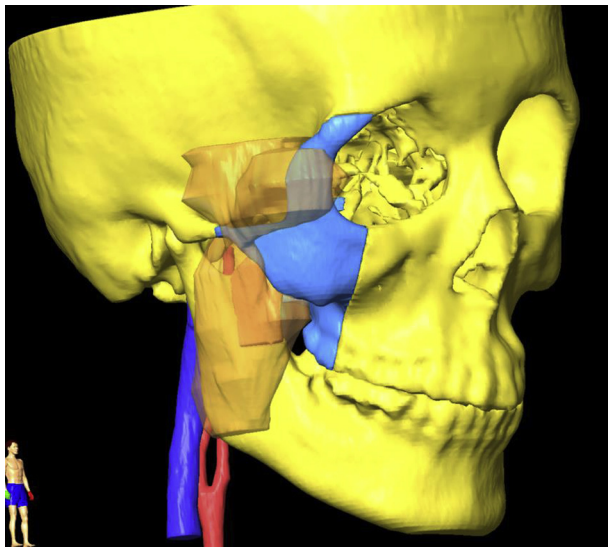

FIGURE 2. Simulation of tumor resection and maxillectomy including the zygomatic complex.

Zhang et al. Computer-Assisted Zygomatic Complex Recontruction. J Oral Maxillofac Surg 2019.

complex reconstruction with patient-specific titanium mesh using a computer-assisted technique.

Extensive zygomatic complex reconstruction is challenging for oral and maxillofacial surgeons and the key point of success is in restoration of the shape and framework of the zygomatic area, provision of support and maintenance of the position of the orbital content by rehabilitating the floor and lateral wall of the orbit, and restoration of facial esthetics. In the present study, all zygomatic complex defects were unilateral, so a computerized mirror image of the unaffected

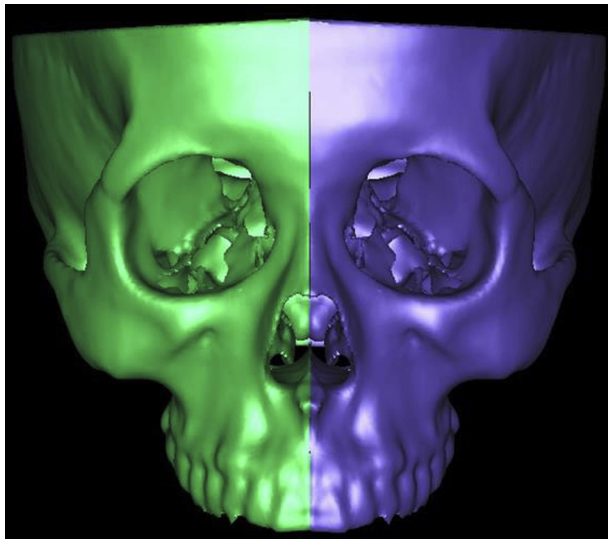

FIGURE 3. Use of a mirror image of the unaffected side to rehabilitate the contour of the zygomatic complex and facial symmetry.

Zhang et al. Computer-Assisted Zygomatic Complex Recontruction. J Oral Maxillofac Surg 2019.

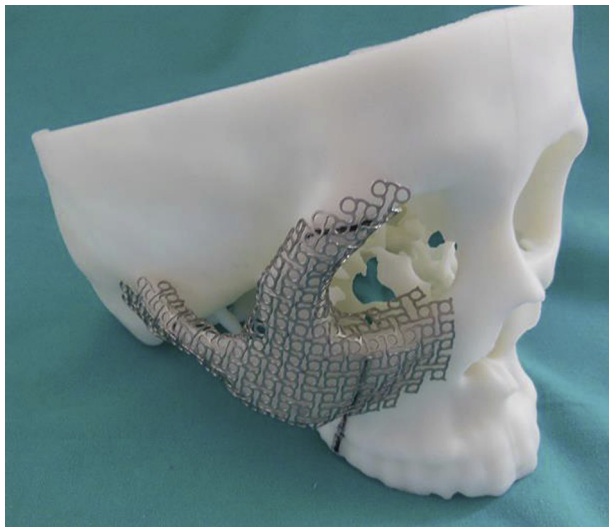

FIGURE 4. Printed stereo model based on the mirror plan that was used to fabricate an individualized titanium mesh to reconstruct the zygomatic complex.

Zhang et al. Computer-Assisted Zygomatic Complex Recontruction. J Oral Maxillofac Surg 2019.

side was used to restore the individual position and contour of the zygomatic complex.[10]

To date, only a few studies have reported on reconstruction of extensive zygomatic complex defects.[11-13] Bony reconstruction with free flap transfer remains the gold standard for reconstruction of maxillary and midface defects, especially when considering future dental implant rehabilitation. Modabber et al[11] reported on a case of zygomatic complex reconstruction with a vascularized iliac crest bone graft. The best-fitting portion on the iliac crest was designed by virtual planning, and the surgery was performed using 3D-printed surgical guides. Accuracy of the procedure was evaluated based on postoperative CT data, and only a small surface deviation of the grafted bone was detected on color mapping. The patient also presented good facial symmetry postoperatively. These findings suggested that the use of autogenous bone grafts with computer-assisted techniques can help restore the contour of the zygomatic complex region with acceptable results. However, reconstructing such an extensive zygomatic complex defect using only a vascularized bony flap in every similar case remains a challenge. The main problem is that the contour of the zygomatic, maxillary, and orbital complex is unique and irregular, the moulding and shaping of the bone is time consuming, and the segments cannot be shaped to fit the ideal contour and position in every case. Further studies with larger samples are warranted to evaluate the long-term efficacy and benefits of this method.

Apart from bony flap transfer, different types of alloplastic materials, such as metals, silicone, polymer, and hydroxyapatite-based products, have been used for

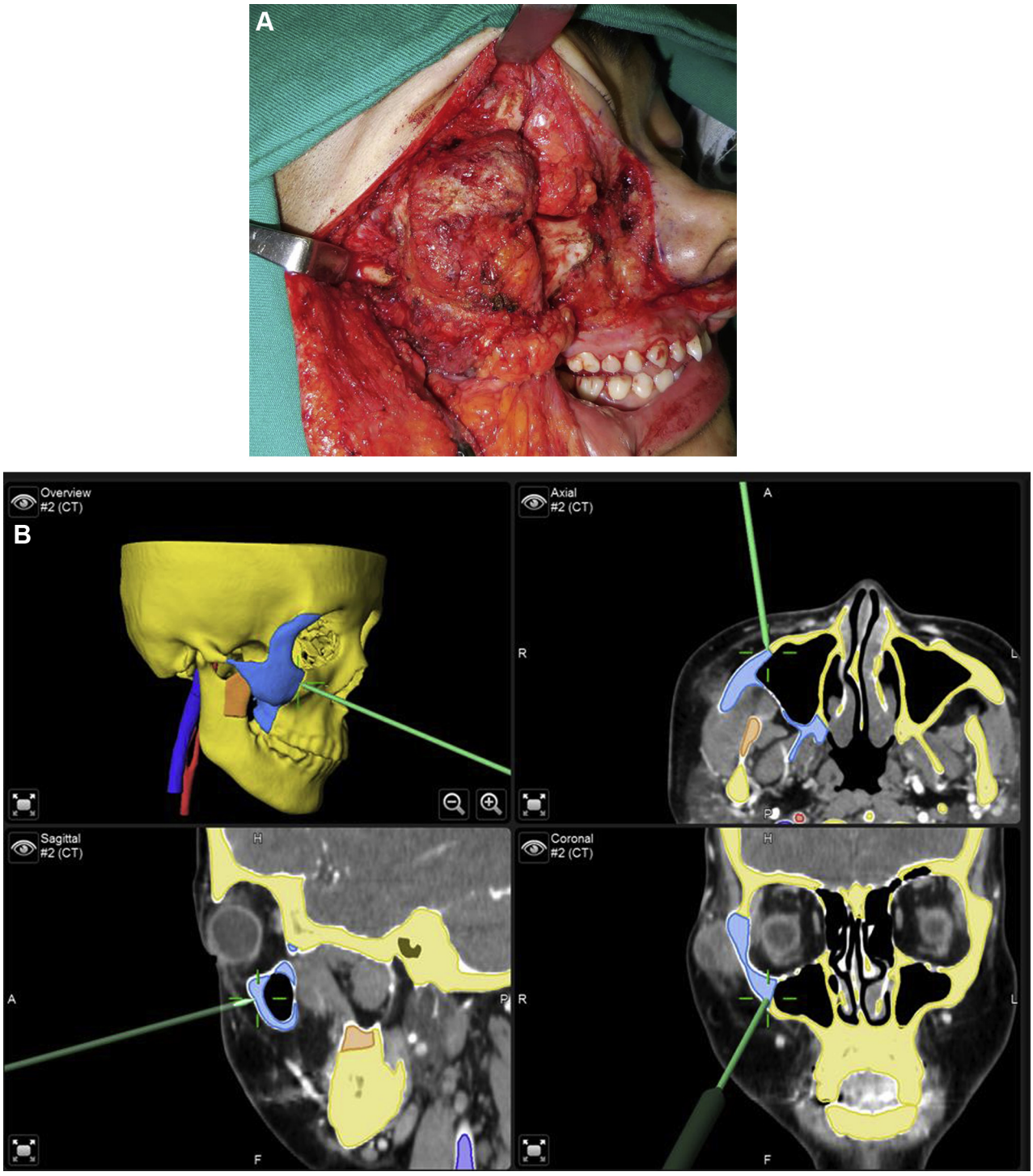

FIGURE 5. *A,* Tumor was exposed using a Weber-Ferguson approach. *B,* Osteotomy lines were confirmed using the navigation system during resection.

Zhang et al. Computer-Assisted Zygomatic Complex Recontruction. J Oral Maxillofac Surg 2019.

reconstruction of different types of midface defects.[6-9] It also is difficult to manipulate such materials to fit the unique contour of midface structures, particularly for extensive zygomatic complex defects. In addition, the rate of infection and resorption with these materials cannot be ignored.[6-9]

In recent years, the titanium implant has become the most commonly used material in craniomaxillofacial reconstruction.[14-19] Rotaru et al[14] reported on an impressive case with a new technique for extensive zygomatic complex reconstruction using selective laser-melted titanium implants. This particular implant

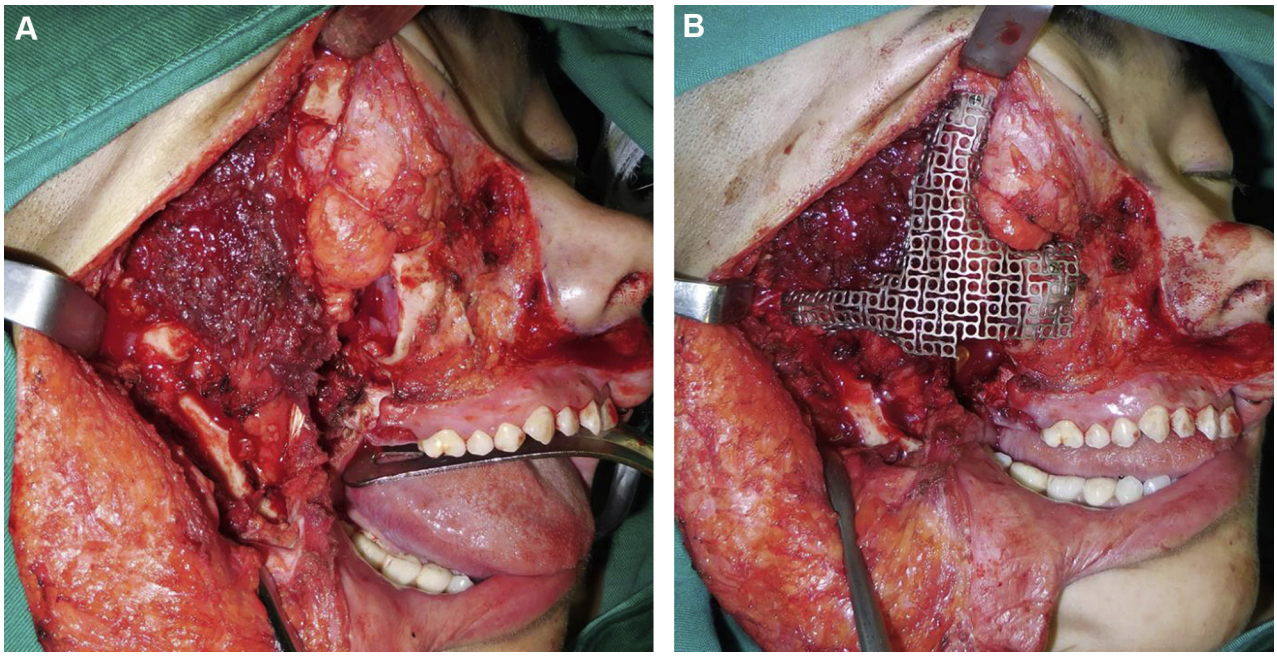

FIGURE 6. *A,* The zygomatic complex was severely damaged after tumor resection. *B,* Titanium mesh was adjusted to fit the defect and was fixed to residual bone.

Zhang et al. Computer-Assisted Zygomatic Complex Recontruction. J Oral Maxillofac Surg 2019.

appeared to be useful for recontouring anatomic characteristics of the zygomatic area and helped improve esthetic outcomes. However, the flexibility of this custom-made implant is poor, making it almost nonadjustable and impossible to modify during surgery. This technique could be a promising alternative approach, but long-term outcomes must be evaluated in future large-scale studies.

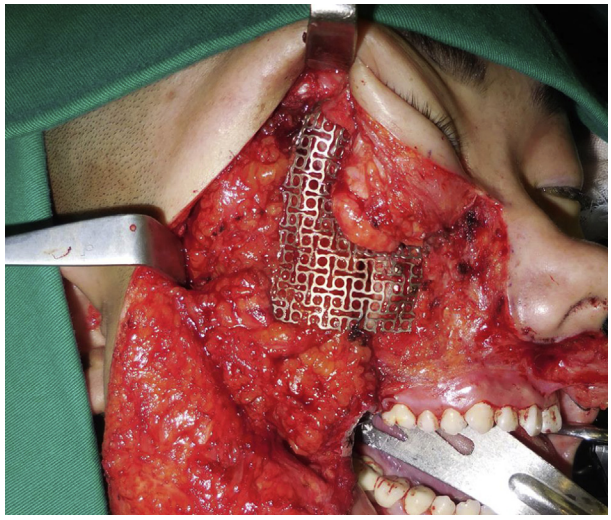

FIGURE 7. An anterolateral thigh flap was typically used to reconstruct the defect. The flap should fill the space beneath the mesh, and part of the flap must be used to cover the nasal and lateral surface of the mesh.

Zhang et al. Computer-Assisted Zygomatic Complex Recontruction. J Oral Maxillofac Surg 2019.

Titanium mesh, which has become more and more popular for the convenience of its fabrication, stability, and flexibility, seems to be a better option for midface defects resulting from tumor resection or trauma.[5,6,15-19] The authors previously reported on reconstruction of orbital floor defects resulting in ablation surgery with prefabricated titanium mesh.[4] The satisfactory and impressive results of that study directed and encouraged the authors to perform the present study. Compared with the single orbital floor defect, the zygomatic complex consists of more subunits, including the malar and maxilla, inferior and lateral parts of the orbit, and even the zygomatic arch in certain cases. Of note, a much larger mesh would be required for such extensive defects, which could result in the increased risk of exposure of the titanium mesh and infection, particularly in patients with malignant tumors who underwent adjuvant radiotherapy. Several previous studies have reported on the use of titanium mesh and soft tissue flaps or free bone grafts for maxillary reconstruction; infections and exposure were not uncommon in these studies.[15-18] Nakayama et al[17] reported radiotherapy-related titanium mesh exposure in 27.8% of patients who underwent maxillary reconstruction with soft tissue flaps and a titanium mesh. In contrast, Sun et al[18] used radial forearm flaps and titanium mesh for maxillary and orbital floor reconstruction and reported exposure in 15.8% of patients (3 of 19) during the follow-up period. To decrease the risk of mesh exposure, a flap with a sufficient volume of soft tissue

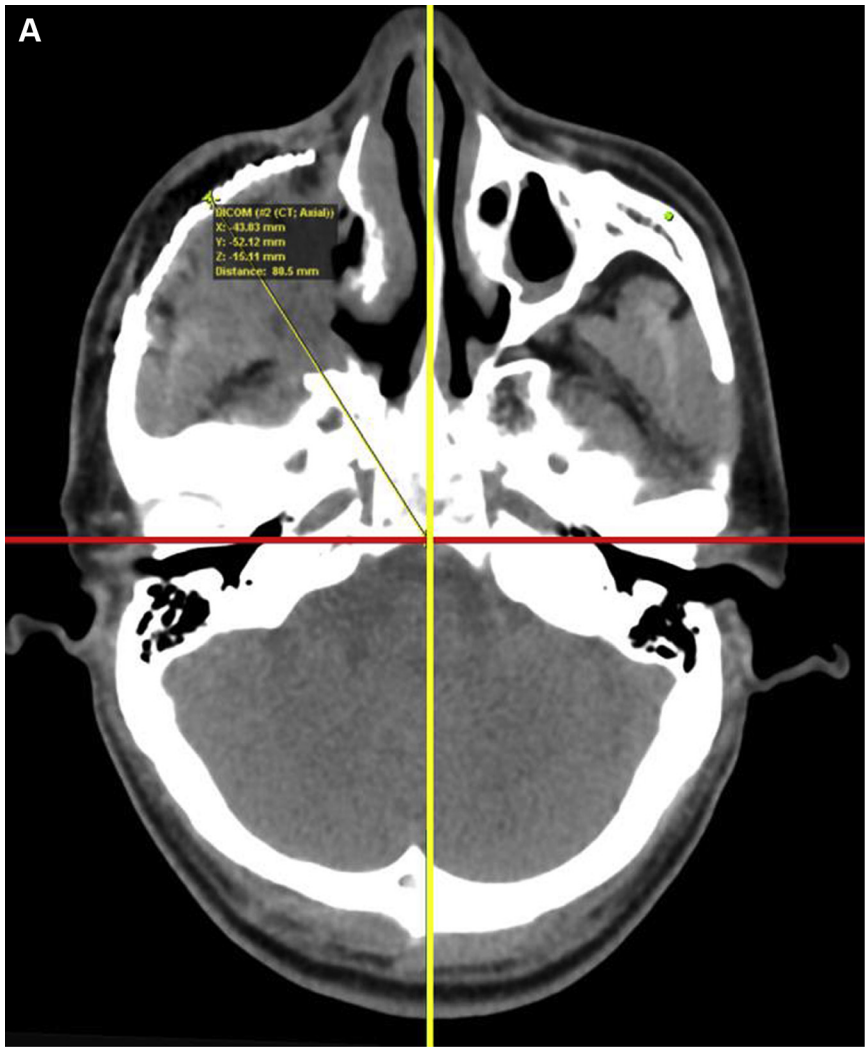

FIGURE 8. *A,* The coordinate system was established on the axial slice of the postoperative computed tomogram, and the eminence of the zygomatic complex was calculated on the system by using software. **(Fig 8 continued on next page.)**

Zhang et al. Computer-Assisted Zygomatic Complex Recontruction. J Oral Maxillofac Surg 2019.

was needed to fill the potential dead space around the mesh and cover the surface of the mesh. In the present study, an ALTF was used in most cases (8 of 9), because this flap could provide an adequate volume of soft tissue (fat and muscular tissue). For benign cases, implant placement is indeed a problem with soft tissue flap reconstruction and it could be considered in second stage when tumor recurrence and mesh exposure are excluded. In the present study, given the relatively low risk of exposure without radiotherapy, myocutaneous fibula flaps were used only in a young patient with benign tumor, in whom the entire flexor hallucis longus muscle was harvested to fill in the palatal defect and a skin paddle without epidermis was used to cover part of the mesh. Nevertheless, mesh exposure still occurred in 1 patient with extensive SCC after radiotherapy. This particular case was performed in the early phase of the present study, and the flap tissue was noted to be inadequate to cover the mesh because of the authors' limited experience at the initial stage. A small (2- × 2-mm) exposure area without infection was noted at the lateral part of the zygoma. A local advancement flap was rotated to restore this small defect.

Another key point for success of zygomatic complex reconstruction with a titanium mesh is in the accuracy of restoration of the unique anatomic contour of the zygomatic area in each case. Failure to achieve the correct anatomic position can lead to complications such as diplopia or other visual problems.[19] Preoperative virtual planning and intraoperative navigation proved to be helpful solutions. These computer-assisted procedures have been widely accepted for various types of craniofacial surgeries.[10,19-21] Zhang et al[19] used a computer-assisted technique for post-traumatic orbital wall reconstruction and achieved satisfactory clinical outcomes. In addition, the authors observed impressive

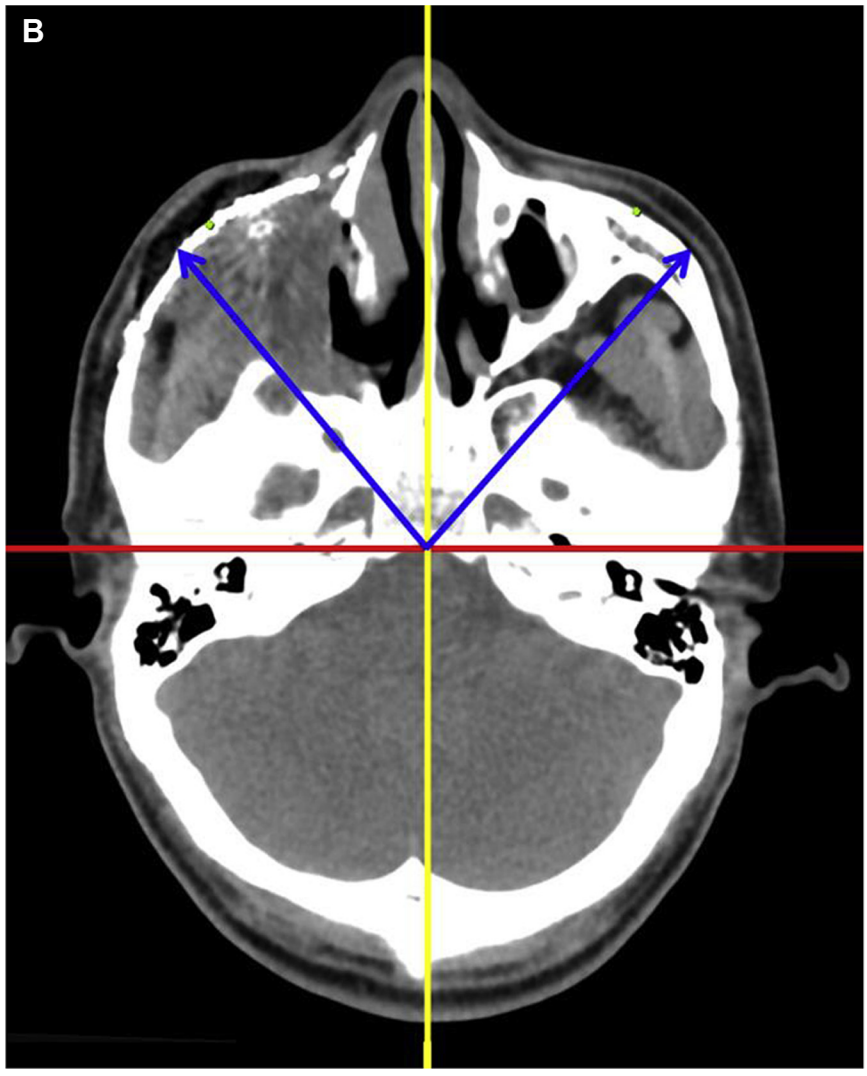

FIGURE 8 (cont'd). *B,* Comparison of deviation of the eminence between the affected and unaffected sides.

Zhang et al. Computer-Assisted Zygomatic Complex Recontruction. J Oral Maxillofac Surg 2019.

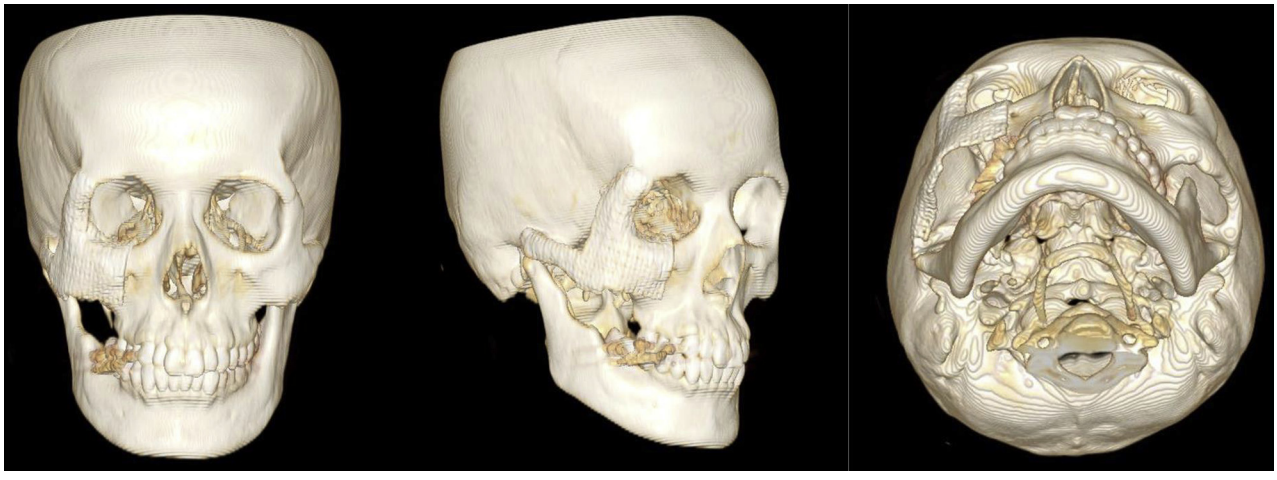

FIGURE 9. Postoperative scan showed good outcomes of anatomic restoration and facial symmetry.

Zhang et al. Computer-Assisted Zygomatic Complex Recontruction. J Oral Maxillofac Surg 2019.

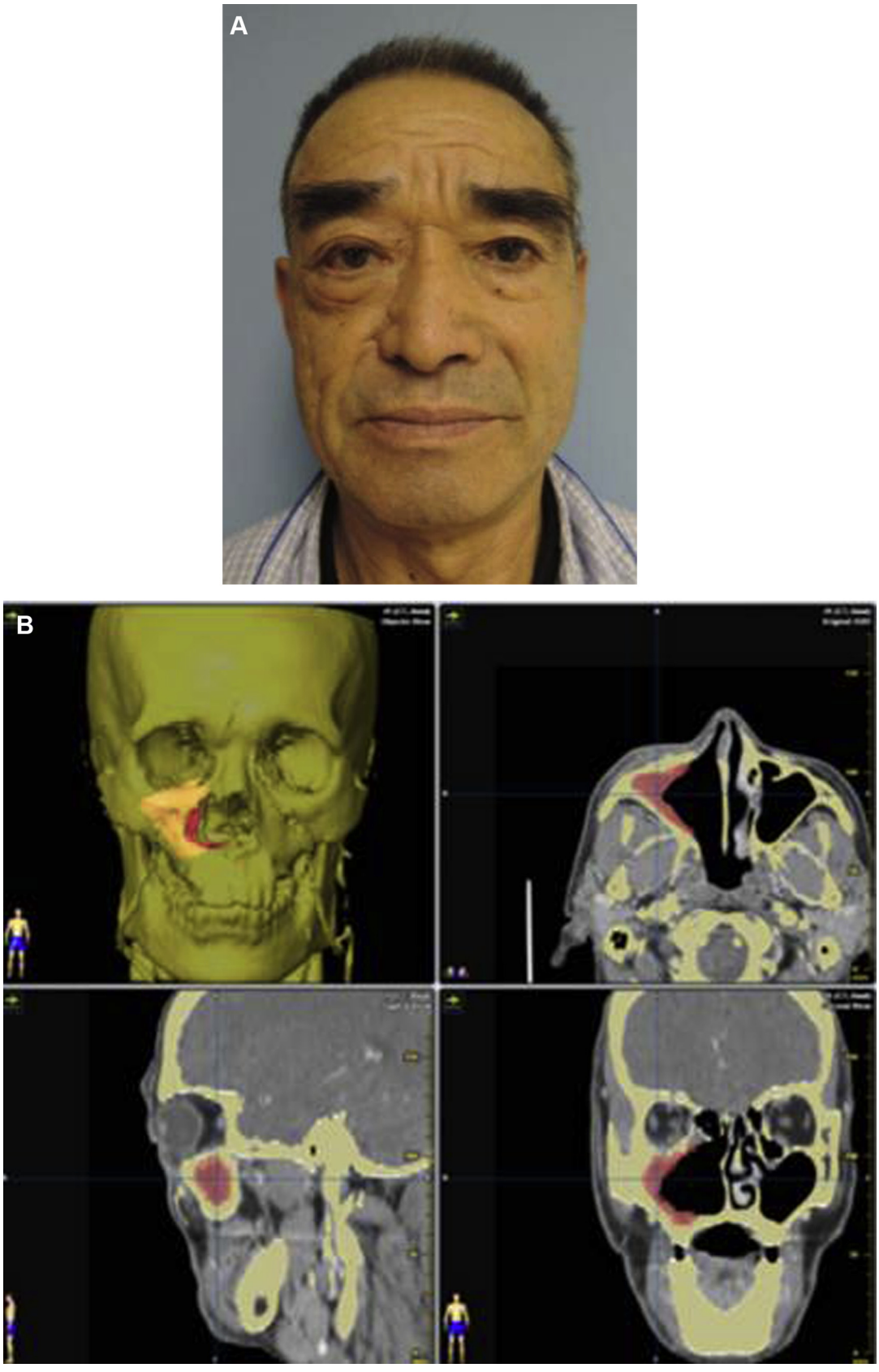

FIGURE 10. Clinical outcomes of a representative case. *A-C,* A patient with squamous cell carcinoma in the right maxilla underwent extensive maxillectomy including the zygoma and reconstruction with titanium mesh combined with an anterolateral thigh flap. **(Fig 10 continued on next page.)**

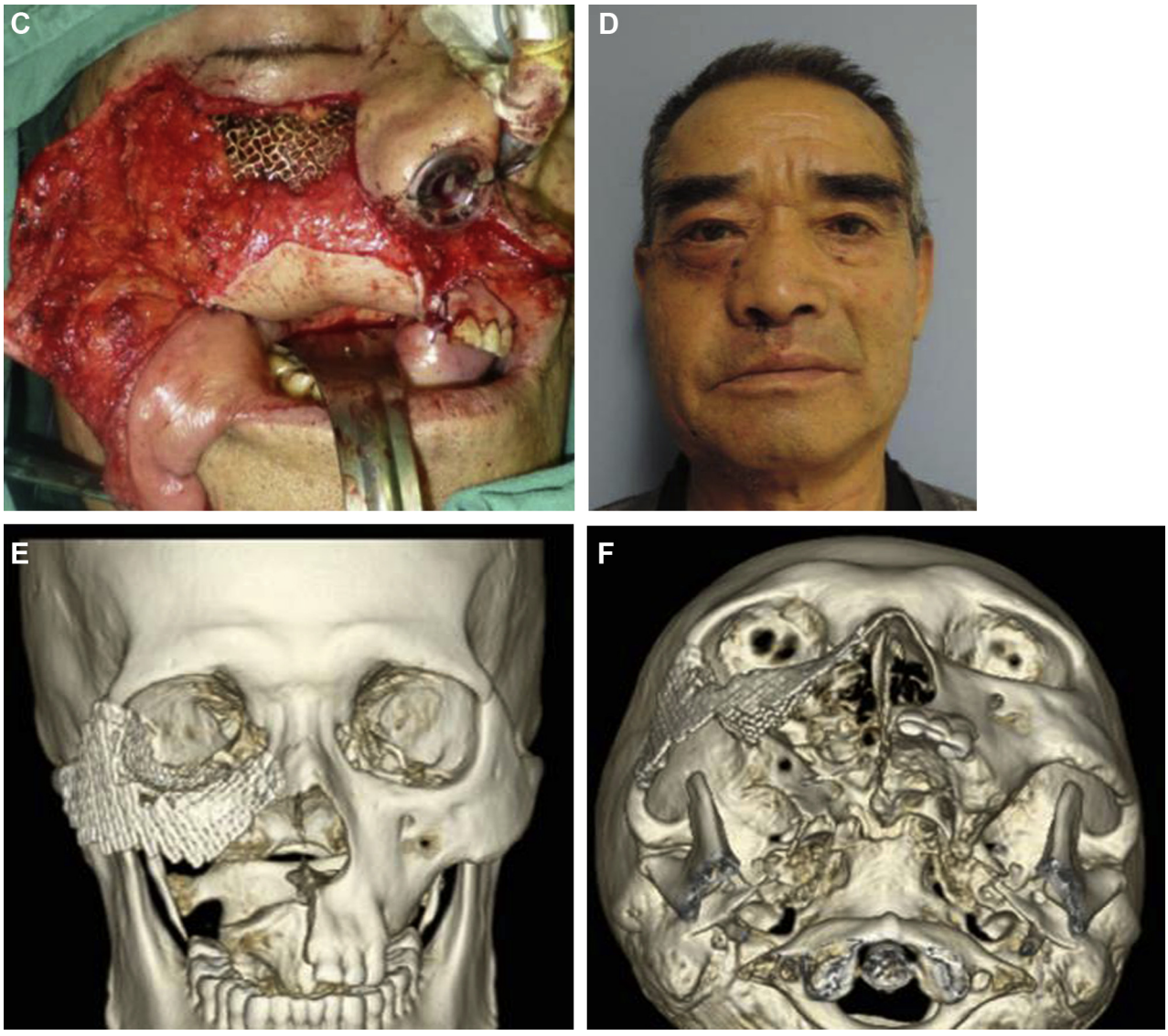

FIGURE 10 (cont'd). *D-F,* Facial symmetry was achieved after surgery.

Zhang et al. Computer-Assisted Zygomatic Complex Recontruction. J Oral Maxillofac Surg 2019.

outcomes for midface reconstruction in their previous studies.[4,21] In the present study, the contour of the zygomatic complex was determined by a virtual plan using a mirror image, the exact position was confirmed with a navigation system during surgery, and the entire titanium mesh fitted well into the defects in their anatomic position. No serious complications, such as diplopia or ocular dysfunction, were reported during the follow-up period.

The computer-assisted technique is not only useful in preoperative virtual surgical planning and intraoperative navigation-assisted surgery, it is also valuable in the evaluation of postoperative surgical outcomes.[4,5,22,23] For zygomatic complex reconstruction, one of the most important aims is to rehabilitate the midface projection and facial symmetry. He et al[5] documented an ideal method to calculate and evaluate the zygomatic eminence using 3D measurements on CT images. In the present study, their technique was used to evaluate outcomes of reconstruction. Results showed that deviation of the zygomatic eminence between the affected and unaffected sides was 1.4 ± 0.5 mm, which is similar to results reported by He[5] and Ogino et al,[23] indicating good facial symmetry.

The present article proposes a preliminary clinical procedure with the use of patient-specific fabricated titanium mesh for zygomatic complex reconstruction. Although clinical results were satisfactory, the study has its limitations. The use of titanium mesh for reconstruction after resection of benign tumors is an acceptable technique, but considering the risk of exposure after radiotherapy, its efficiency in malignant cases,

especially those involving radiotherapy, remains controversial. Using free flap transfer with adequate soft tissue bulk to cover the mesh could be helpful in decreasing the risk of mesh exposure. However, more evidence-based studies with larger samples and long-term follow-up are needed to evaluate the validity of this method. The computer-assisted technique played an important role in improving accuracy and individualized outcomes of reconstruction. In the present study, the mean deviation of the zygomatic eminence was 1.4 ± 0.5 mm, which was acceptable when considering a systematic error of 2 mm. However, various factors could still influence accuracy, including imaging resolution, accuracy of registration of the navigation system intraoperatively, and accuracy of the computer algorithm.[24] These issues should be identified and addressed in future prospective studies with larger samples.

Extensive zygomatic complex reconstruction using the patient-specific fabricated titanium mesh technique is a feasible and acceptable clinical procedure. Free flap transfer with adequate soft tissue bulk is strongly recommended to decrease the risk of exposure, particularly in patients with malignant tumors subjected to radiotherapy. Although good results were achieved in this study, a larger sample with long-term follow-up is still needed for the observation of long-term outcomes and mesh-related complications.

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