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# Virtual Surgical Planning in Free Tissue Transfer for Orbito-Maxillary Reconstruction

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## Abstract

Since its introduction, virtual surgical planning (VSP) has been rapidly adopted as a part of reconstructive surgeon's armamentarium. VSP allows reconstructive surgeons to simulate resection, plan osteotomies, and design custom plates. These unique advantages have been especially beneficial for head and neck reconstructive surgeons as there is small room for error and high technical demand in head and neck reconstruction. Despite its popularity, most surgeons have limited experience in using VSP for orbito-maxillary reconstruction as tumors that involve the midface are relatively rare compared with other head and neck oncologic defects. In our institution, we routinely use VSP for orbito-maxillary reconstruction using free fibula flap to provide support for orbit, to restore normal dental occlusion, and to restore midface projection. In this chapter, we will discuss the role of virtual surgical planning and our algorithmic approach of performing orbito-maxillary reconstruction using free tissue transfer.

**Keywords**

- orbito-maxillary reconstruction
- fibula flap
- virtual surgical planning
- VSP
- 3D printing
- CAD/CAM
- computer-aided design and computer-aided manufacturing

Orbito-maxillary reconstruction after maxillectomy is one of the most challenging reconstructive dilemmas that requires extensive preoperative planning, careful surgical execution, and vigilant postoperative monitoring.[1–3] Orbito-maxillary defects involve multiple critical structures that need to be addressed during the reconstruction: orbital floor, orbit, maxillary sinuses and facial buttresses, alveolar ridge, hard palate, and soft palate.[1,4–6] Therefore, the goals of orbito-maxillary reconstruction include providing support for orbit, restoring normal dental occlusion, maintaining oronasal separation, and recreating midface projection. Additionally, reconstructive surgeons aim to restore normal vision, mastication, speech, and swallowing.[1,2,4] Historically, palato-maxillary defects were reconstructed with palatal obturators, which may be useful for small defects but are plagued by inherent problems with stability and fitting in larger defects.[7–10] In contrast, orbito-maxillary defects were reconstructed using soft tissue free flaps such as the rectus abdominus myocutaneous (RAM) and anterolateral thigh (ALT) flaps combined bone graft or implant materials to replace the orbital floor.[10–12] While this type of reconstruction provided needed coverage, it was not an anatomic form of restoration. Therefore, reconstructive surgeons have transitioned to using free osteocutaneous flaps such as fibula or scapula.[2,13,14]

With the advent CAD/CAM (computer-aided design and computer-aided manufacturing) software specific to the craniofacial skeleton and 3-dimensional (3D) printing for medical models, implants, and hardware, many head and neck reconstructive surgeons have transitioned to adopting these technologies, together known as virtual surgical planning (VSP), as a part of their armamentarium.[15–18] VSP promotes individualized reconstruction for patients by allowing simulation of both the resection and reconstruction of complex maxillofacial defects. In addition, studies have shown that VSP improves surgical accuracy, reduces

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operative times, and increases control of the final outcome.[13,16,19–22] Therefore, use of VSP became a critical component of orbito-maxillary reconstruction using free flaps at our institution. In this chapter, we discuss the role of virtual surgical planning and our algorithmic approach of performing orbito-maxillary reconstruction using free tissue transfer.

## Role of Virtual Surgical Planning

Prior to the introduction of VSP, reconstruction of orbito-maxillary defects using fibula flap was performed by free-hand. Using this technique, any minor imprecision in performing osteotomies, assembling, and positioning of fibula segments led to potential suboptimal results.[12,19] Patients with maxillary defects were more susceptible to unfavorable results such as malocclusion and changes in facial shape than those with mandibular defects as the mandible has a greater degree of freedom in mobility and, therefore, can better compensate for moderate inaccuracies in reconstruction.[13,14,19] With VSP, reconstructive surgeons have been able to simulate the extirpative scenario, plan the most accurate reconstruction with free tissue transfer, fabricate surgical osteotomy guides, and obtain custom fixation hardware and implants. Studies have demonstrated that VSP decreases operative time, improves precision to within 1.4 to 2.4 mm, facilitates immediate dental placement, and increases reproducibility.[5,6,15,23–25] Despite its advantages, there is a learning curve to using VSP mainly involving accurately predicting the extent of the resection preoperatively and being able to modify the plan intraoperatively when the oncologic margins require further resection.[4,26–28]

## Reconstructive Algorithm

For patients who are expected to have orbito-maxillary defects, we follow a step-by-step algorithmic approach to minimize potential sources of error and facilitate the planning process. First, computed tomography (CT) scan of the craniofacial skeleton with a minimum of 1 mm cuts is obtained. Given that tumors may grow and oncologic margins may change, up to date maxillofacial CT scans are needed. Computed tomography angiography (CTA) of the ipsilateral leg is also obtained to visualize vascular supply of fibula flap and lower leg, perforators to skin, and length and shape of fibula. While it is possible to use a standardized fibula for planning, the exact dimensions of fibula can vary from patient to patient and use of images from the patient's own fibula improves the accuracy of reconstruction, preventing misalignment of cutting guides and plates.[14,19] In our experience, this degree of accuracy is particularly important if simultaneous CAD/CAM-planned placement of dental implants are planned. In addition, some patients have anatomic variant vessels that prevent the use of the ipsilateral leg, which would require the use of contralateral leg to prevent any compromise of leg blood supply, such as the presence of a peronea arteria magna.[14,20,29] This situation cannot be predicted with the use of a standardized fibula.

Copies of CT and CTA scans are transferred to the VSP engineers (Materialise, Plymouth, MI) in the Digital Imaging and Communications in Medicine (DICOM) format. Once the images are received, VSP planning sessions are performed online with the reconstructive surgeon, resecting surgeon, prosthodontists, and engineers. During the planning session, resection margins are carefully planned to account for any situations that may occur intraoperatively as the plan allows limited flexibility during surgery.[30,31]

Of the different types of osteocutaneous free flaps available, fibula flap is the go-to-choice of flap at our institution. It is an ideal flap to restore the complex three-dimensional form of the midface while providing the bony framework of dental implants, midfacial projection, and orbital support. It provides multiple advantages: 1) ability to create chimeric flaps by combining soleus muscle or a segment of flexor hallucis longus (FHL); 2) ability to make several skin islands flaps based on different perforators; 3) good caliber of vessels; 4) consistent anatomy; 5) sufficient bony thickness for osseointegrated dental implants; and 6) a long pedicle length.[2,15,18,29,32] Additionally, multiple osteotomies can be performed using the fibula flap to restore the curvature of the maxilla.

We prefer using the ipsilateral fibula for orbito-maxillary defects to allow positioning of the lateral surface of the fibula superficially, the skin paddle inferiorly to restore the palate, and the pedicle of the flap posteriorly and laterally. The location of perforators obtained from the preoperative CTA is used to determine the location of the skin paddle and assist with the placement of the cutting guide. In patients with inadequate ipsilateral fibula due to anatomic abnormalities, trauma, or previous use, the contralateral fibula is used with saphenous vein graft to increase the pedicle length. Previously, we performed midface reconstruction using the omega-shaped fibula for bilateral defects, and a portion of an omega for the unilateral defects.[33] However, we have transitioned to using a double-barrel configuration due to its versatility: 1) ability to augment malar projection; 2) provide bony scaffold for orbital floor plates; 3) recreate horizontal and vertical facial buttresses; 4) restore the curvature of dental alveolus, and 5) bony support to avoid deviation/collapse of the nose and lips.[13]

## Palatomaxillary Reconstruction

Palatomaxillary defects involve multiple critical structures that need to be addressed during the reconstruction: hard palate, soft palate, alveolar ridge, facial buttresses, and the maxillary sinus.[8–11,34] In patients with skin involvement, cheek skin, lips, and noses can be involved. The goal of palatomaxillary reconstruction is to recreate midfacial projection, isolate the oral cavity from the nasal cavity, restore swallowing, mastication, and speech.[2,10,35] While many authors use classification systems to categorize the type of palatomaxillary defects, we prefer to formulate our surgical approach based on the extent of resection of the orbital walls, and the palate and alveolus.

 

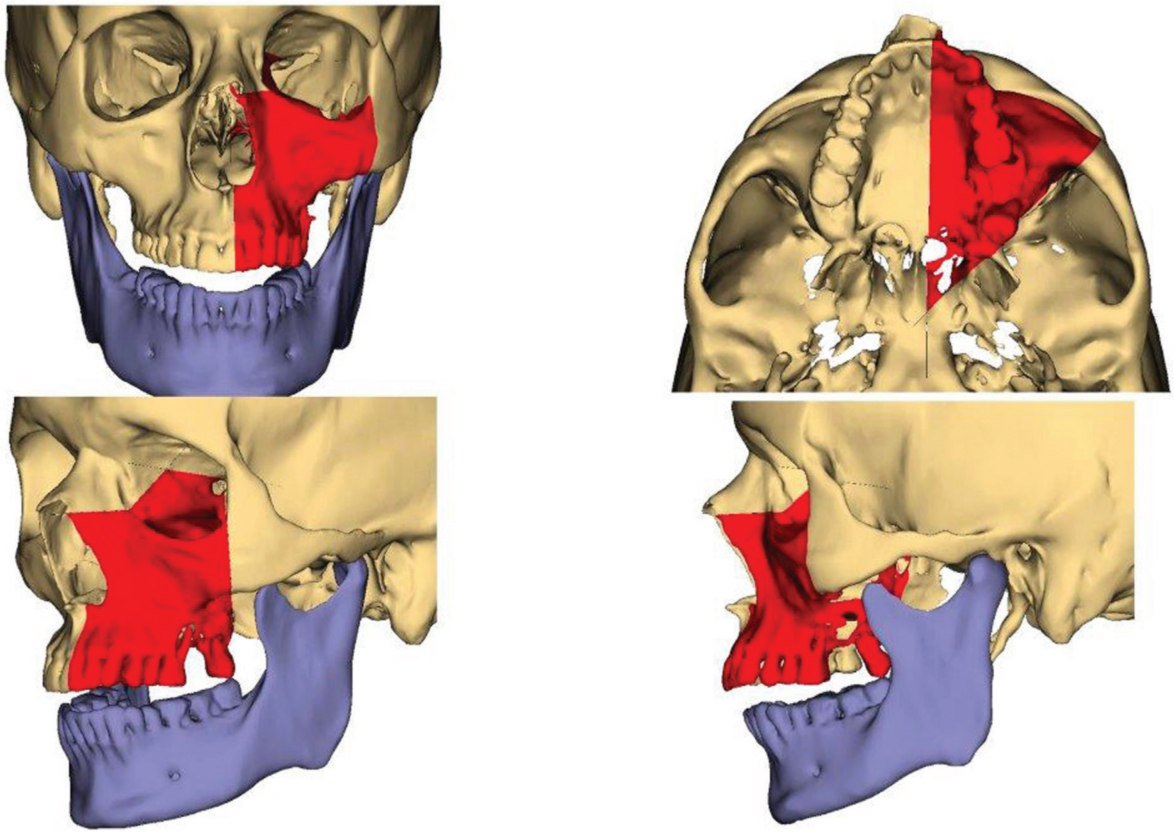

**Fig. 1** A CAD/CAM plan showing planned resection in the case example 1.

For the palato-alveolar defects posterior to the canine tooth, an obturator or a soft tissue flap is usually satisfactory as the missing teeth are not visible in repose.[2,7,8,29] Therefore, VSP is not typically utilized in these patients. In patients who are motivated and have a good prognosis with high functional status, they may undergo osteocutaneous free flaps after postoperative radiation therapy for the placement of osseointegrated dental implants.

In patients with palatomaxillary defects extending anteriorly beyond the canine tooth, we perform an osteocutaneous free flap for bony and soft tissue reconstruction. While some surgeons advocate soft tissue flaps with no bony reconstruction for defects that extend up to the midline, this type of reconstruction can lose the projection of the hemi-face in the long term and cause deviation of the nose toward the side of the defect.[1,12] In addition, dental restoration with an obturator is challenging in defects of these size because there is not enough bone stock and remaining teeth for stable fixation. Therefore, we prefer using fibula flap for palatomaxillary defects that extend anterior to the canine tooth.

Using VSP for palatomaxillary reconstruction offers key advantages over free-hand surgery including the ability to: 1) select a segment of fibula with adequate bony stock for dental implants; 2) design patient-specific plates; 3) plan osteotomies to most accurately restore occlusion and facial projection; 4) anticipate the location of skin paddle based on the perforator location; and 5) minimize the length of surgery.[3,5,6,16,21,24,36] These advantages are highlighted in the following case examples.

**Case 1**

A patient presented with a left maxillary osteosarcoma involving his left orbit. The anticipated defect included a left hemi-maxillectomy including the medial and inferior orbital walls (►**Fig. 1**). Given the extent of defect, we decided to perform palatal and orbitomaxillary reconstruction using a double-barrel configuration with three fibula segments (►**Fig. 2**). The double barrel configuration gives the best

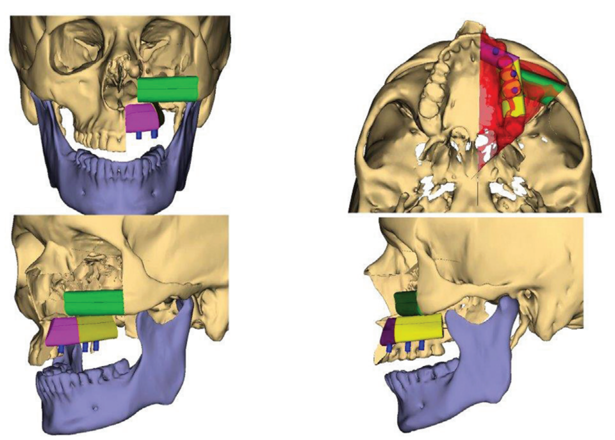

**Fig. 2** A CAD/CAM plan showing planned orbito-maxillary reconstruction using a double-barrel fibula in the case example 1.

 

approximation of maxillary shape, given that the average height of the premaxilla and alveolus, the average height of the malar portion of the maxilla (including the infraorbital rim), and the average height of the lateral surface of the fibula are all about the same.[7] VSP planning was performed for osteotomy sites, 3D custom titanium mesh, pre-bent titanium plates, and dental implants (►**Fig. 2**). With the resecting surgeon, we first planned the extent and location of the anticipated resection. Then, we determined that the patient would need 92.6 mm of fibula, comprising three segments (►**Fig. 3**). The two distal segments (12.8 mm and 25.4 mm) were used for alveolar ridge reconstruction, providing midface projection and acting as a bony scaffold for osseointegrated dental implants. The shorter segment had one dental implant placed, and the longer segment had two dental implants placed. The proximal segment (41.2 mm) was used for orbital floor reconstruction. To prevent twisting and kinking of the pedicle between two distal segments and the proximal segment, the proximal segment was placed in the middle of the fibula, ~25 mm from the middle segment. Then, a titanium 3D printed plate (1.5 mm thick) was designed to provide rigid fixation of fibula segments to the right maxilla and left zygoma (►**Fig. 4**). The titanium plate was placed inferiorly on the proximal fibula segment to allow space for the placement of titanium implant for orbital floor reconstruction. The titanium orbital implant was manufactured to follow the exact contour of the native orbital floor, and designed to be secured on the superior surface of the proximal segment. Additional "arms" were included to secure the implant to the nasal bone and the zygoma for added stability and to help guide the accurate placement. Given that the patient was expected to undergo radiation, we harvested a slip of flexor hallucis longus to provide coverage over the orbital implant to minimize the chance for infection due to contamination with intranasal bacteria. One of the disadvantages of the double-barrel fibula flap is a short pedicle length. Therefore, the patient underwent microvascular anastomosis using the left facial artery and vein via a left

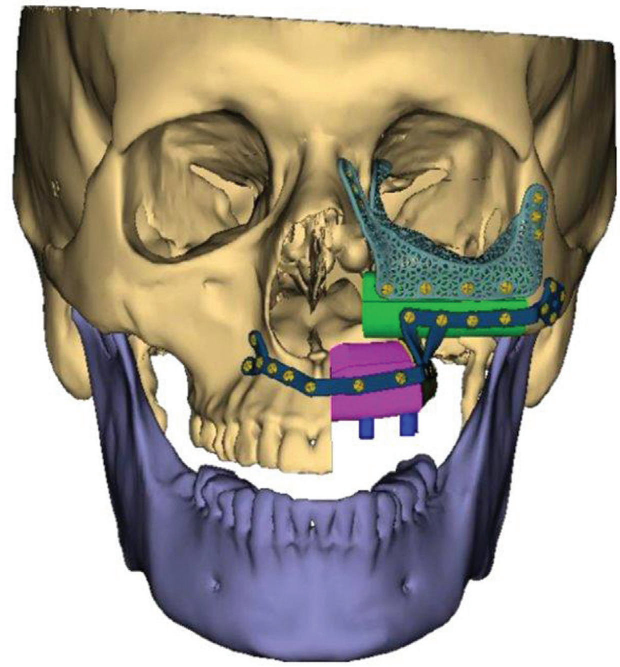

**Fig. 4** A CAD/CAM plan with patient-specific orbital implant, pre-bent titanium plate, and a planned reconstruction in the case example 1.

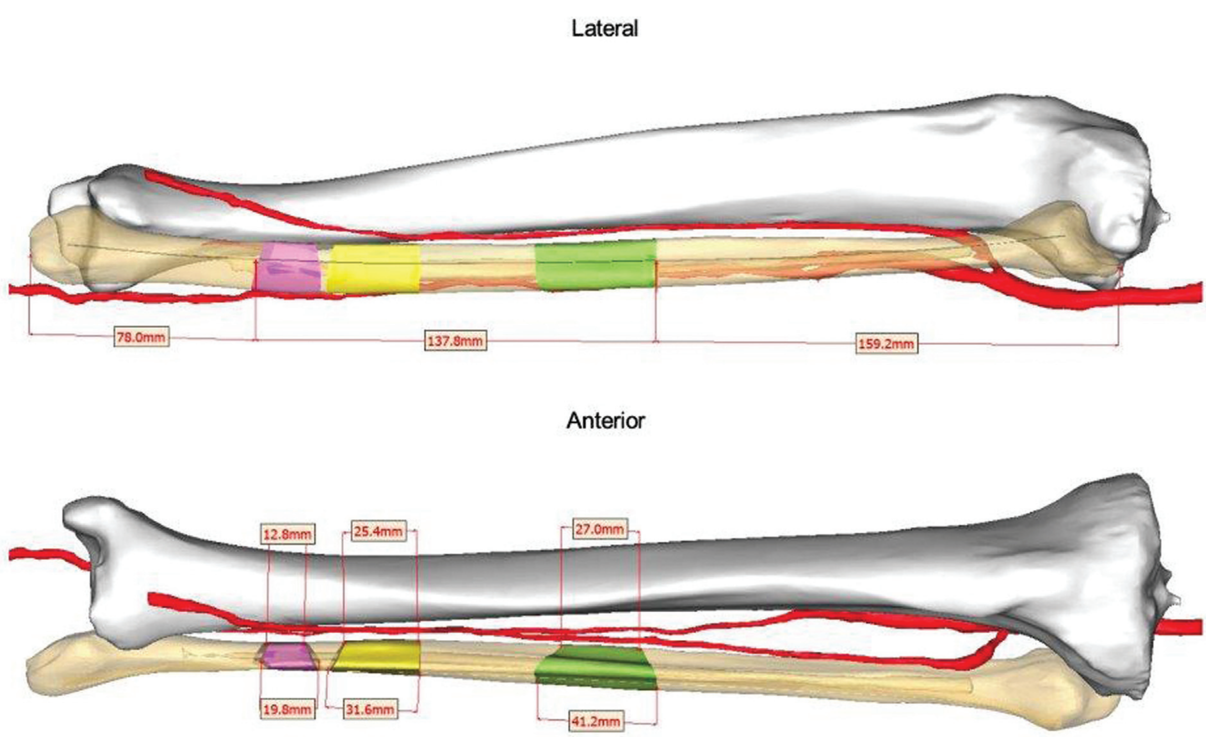


**Fig. 3** A copy of patient-specific fibula with planned osteotomies in the case example 1.

greater saphenous vein graft (artery) and left cephalic vein graft (vein).

By increasing operative efficiency and providing personalized reconstruction via VSP, we were able to significantly reduce operative time in this complex palate and orbitomaxillary reconstruction.[14,19,25,27] VSP improves precision by allowing resecting surgeons to resect the desired specimen using cutting guides based on the patient's unique anatomy while reconstructive surgeons to pre-plan osteotomy sites and angles based on VSP. In addition, the trajectory and curvature of reconstructed maxilla can be evaluated and any hindrance to bony apposition between the fibula segments can be modified.[30] VSP also facilitates immediate dental implant placement and encourages early dental rehabilitation. It is challenging to perform immediate dental implants without VSP as the fibula is a multi-shaped bone that is triangular-shaped proximally and pentagonal-shaped distally.[5,16,17,21,22] This patient did well postoperatively and is currently receiving postoperative radiation therapy.

## Orbital Floor Reconstruction

Achieving precise recreation of the orbital floor is crucial to restore vision and facial appearance. The goal of orbital floor reconstruction is to provide rigid restoration of the orbital floor to prevent vertical dystopia, enophthalmos, and diplopia. Historically, reconstructive surgeons used a soft tissue free flap with bone grafts or alloplastic material for orbital reconstruction.[7,35] While orbital reconstruction using bone grafts offers an advantage of increased resistance against radiation-associated complications, such as exposure and infection, it has been found to have an increased rate of enophthalmos and orbital dystopia compared with titanium mesh and porous polyethylene. This finding could be secondary to unpredictable bony resorption, difficulty with shaping the bone graft, and nonuniform graft thickness.[2,23,26]

While we have used both bone graft and titanium mesh for orbital reconstruction in the past, whenever possible we currently use VSP to create a patient-specific titanium implant for orbital wall reconstruction. Using VSP for orbital floor reconstruction, reconstructive surgeon can obtain critical benefits including ability to: 1) reconstruct the orbital walls accurately to minimize the changes for globe malposition (e.g., enophthalmos, vertical dystopia); 2) prevent possible the optic nerve by use of a graft or implant that is too long and impinges on the orbital apex; and 3) minimize the changes of entrapment or impingement of the extraocular muscles by facilitating accurate implant placement.[4–6,15,26,31]

### Case 2

A patient presented with sinonasal chondrosarcoma involving right frontal sinus, sphenoid sinus, ethmoid sinus, cribriform plate, bilateral medial orbital walls, orbital floors, maxillary sinuses, nasal cavity, and anterior right hard palate (►Fig. 5). Given the extent of defect, virtual surgical planning was performed for maxilla, skull base, and orbital

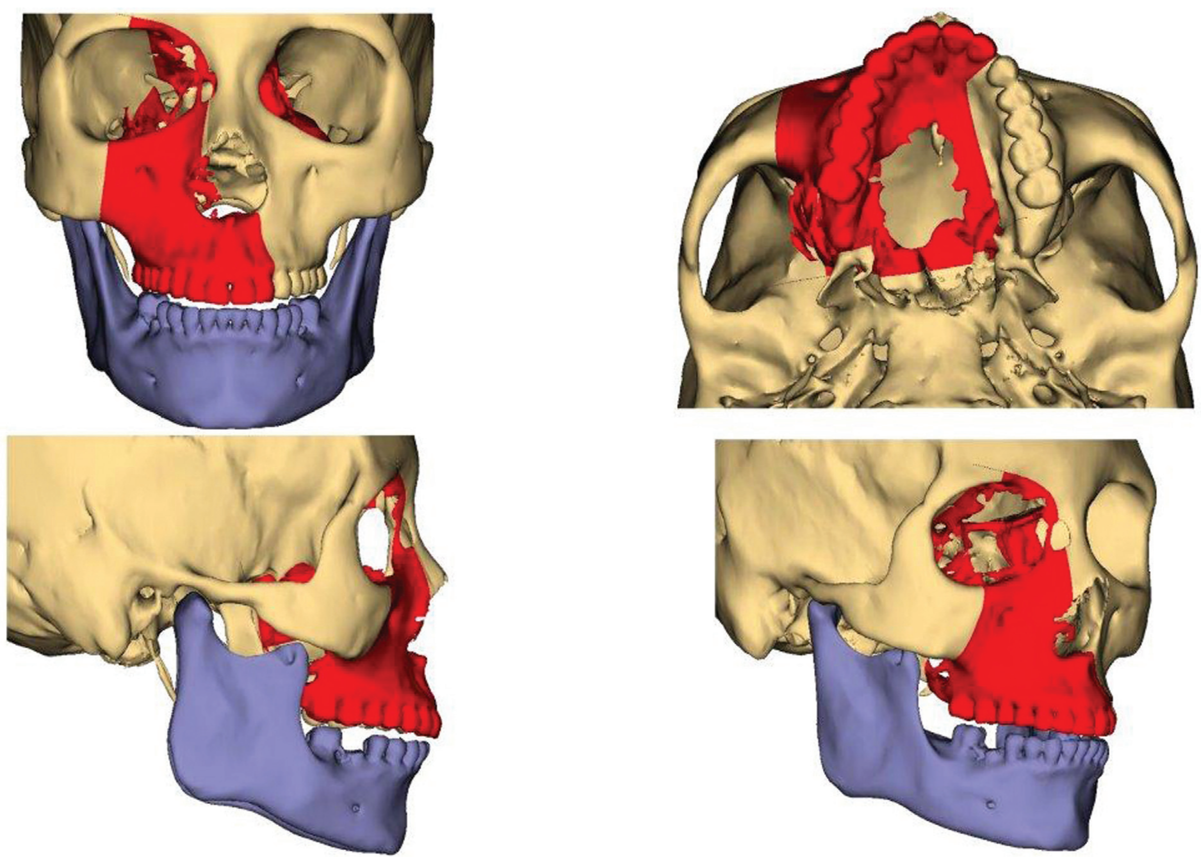

**Fig. 5** A CAD/CAM plan showing planned resection in the case example 2.

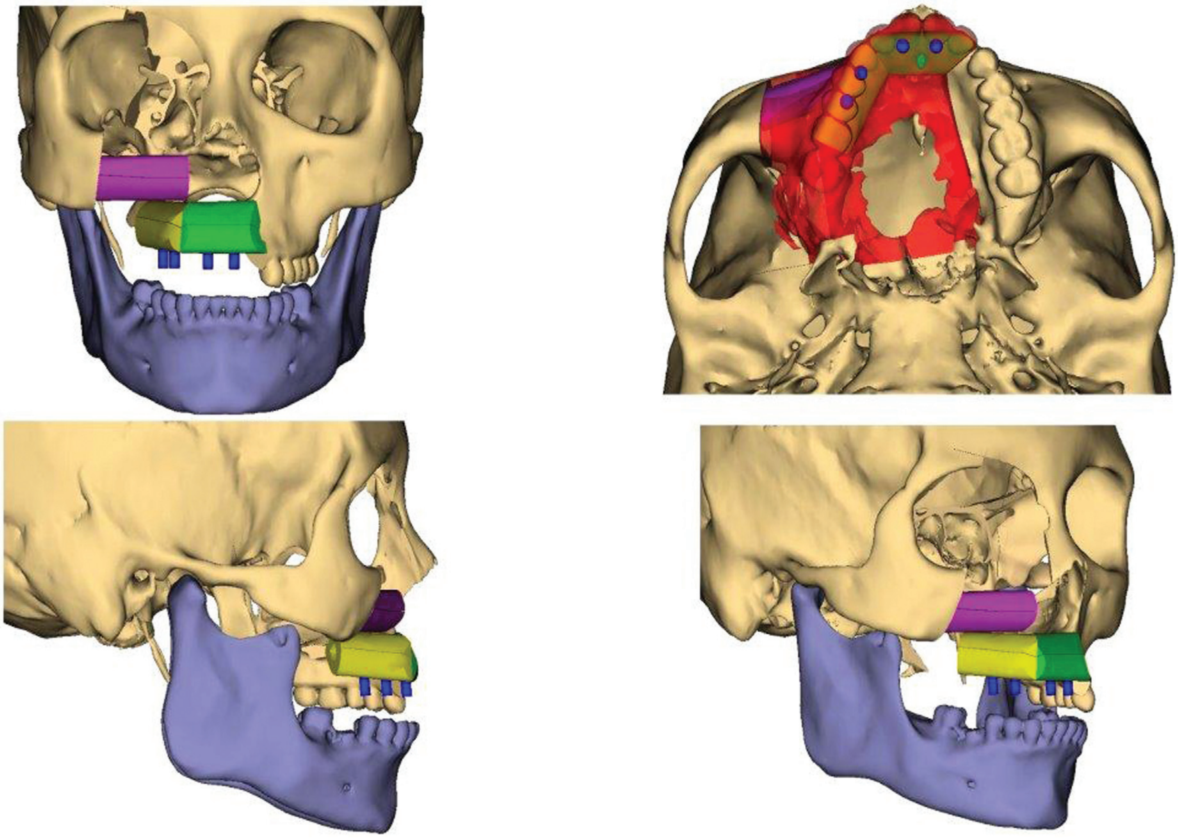

**Fig. 6** A CAD/CAM plan showing planned orbito-maxillary reconstruction using a double-barrel fibula in the case example 2.

reconstruction using a double-barrel configuration with three fibula segments (►**Fig. 6**). We determined that the patient would need 82.8 mm of fibula. In this patient, we used the left fibula, even though most of the maxillary defect would be on the right due to a vascular abnormality in the right posterior tibial artery seen on preoperative CTA. The two proximal segments (19.5mm and 30.1mm) were used for alveolar ridge reconstruction and bony scaffold for osseointegrated dental implants (►**Fig. 7**). Two dental implants were placed in the shorter segment, and three dental implants were placed in the longer segment. Then, the distal segment (33.2mm) was used for orbital rim reconstruction. Like the first case example, a patient-specific 3D printed plate (1.5mm) was custom made for rigid fixation of fibula segments.

Two patient-specific titanium 3D orbital implants were manufactured for the bilateral orbital defects (►**Fig. 8**). The titanium implant for the right orbit was fixated to the superior surface of the fibula while the left orbital mesh was secured to the native maxilla. Due to the involvement of the frontal sinus and nasal cavity, we planned for a second free flap, an anterolateral thigh flap with vastus lateralis muscle, to obliterate the dead space as well as provide soft tissue coverage of the titanium orbital wall implants to prevent their intranasal exposure.

Formulating the surgical plan was challenging because the extent of resection and number of involved structures were dependent on the intraoperative result of the frozen specimen. Therefore, we prepared multiple scenarios of resection and reconstruction prior to surgery. After performing these scenarios, we ultimately decided on this plan: 1) neurosurgery team performing the anterior craniotomy to remove the frontal sinus; 2) subsequent intraoperative evaluation of orbits to determine whether globes can be salvaged with 3D printed titanium implants designed to restore the maximum estimated defect of the orbits based on the input of the head and neck team; 3) harvesting of fibula, anterolateral thigh flap, and vein grafts during resection by head and neck service; 4) fibula osteotomy once resection has been completed allowing for deviation from the VSP plan if necessary; 5) orbital implant placement and recipient vessel preparation; 5) inset of the fibula flap skin paddle and rigid fixation of the bone using the 3D printed titanium reconstruction plate followed by microanastomoses; and 6) inset followed by microanastomoses of the anterolateral thigh flap. In this case, VSP facilitated preoperative planning in concert with the head and neck and neurosurgery teams and intraoperative time-savings via computer generated fibula cutting guides and 3D printed orbital implants and reconstruction plate in this complex orbito-maxillary and skull base reconstruction. The coordinated timing of the steps involved allowed for adjustment of the surgical plan should tumor involvement necessitate it. For instance, if the maxillary defect proved larger than anticipated, additional fibular bone could have

 

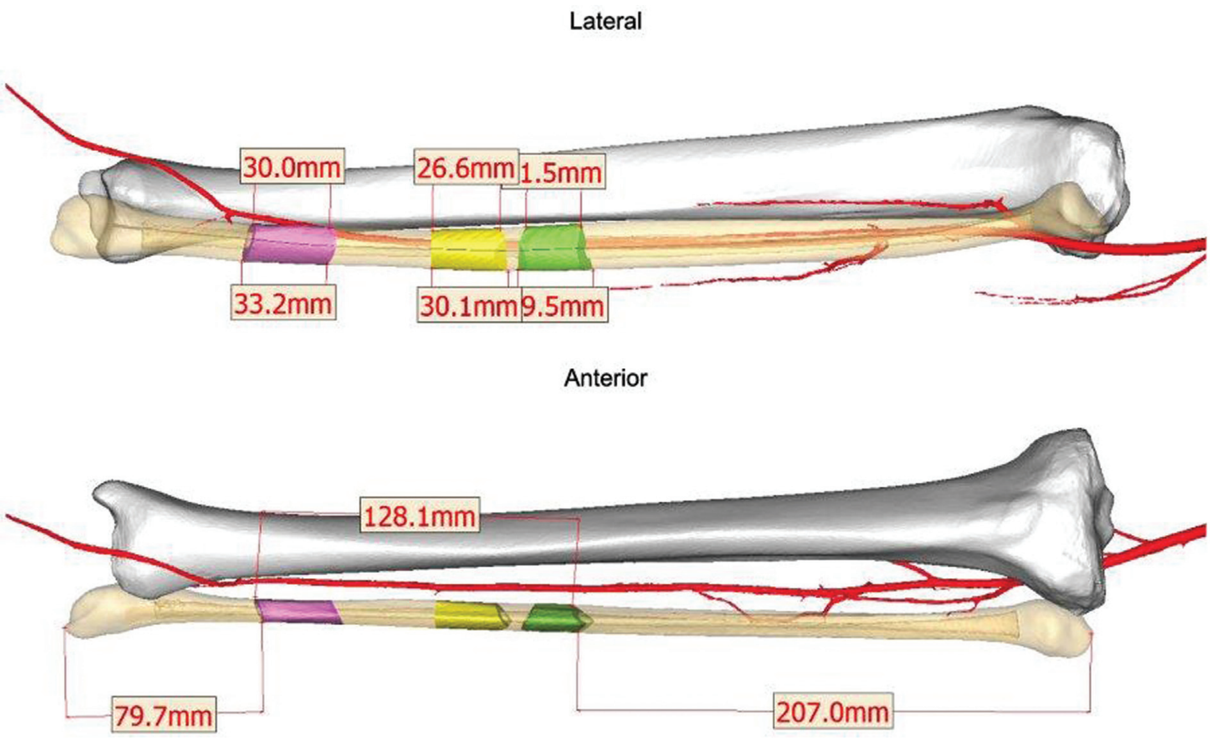


**Fig. 7** A copy of patient-specific fibula with planned osteotomies in the case example 2.

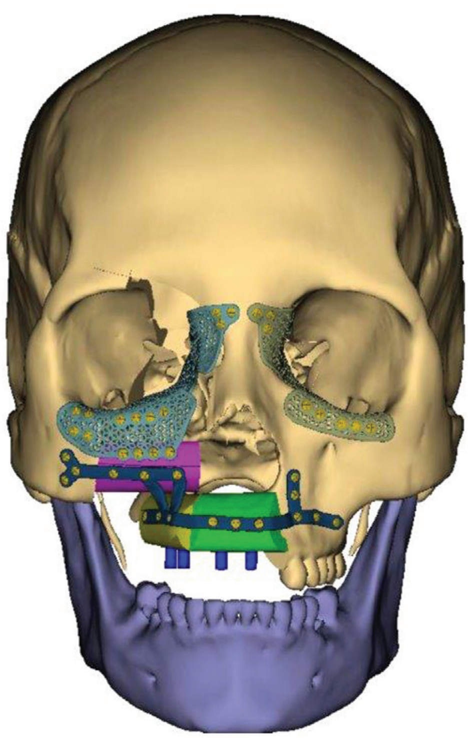

**Fig. 8** A CAD/CAM plan with patient-specific orbital implant, pre-bent titanium plate, and a planned reconstruction in the case example 1.

been included, or, if the orbit needed to be exenterated, then the orbital implant would not have been used and a soft tissue flap would have been performed to obliterate orbital dead space and close the orbital wound.

## Postoperative Considerations

### Flap-related Complications

Due to the complexity of orbito-maxillary reconstruction, it is critical to perform methodical and meticulous reconstruction to prevent any flap-related complications and to provide functional restoration. As orbito-maxillary reconstruction involves multiple components including fibula bony segments, titanium plates, skin paddle, a strip of soleus/flexor hallucis longus muscle, and dental implants, any flap compromise is detrimental. We utilize several maneuvers minimize vascular compromise to the flap: 1) marking of flap pedicle orientation in situ; 2) complete visualization of flap pedicle when it's being delivered to the neck via subcutaneous tunnel; 3) continuous inspection of pedicle orientation intraoperatively; 4) use of vein grafts as needed to avoid tension on the pedicle or unfavorable pedicle positioning; and 5) using strict postoperative flap protocol. All patients are admitted to a specialized free flap unit, and their flaps are monitored vigilantly using this protocol: flap check every 1 hour for the first 48 hours, flap check every 2 hours for next 48 hours, and flap check every 4 hours until discharge, which is typically on days 5 to 7.

### Non Flap-related Complications

For the recipient-site morbidity, we routinely use these maneuvers to prevent any plate exposure or fistula development: 1) anchoring of the flap skin paddle to teeth using 3–0 braided polyglactin suture; 2) performing water-tight inset of skin paddle using 2–0 and 3–0 braided polyglactin sutures (size dependent on anticipated wound tension once awake and swallowing); 3) allowing mild redundancy of flap if patient is expected to have postoperative radiation, especially in the anterior-posterior direction; 4) covering of orbital mesh with a strip of flexor hallucis longus muscle; 5) placement of a Dobhoff tube for 2–4 weeks postoperatively (2 weeks in non-radiated and 4 weeks in radiated patients) to allow healing of suture lines; and 6) harvesting of second free flap as need for external skin coverage.

## Conclusion

Achieving successful reconstruction of the orbit and maxilla is extremely challenging due to small room for error and high technical demand in this type of reconstruction. In this chapter, we discussed the pearls and pitfalls of performing orbito-maxillary reconstruction with virtual surgical planning. Virtual surgical planning has refined orbito-maxillary reconstruction with free osteocutaneous flaps through simulation and pre-fabrication patient-specific reconstructive needs. In addition, it allows for complex maxillofacial reconstruction with multiple patient-specific implants and free flaps to be performed successfully. Therefore, we believe VSP can be an invaluable part of a reconstructive surgeon's armamentarium.

Conflict of Interest
None declared.

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