Outcomes of Orbital Floor Reconstruction After Extensive Maxillectomy Using the Computer-Assisted Fabricated Individual Titanium Mesh Technique

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Purpose: Orbital floor defects after extensive maxillectomy can cause severe esthetic and functional deformities. Orbital floor reconstruction using the computer-assisted fabricated individual titanium mesh technique is a promising method. This study evaluated the application and clinical outcomes of this technique.

Patients and Methods: This retrospective study included 10 patients with orbital floor defects after maxillectomy performed from 2012 through 2014. A 3-dimensional individual stereo model based on mirror images of the unaffected orbit was obtained to fabricate an anatomically adapted titanium mesh using computer-assisted design and manufacturing. The titanium mesh was inserted into the defect using computer navigation. The postoperative globe projection and orbital volume were measured and the incidence of postoperative complications was evaluated.

Results: The average postoperative globe projection was 15.91 ± 1.80 mm on the affected side and 16.24 ± 2.24 mm on the unaffected side ($P = .505$), and the average postoperative orbital volume was 26.01 ± 1.28 and 25.57 ± 1.89 mL, respectively ($P = .312$). The mean mesh depth was 25.11 ± 2.13 mm. The mean follow-up period was 23.4 ± 7.7 months (12 to 34 months). Of the 10 patients, 9 did not develop diplopia or a decrease in visual acuity and ocular motility. Titanium mesh exposure was not observed in any patient. All patients were satisfied with their postoperative facial symmetry.

Conclusion: Orbital floor reconstruction after extensive maxillectomy with an individual titanium mesh fabricated using computer-assisted techniques can preserve globe projection and orbital volume, resulting in successful clinical outcomes.

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Maxillary defects created after tumor ablation can cause severe functional and esthetic deformities. The orbit is located adjacent to the maxillary bone, and the orbital floor often requires removal, if involved. Orbital floor defects also result in esthetic and functional deformities, including enophthalmos, hypophthalmos, diplopia, and impaired visual acuity. The reconstruction of post-traumatic orbital defects has been well documented in recent years.[1-3] However, the reconstruction of total orbital floor defects after extensive maxillectomy remains a challenge for surgeons.

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Currently, various types of materials, such as titanium meshes, hydroxyapatite, silica gel, Teflon, and Medpor, and autogenous bones, such as the iliac and cranial bones and ribs, are used for orbital reconstruction.[4-8] However, reports on the reconstruction of orbital floor defects resulting from tumor resection are few. Furthermore, the irregular contour of the orbit makes it difficult to precisely rehabilitate orbital defects, and complications, such as diplopia, malpositioning of the globe, restriction of ocular motility, and a decrease in visual acuity, become inevitable in some cases. Although the use of a titanium mesh, which is flexible and can easily simulate the orbital bone structure, is well accepted as the primary choice for orbital fracture repair, there are no reports on its use for orbital floor reconstruction after maxillary tumor resection.

Computer-assisted design and manufacturing techniques combined with intraoperative navigation have been widely used for various craniomaxillofacial surgeries.[9-11] Preoperative designing and intraoperative navigation can provide additional accuracy and safety during orbital floor reconstruction, with improved clinical outcomes. The aim of this study was to evaluate the clinical procedure and outcomes of orbital floor reconstruction after extensive maxillectomy using the computer-assisted fabricated individual titanium mesh technique.

Patients and Methods

PATIENT DEMOGRAPHICS

This retrospective study included 10 consecutive patients (5 men and 5 women; mean age, 42.1 yr; age range, 9 to 75 yr) who underwent orbital floor reconstruction using an individual titanium mesh fabricated using computer-assisted techniques after maxillectomy at the authors' institution from April 2012 to March 2014. This study followed the Declaration of Helsinki on medical protocol and was approved by the institutional ethic committee and review board. All patients were diagnosed with maxillary tumors requiring resection with extensive maxillectomy including the orbital floor. The tumors were benign in 4 patients and malignant in 6. None of the patients presented with ocular symptoms, such as diplopia, enophthalmos, impaired visual acuity, and restricted globe movements. All orbital defects were limited to the orbital floor. The primary maxillary defects were restored with a free fibula flap (n = 4), an anterior lateral thigh flap (n = 5), or a rectus abdominis muscle flap (n = 1), and the orbital floor defects were reconstructed with an individual titanium mesh fabricated using computer-assisted techniques (Table 1).

VIRTUAL SURGICAL PLANNING

All patients underwent spiral computed tomographic (CT) scanning of the head and neck region before surgery (field of view, 20 cm; pitch, 1.0; slice, 0.75 mm; 120Y280 mA), and all imaging data were imported to iPlan CMF (BrainLAB, AG, Feldkirchen, Germany) and ProPlan CMF (Materalise, Leuven, Belgium). Then, tumor resection and maxillectomy were simulated on the computer. A 3-dimensional image of the orbital floor was reconstructed from a mirror image of the unaffected side (Fig 1), after which a 3-dimensional resin stereo model was printed based on the mirror image using rapid prototyping

Table 1. PATIENT CHARACTERISTICS (N = 10)

Patient Number	Gender	Age (yr)	Affected Side	Primary Diagnosis	Reconstruction Option	Recurrence	Adjuvant Treatment	Follow-Up (mo)	Outcome
1	F	75	Right	Adenocarcinoma	ALTF	No	None	34	ANED
2	M	71	Left	Myoepithelial carcinoma	ALTF	No	None	30	ANED
3	F	10	Left	Ameloblastoma	ALTF	Yes	Surgery	30	AWD
4	M	51	Right	Osteosarcoma	FFF	Yes	Rad + chemo	12	DOD
5	F	18	Left	Osteofibroma	FFF	No	None	27	ANED
6	M	9	Left	Osteosarcoma	RAMF	No	None	27	ANED
7	F	56	Left	Adenoid cystic carcinoma	ALTF	Yes	Rad + GKR	26	AWD
8	M	31	Left	Osteofibroma	FFF	No	None	18	ANED
9	M	75	left	Osteosarcoma	ALTF	No	None	16	ANED
10	F	25	Right	Myxoma	FFF	No	None	14	ANED

Abbreviations: ALTF, anterior lateral thigh flap; ANED, alive without evidence of disease; AWD, alive with disease; chemo, chemotherapy; DOD, dead of disease; F, female; FFF, free fibula flap; GKR, gamma knife radiosurgery; M, male; Rad, radiotherapy; RAMF, rectus abdominis muscle flap.

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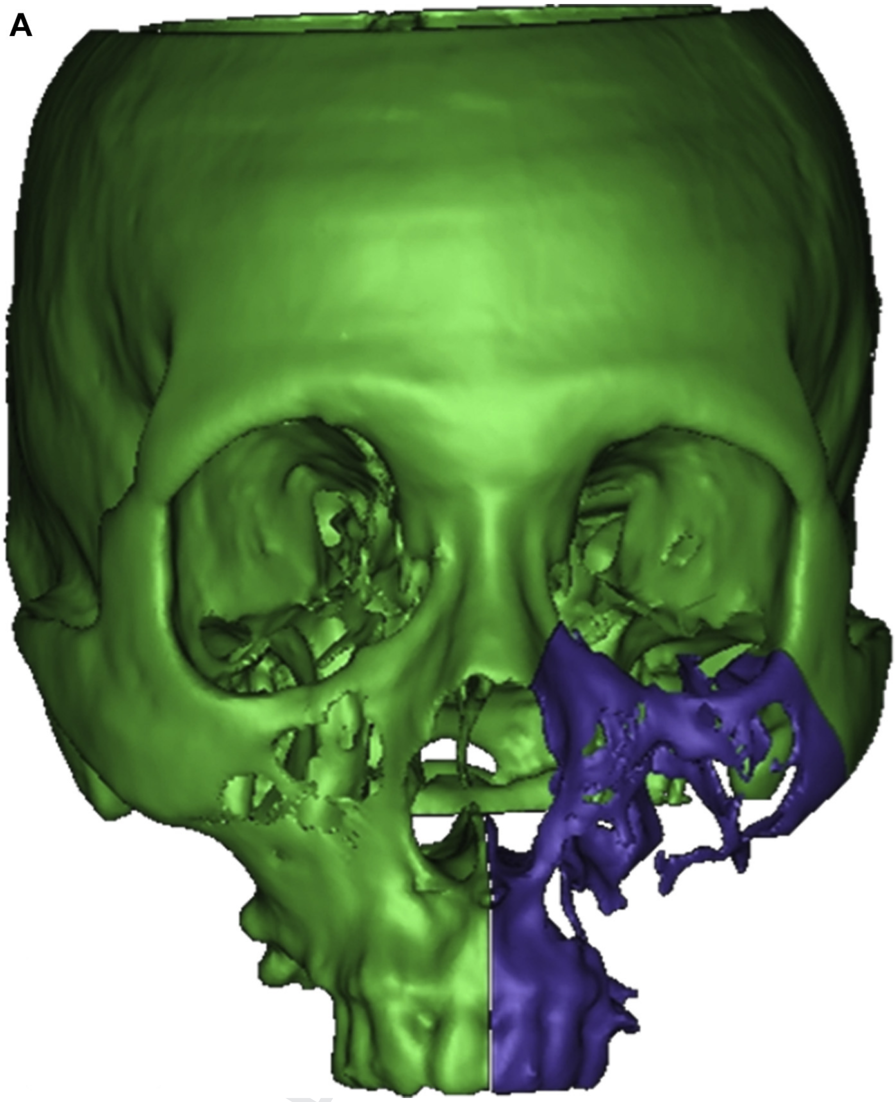

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FIGURE 1. Preoperative virtual planning. *A*, Maxillectomy was simulated on the computer. **(Fig 1 continued on next page.)**

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techniques. The model was used to pre-bend a titanium mesh (0.6 or 0.4 mm; AO CMF, Synthes, Switzerland) that would be used to rehabilitate the contour of the orbital floor in each patient (Fig 2).

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SURGICAL PROCEDURE

Tumor resection and maxillectomy were performed according to the virtual plan completely under the guidance of a computerized navigation system (BrainLAB; Fig 3). The prefabricated titanium mesh was trimmed and fitted to the orbital floor defect. The position and depth of the mesh were guided and controlled by the navigation system (Fig 4). After confirming the final position, the mesh was fixed to the nasal bone and zygoma using 4- to 5-mm microscrews. Extensive maxillary defects were reconstructed with bony or soft tissue free flaps; the dead space under the mesh was filled by the fat tissue or muscles present on the flap. The surface of the mesh was completely covered by the flap tissue.

OUTCOME EVALUATION

All patients were followed for at least 6 months. Postoperative complications, such as diplopia, restriction of ocular motility, a decrease in visual acuity, and exposure of the titanium mesh, were evaluated by clinical examination. Facial symmetry was self-evaluated and scored by the patients, and the results were classified as satisfactory (8 to 10), fair (4 to 7), and poor (0 to 3). The postoperative globe projection and orbital volume on the reconstructed and unaffected sides were measured using iPlan CMF (BrainLAB) based on the spiral CT images obtained 6 months after the primary surgery. Globe projection was measured on an axial

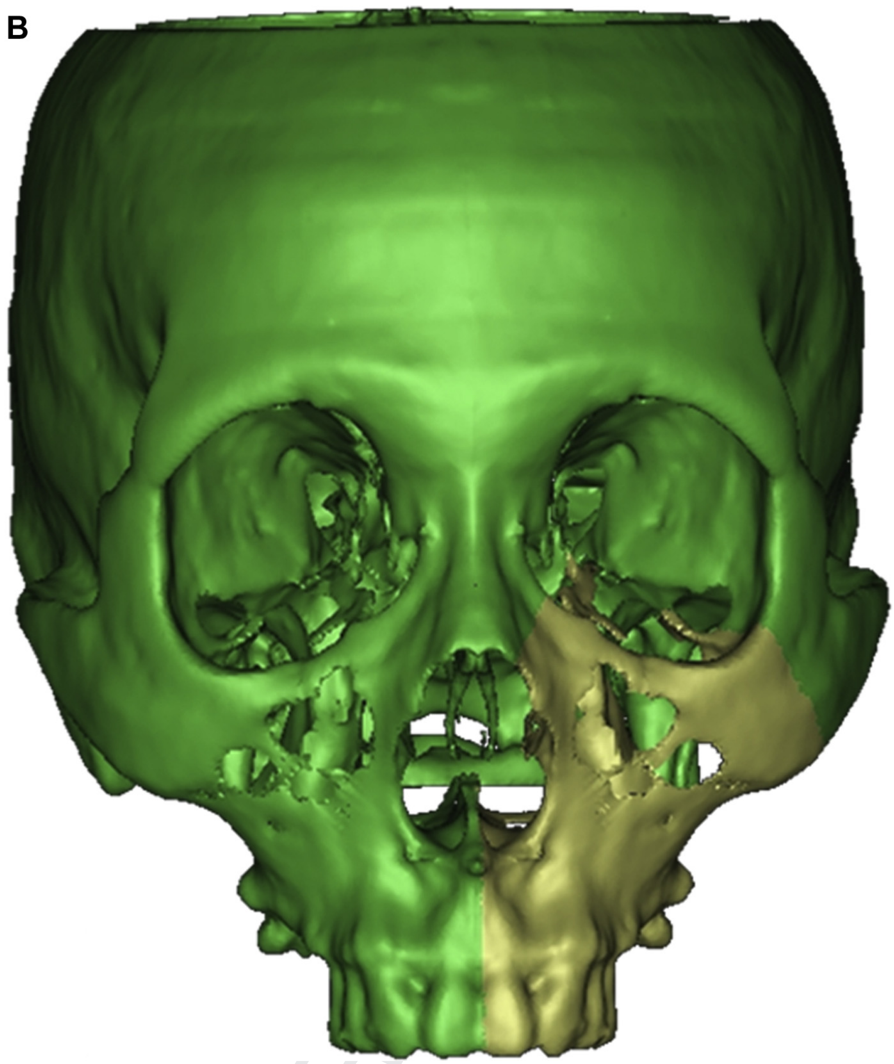

FIGURE 1 (cont'd). *B*, The mirror image of the unaffected side was used to rehabilitate the contour of the orbital floor and facial symmetry.

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slice with the largest diameter of the eye globe. A baseline was drawn from the anterior point of the lateral orbital rim to the median sagittal line, and the distance from the most projecting point of the cornea to the baseline was defined as the globe projection (Fig 5). Orbital volume was measured based on a series of axial CT slices. The bony border between the optic nerve foramen and the connecting line between the zygomaticofrontal suture and the nasomaxillary suture were outlined, and the volume of the outlined area was calculated as the orbital volume using a computer (Fig 6). The depth of the titanium mesh also was measured on a sagittal CT slice. The distance from the orbital rim to the deepest point at the posterior end of the titanium mesh was defined as the depth of the titanium mesh (Fig 7).

Differences in globe projection and orbital volume between the unaffected and reconstructed sides were determined using paired sample *t* tests with SPSS 17.0 (SPSS, Inc, Chicago, IL). A *P* value less than .05 was considered statistically significant.

Results

The mean follow-up duration was 23.4 ± 7.7 months (range, 12 to 34 months). During the follow-up period, 1 patient developed a local recurrence of adenoid cystic carcinoma with invasion of the extraocular muscles and extension to the intracranial area. Distant metastasis to the lung also was detected. This recurrence resulted in postoperative diplopia and visual problems. Salvage treatment was performed using gamma knife radiosurgery, and the patient survived with the tumor until the end of follow-up. Another patient who presented with recurrent osteosarcoma in

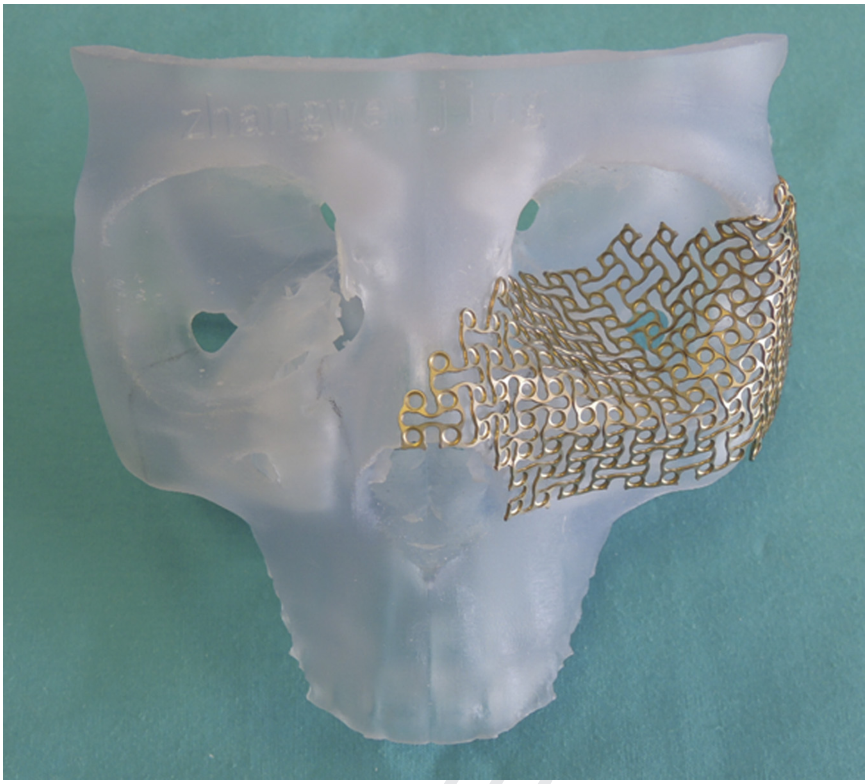

FIGURE 2. Fabricated individual titanium mesh. A 3-dimensional stereo model based on the mirror plan was printed using the rapid prototyping technique to fabricate an individual titanium mesh to reconstruct the orbital floor of the affected side.

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the inferior temporal fossa and received salvage chemoradiotherapy died of the disease a year after the primary surgery, and a young patient with an ameloblastoma who presented with local recurrence in the infraorbital region 14 months after the primary surgery underwent titanium mesh removal with tumor resection in the secondary surgery. However, neither of these 2 patients complained of specific complications, such as diplopia or a decrease in visual acuity and ocular motility, before tumor recurrence (Table 2).

Thus, 9 of the 10 patients exhibited normal visual acuity and ocular motility after orbital floor reconstruction. There was no mesh rejection or exposure in any of the 10 patients (Table 2). Globe projection was 15.91 ± 1.80 mm on the reconstructed side and 16.24 ± 2.24 mm on the unaffected side (P = .505). The orbital volume was 26.01 ± 1.28 mL on the reconstructed side and 25.27 ± 1.89 mL on the unaffected side (P = .312). The 2 parameters showed no statistical differences between the reconstructed and unaffected sides, consistent with the clinical findings of no postoperative diplopia or enophthalmos (Table 3). The mean depth of the titanium mesh was 25.11 ± 2.13 mm, with no indication of damage to the optic nerve. All patients were satisfied with their postoperative facial symmetry (Fig 8, Table 2).

Discussion

Maxillary defects after trauma or tumor resection can cause severe functional and esthetic disturbances. The orbital floor forms the roof of the maxilla and is usually involved in extensive maxillectomy for midfacial tumors. The orbital floor is a very important bony structure in the midfacial region that is responsible for supporting the eye globe, midfacial projection, and facial symmetry. Orbital floor defects also result in various deformities and functional disturbances, such as diplopia, enophthalmos, restriction of globe movement, a decrease in visual acuity, and depression of the infraorbital region. The reconstruction of post-traumatic orbital defects has been well documented in recent years.[1-3] However, the reconstruction of total orbital floor defects after extensive maxillectomy remains a challenge for surgeons.

Several materials and methods have been used for orbital floor reconstruction, including autogenous bone grafts, alloplastic materials, and other manufactured materials.[4-8,12-14] Previous studies have reported the use of nonvascularized autogenous bones, such as the iliac bone, ribs, and calvaria, as grafts for orbital floor reconstruction.[15,16] However,

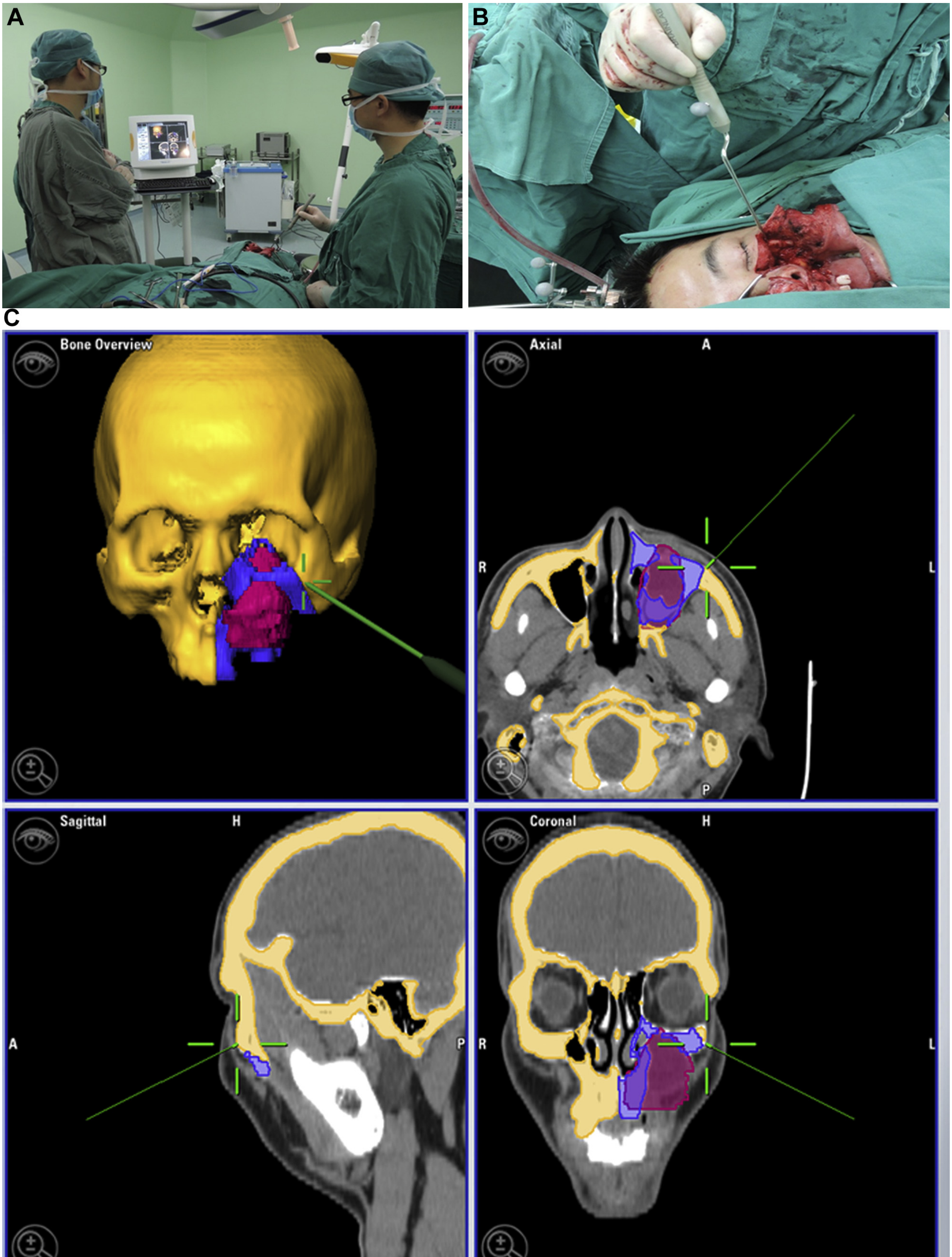

FIGURE 3. Intraoperative navigation-guided tumor resection and maxillectomy. *A*, The intraoperative navigation system was used to control the accuracy of the surgery. *B*, The probe was used to detect the points on the bone. *C*, The navigation system showed the exact position of the osteotomy plane as the virtual plan before surgery.

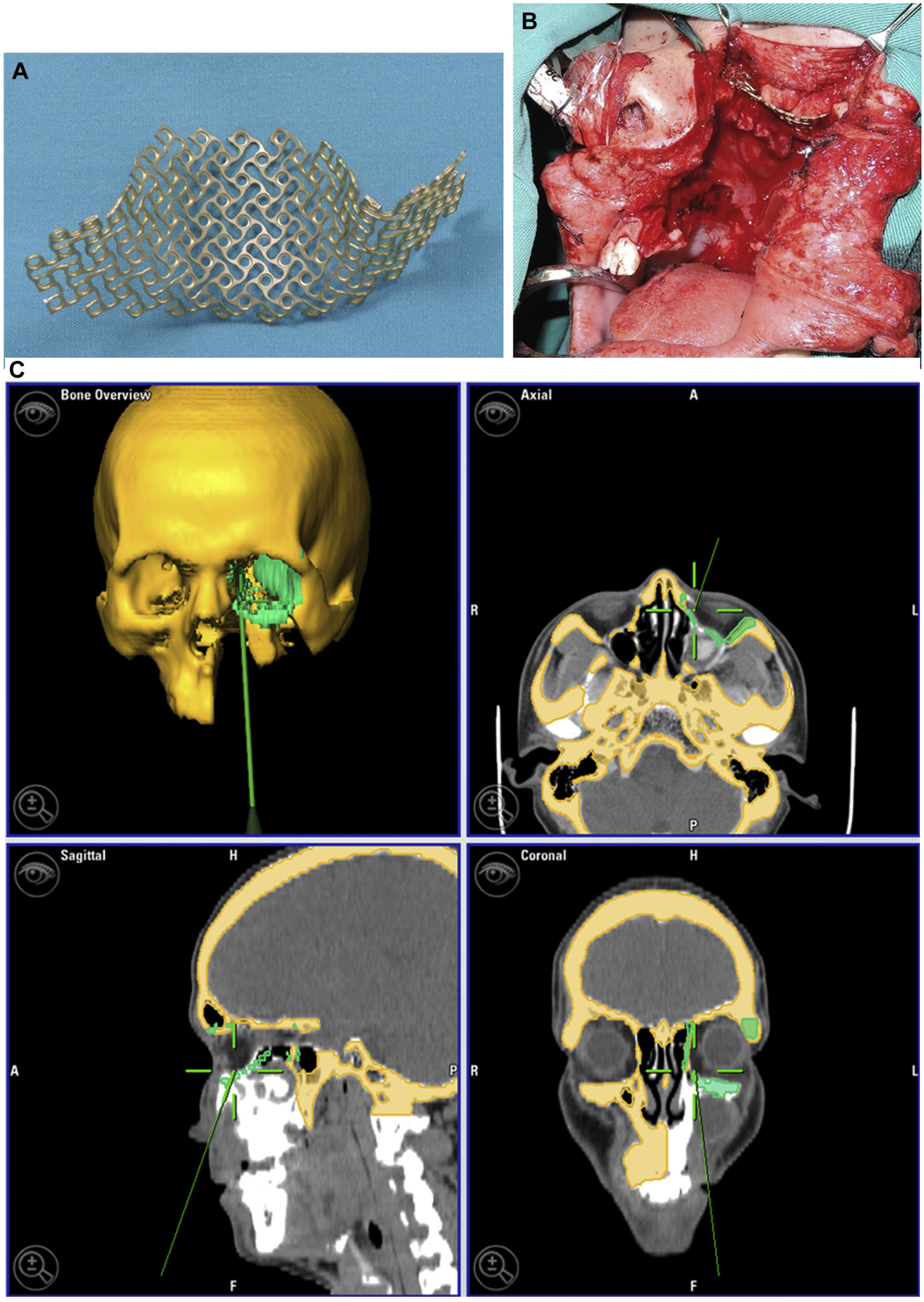

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FIGURE 4. Intraoperative navigation-guided titanium mesh placement. The titanium mesh was *A*, trimmed and *B*, placed into the defect. *C*, The navigation provided the position and depth guidance. *B*, Afterward, the mesh was fixed to the nasal bone and zygoma.

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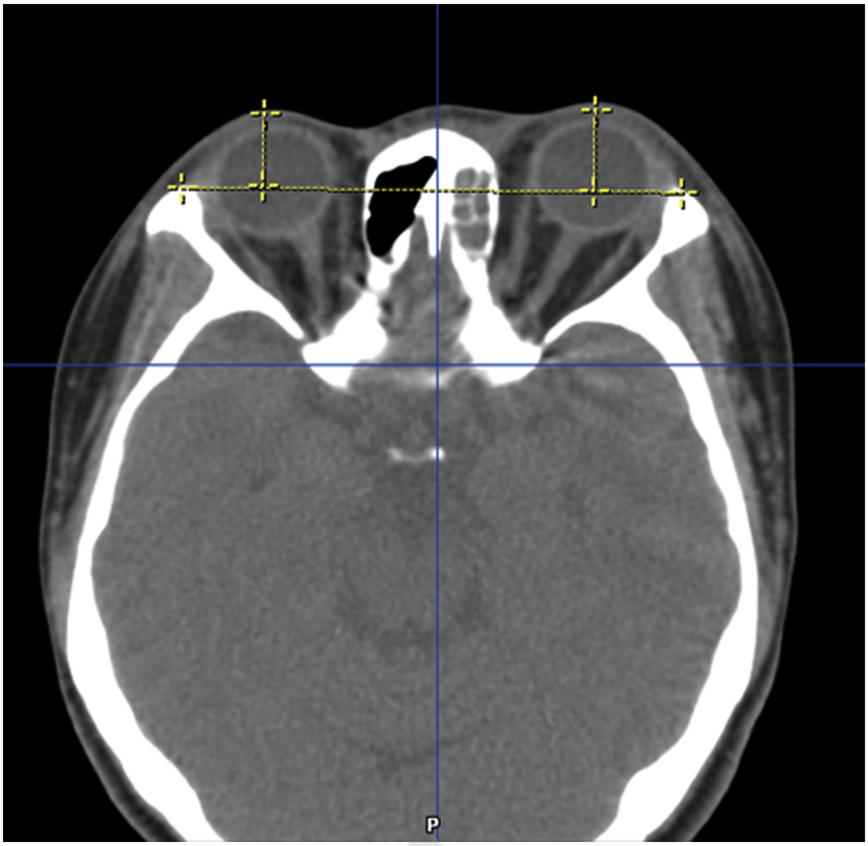

FIGURE 5. Globe projection measurements. An axial slice with the largest diameter of the eye globe is obtained using spiral computed tomography. Then, a baseline is drawn from the anterior point of the lateral orbital rim to the median sagittal line. The distance from the most projecting point of the cornea to the baseline is defined as the globe projection.

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the rate of infection and resorption with these materials is high. In addition, donor-site morbidity is a potential disadvantage of these materials. The goals of orbital floor reconstruction include restoration of the shape and framework of the orbit, provision of support and maintenance of the position of the eye globe, rehabilitation of the orbital volume, and restoration of facial esthetics. However, the thinness and irregular contour of the orbit make it difficult to find an appropriate material for precise reconstruction of orbital defects, and complications, such as diplopia, enophthalmos, and restriction of ocular mobility, become inevitable in some cases.

Titanium meshes are commonly used for reconstruction of the midface and skull base defects after ablative surgery and trauma, and they are currently the first choice of material for post-traumatic orbital reconstruction.[17-19] Convenience of fabrication, stability, flexibility, no donor-site morbidity, and a decreased surgical duration have increased the popularity of titanium meshes for maxillofacial surgeries. However, there are some differences between post-traumatic orbital floor reconstruction and postmaxillectomy orbital floor reconstruction.

The major difference between the 2 procedures is the extent of the defect. Complex midfacial defects, including the maxilla, part of the zygoma, and the orbital floor, always remain after tumor resection and maxillectomy as opposed to small defects, including the orbital walls, after post-traumatic surgery. Extensive defects require a completely different clinical protocol for reconstruction. As an example, a much larger titanium mesh is required, in addition to a free flap with enough volume for reconstruction of the maxillary defect and prevention of mesh exposure. In the present study, a large prefabricated titanium mesh was used to cover the entire orbital floor defect in each patient. A free fibula flap (n = 4), an anterior lateral thigh flap (n = 5), and a rectus abdominis muscle flap (n = 1) were used for complex defects. All these flaps included an adequate soft tissue volume (fat tissue or muscles) to fill in the defects and shield the titanium mesh.

The success of orbital floor reconstruction with a titanium mesh depends on 2 critical factors. First is the restoration of the shape of the individual orbital floor, and second is the definition of the appropriate position of the titanium mesh, including the level and

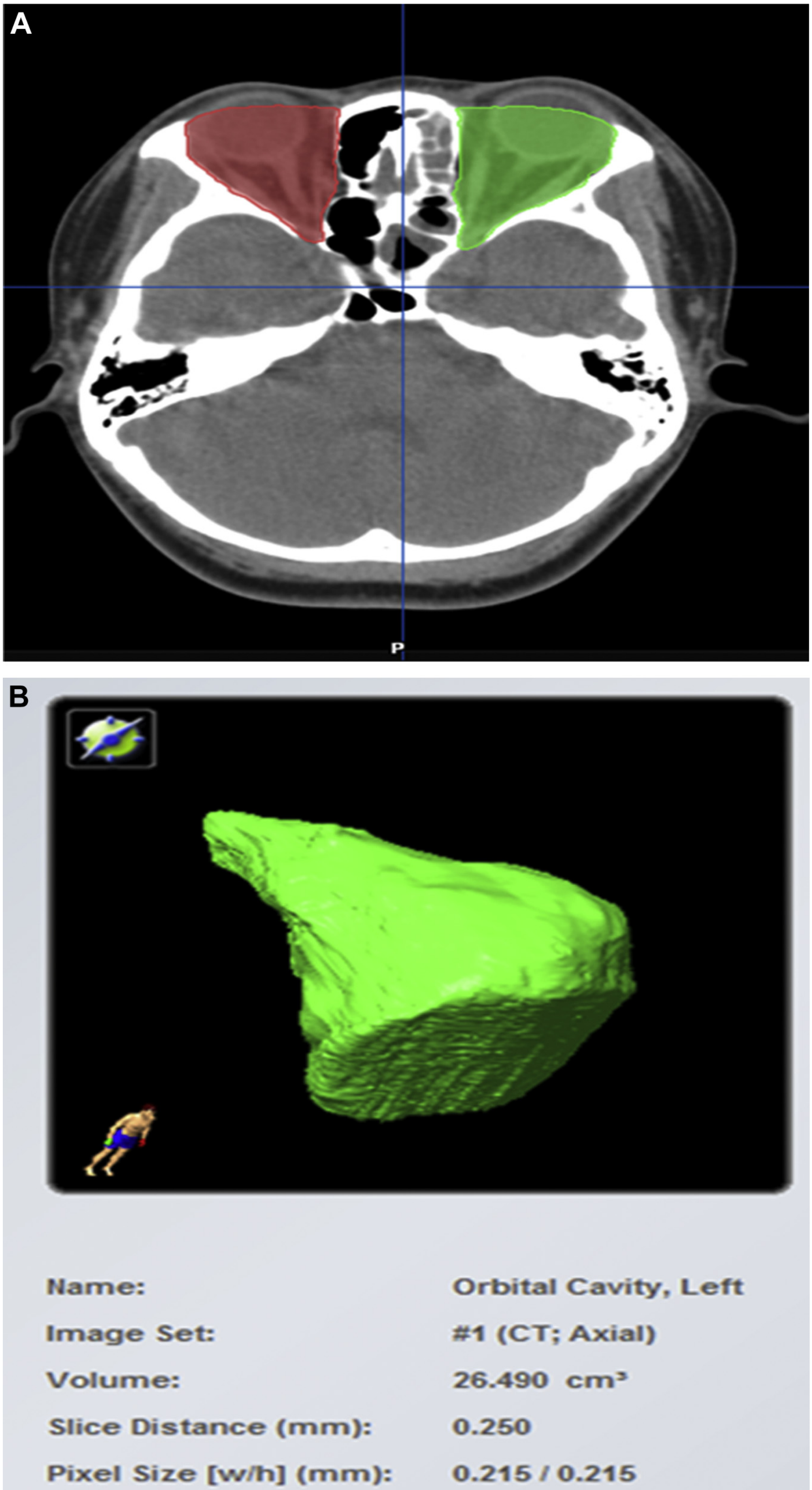

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FIGURE 6. Orbital volume measurements. A series of axial computed tomographic slices is obtained. *A*, Then, the bony border between the optic nerve foramen and the connecting line between the zygomaticofrontal suture and the nasomaxillary suture is outlined. *B*, The orbital volume is calculated by the computer.

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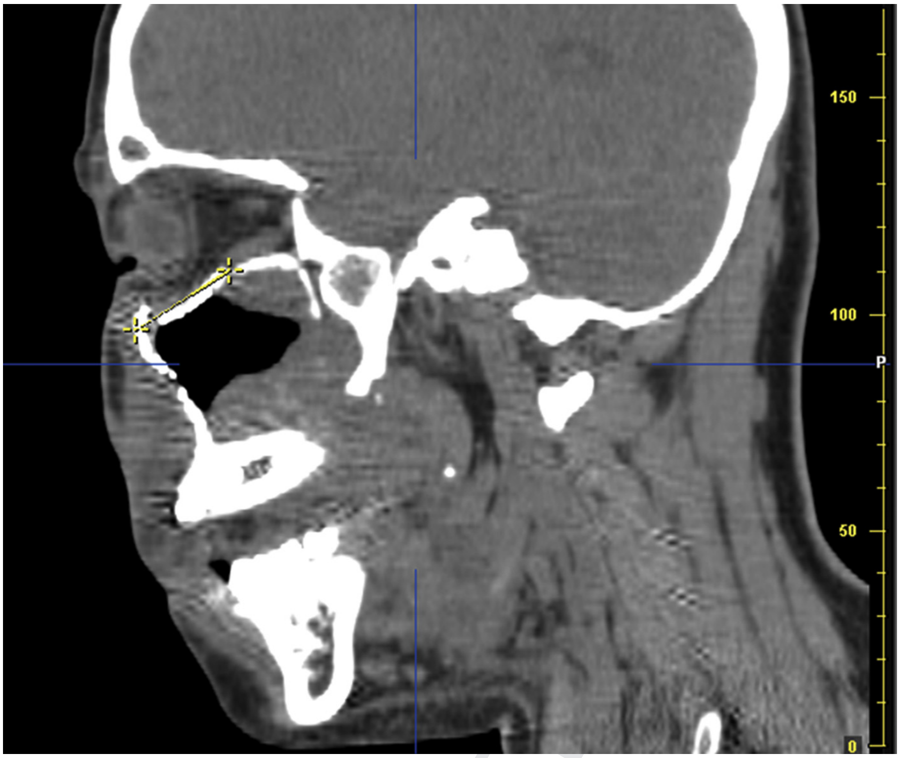

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FIGURE 7. Measurement of the depth of the titanium mesh. A sagittal slice of the deepest position of the titanium mesh is obtained using postoperative computed tomography. The depth of the titanium mesh is calculated as the distance from the orbital rim to the posterior end point of the titanium mesh.

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depth. Preoperative virtual surgical planning and intraoperative navigation provide a useful solution to achieve these requirements. These computer-assisted protocols have been widely used for various types of craniomaxillofacial surgeries, including osteotomy, orthognathic surgery, fracture reduction, and bony flap reconstruction.[20,21] Zhang et al[19] and Yu et al[22] used this procedure for post-traumatic orbital wall reconstruction and achieved satisfactory clinical outcomes. Therefore, in the present study, the outcomes of this

Table 2. OUTCOMES OF ORBITAL FLOOR RECONSTRUCTION USING AN INDIVIDUAL TITANIUM MESH FABRICATED USING COMPUTER-ASSISTED TECHNIQUES

			Postoperative Complications				
Patient Number	Primary Diagnosis	Depth of Titanium Mesh (mm)	Diplopia	Ocular Mobility	Visual Acuity	Titanium Mesh Exposure	Facial Symmetry
1	Adenocarcinoma	26.12	No	Normal	Normal	No	Satisfactory
2	Myoepithelial carcinoma	21.03	No	Normal	Normal	No	Satisfactory
3	Ameloblastoma	25.32	No	Normal	Normal	No	Satisfactory
4	Osteosarcoma	24.26	No	Normal	Normal	No	Satisfactory
5	Osteofibroma	22.04	No	Normal	Normal	No	Satisfactory
6	Osteosarcoma	25.06	No	Normal	Normal	No	Satisfactory
7	Adenoid cystic carcinoma	27.24	Yes	Abnormal	Decrease	No	Satisfactory
8	Osteofibroma	26.56	No	Normal	Normal	No	Satisfactory
9	Osteosarcoma	27.46	No	Normal	Normal	No	Satisfactory
10	Myxoma	26.01	No	Normal	Normal	No	Satisfactory

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Table 3. POSTOPERATIVE GLOBE PROJECTION AND ORBITAL VOLUME

	Reconstructed Side	Unaffected Side	Difference	*P* Value
Postoperative globe projection (mm)	15.91 ± 1.80	16.24 ± 2.24	0.34 ± 1.53	.505
Postoperative orbital volume (mL)	26.01 ± 1.28	25.57 ± 1.89	0.44 ± 1.29	.312

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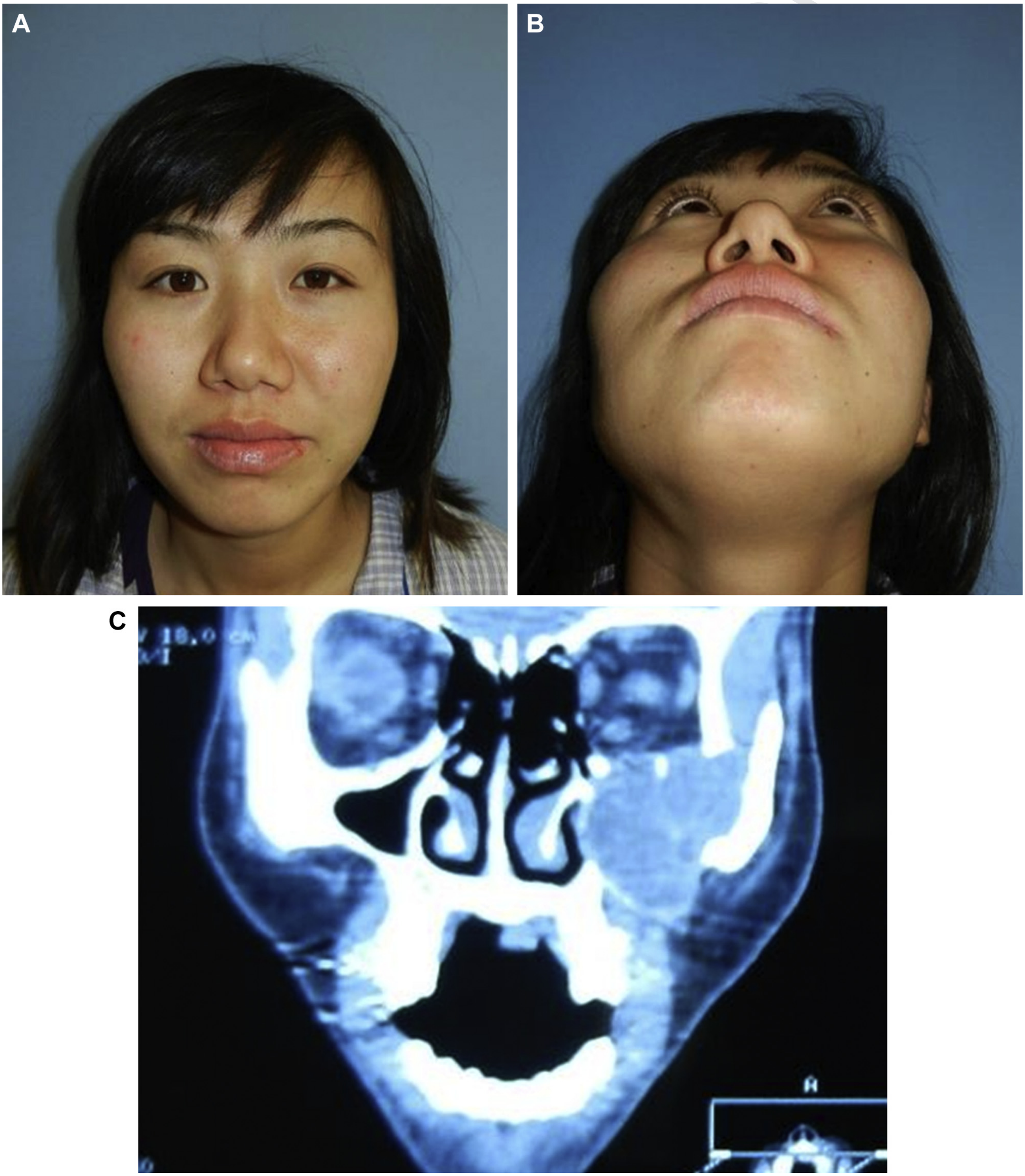

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FIGURE 8. Clinical outcome of a selected case. *A-C*, The patient had extensive recurrent ameloblastoma of the left maxilla with the orbital floor involved and she underwent left maxillectomy including the orbital floor. **(Fig 1 continued on next page.)** Q7

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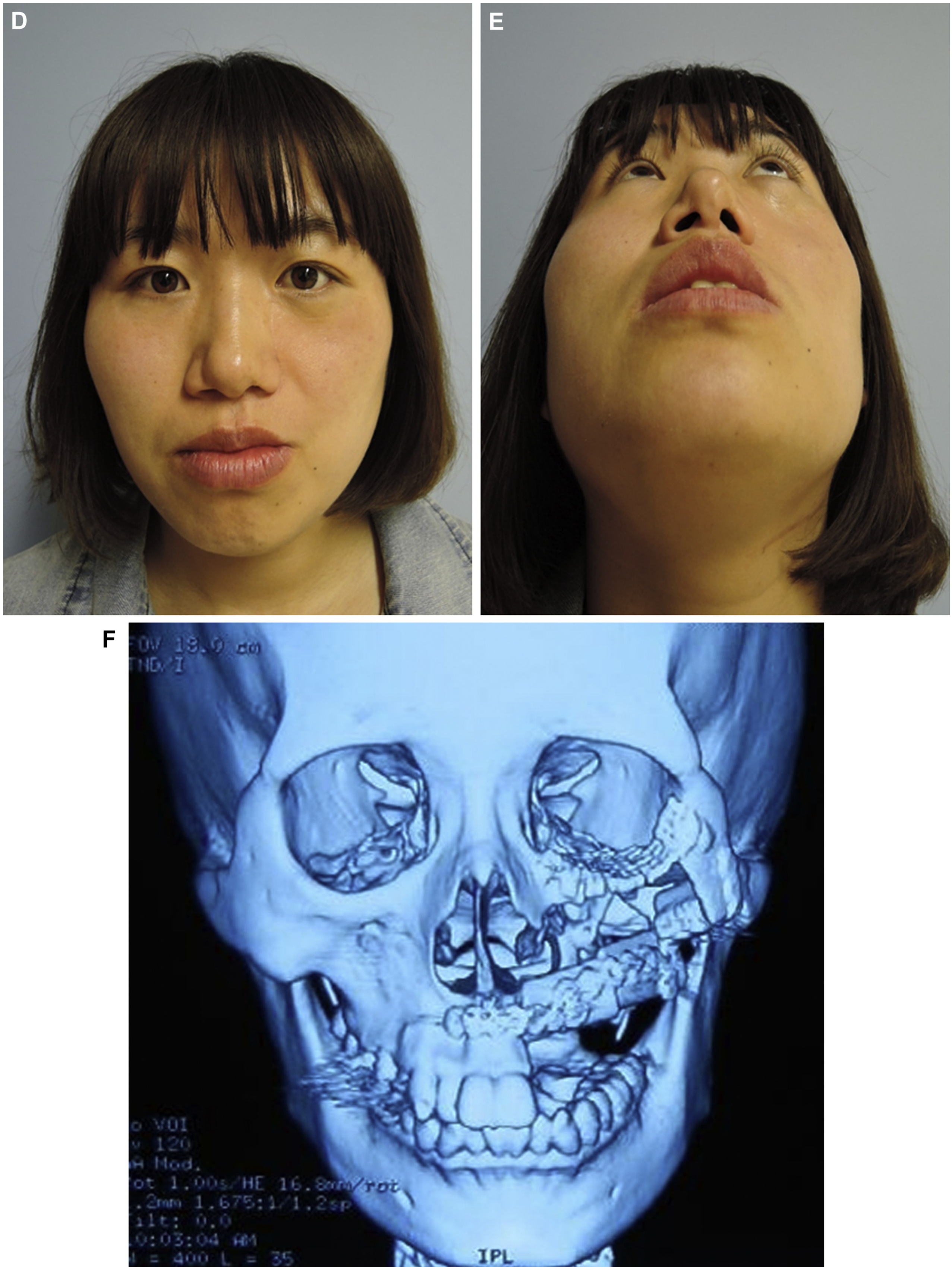

FIGURE 8 (cont'd). *D-F,* Using the computer-assisted individual fabricated titanium mesh technique with free fibula flap reconstruction, a symmetrical appearance was achieved and normal function of the globe was preserved after surgery.

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technique were evaluated in patients who underwent orbital floor reconstruction after extensive maxillectomy.

All tumor-related orbital defects in this study were unilateral, and all defects were limited to the orbital floor without involvement of the other orbital walls. Therefore, rehabilitation of the individual position and contour of the orbital floor using a computerized mirror image of the unaffected side was ideal, presuming individual symmetry of the facial bone structure. Although measurable differences in facial symmetry exist in all individuals, the differences are small and minor in appearance and function.[21,23] An essential parameter for maxillary reconstruction with good esthetic results is recovery of the contour and volume of the maxilla. In this study, an individual fabricated titanium mesh not only supported the eye globe but also rehabilitated the contour and projection of the infraorbital region. Furthermore, the soft tissue on the flaps filled the dead space under the titanium mesh and restored the volume of the defects. Esthetic results were assessed by the patients and surgeons, who were satisfied with the postoperative facial symmetry in all cases.

The normal position of the eye globe is maintained by a balance between the orbital volume and the intraorbital soft tissue. A disturbance in this balance from expansion of the orbital volume or a decrease in the orbital contents can lead to enophthalmos.[19] In most post-traumatic cases, particularly those of delayed orbital fracture repair, changes in the orbital volume and globe projection develop because of absolute expansion of the orbital volume or a decrease in the orbital contents. Enophthalmos is always the chief complaint of such patients. The role of the titanium mesh is to restore the orbital volume and globe projection by anatomic reconstruction.[19] However, during reconstruction of the orbital floor after tumor resection, the periorbital fat pad and extraocular muscles are preserved. In general, there are no changes in the orbital contents, and the purpose of the titanium mesh is to maintain the anatomic position of the orbital floor. In the present study, the orbital contents and extraocular muscles were preserved during primary surgery in all patients, none of whom complained about preoperative enophthalmos or problems with visual acuity and ocular motility. Therefore, rehabilitation of the orbital volume was critical for normal function of the eye globe. Migliori and Gladstone[24] measured the globe projection in 681 patients without any orbital lesions and found that the difference was less than 2 mm in all patients. Koo et al[25] also reported that clinically important enophthalmos can be evaluated by differences in globe projection, with a difference less than 2 mm considered clinically minor. Some investigators have developed the relation between changes in the orbital volume and changes in the globe projection or enophthalmos.[19,26,27] Sun et al[28] reported the use of a fabricated titanium mesh for orbital floor reconstruction after maxillectomy in 19 patients, although a navigation protocol was not included and there was no related analysis of the postoperative globe projection and orbital volume. The results of the present study indicated no statistical differences in the orbital volume and globe projection between the reconstructed and unaffected sides. Postoperative examinations also showed a low rate of complications, such as diplopia and restriction of ocular motility.

Preservation and protection of the optic nerve are essential for any orbital surgery. The depth of the inserted implant should always be accurate. In post-traumatic cases, the depth of the implant depends on the position of the fracture. Therefore, the implant is occasionally inserted very deeply and close to the apex. Zhang et al[19] reported 21 post-traumatic cases in which an individual fabricated titanium mesh was used for orbital wall reconstruction, with an implant depth of 29.33 mm. However, the depth of the implant after tumor resection depends on the extent of the defects. In the present study, the optic nerve was not affected in any patient, and no patient complained about problems with visual acuity before surgery. CT scanning showed a safe distance existed between the apex and the tumor. Therefore, the posterior region of the orbital floor close to the apex remained during tumor resection. The depth of the titanium mesh in the present series was 25.11 mm, which was shallower than that reported for post-traumatic cases. As reported previously for post-traumatic reconstruction,[22,26,27] the depth of the implant can be controlled by intraoperative navigation. By matching the contour of the mobile segment with the preoperative virtual plan, the individual fabricated titanium mesh can be inserted into the ideal position, after which the orbital apex can be checked to determine overextension. Thus, surgical safety can be obtained by navigation. According to the present results, no visual impairment associated with mesh insertion was recorded.

Although titanium mesh is an ideal choice for orbital floor reconstruction, some risks remain. The major risk is infection and exposure of the titanium mesh, particularly in patients with malignant tumors who undergo adjuvant radiotherapy. The presence of hypovascular irradiated tissue and extensive fibrosis that progresses after radiotherapy considerably increases the risk of infection and exposure of the titanium mesh.[28-31] Several previous studies have reported the use of the titanium mesh and soft tissue flaps or free bone grafts for maxillary reconstruction; infections and exposure were not uncommon in these studies.[29-31] Nakayama et al[30] reported radiotherapy-related titanium mesh exposure in 27.8% of patients who underwent maxillary reconstruction with soft tissue flaps and a titanium mesh. Sun et al[31] used a radial forearm flap and a titanium mesh for maxillary and orbital floor reconstruction and reported exposure in 15.8% of patients (3 of 19) during the follow-up period. An inadequate soft tissue volume for covering the mesh is responsible for these complications. In the present patients, a titanium mesh was used with free flaps containing an adequate soft tissue volume, such as an anterior lateral thigh flap, a rectus abdominis muscle flap, or a free fibula flap with the flexor hallucis longus. Furthermore, 2 of the 5 patients with malignancies received radiotherapy, none of whom exhibited mesh exposure or infection during long-term follow-up.

In this study, a preliminary clinical protocol was provided for the application of an individual fabricated titanium mesh for reconstruction of tumor-related orbital floor defects. Although satisfactory clinical results were achieved, some limitations should be noted. Although the use of a titanium mesh for reconstruction after the resection of benign tumors can be well accepted, its use for reconstruction after the resection of malignant tumors remains controversial and requires long-term follow-up data. In addition, the error of the navigation technique should be considered. The technical accuracy of the navigation system used in this study is reportedly less than 1 mm, with an intraoperative accuracy less than 2 mm for some patients.[32-34] Therefore, the results are acceptable according to these values. However, various factors influence this accuracy, including the imaging resolution, accuracy of registration, and accuracy of the computer algorithm.[35] Further prospective studies with a larger sample are required to clarify these issues.

The results of this study suggest that orbital floor reconstruction after extensive maxillectomy using the computer-assisted fabricated individual titanium mesh technique is a feasible and acceptable procedure. Intraoperative navigation combined with preoperative virtual surgical planning can precisely preserve the globe projection and orbital volume; furthermore, complications such as diplopia, restriction of ocular motility, and a decrease in visual acuity can be prevented, thus resulting in successful clinical outcomes.

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