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CLINICAL ARTICLE

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Evaluation of virtual surgical planning and three-dimensional configurations for reconstruction of maxillary defects using the fibula free flap

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Abstract

Background: Maxillary reconstructive surgery with fibula free flaps (FFFs) is a challenging procedure for head and neck surgeons. However, virtual surgical planning (VSP) and three-dimensional (3D) printing technologies have contributed to improved functional and aesthetic outcomes. The objective of this report is to demonstrate VSP/3D application in reconstruction of maxillary defects using the FFF by describing the different configurations available. We reviewed a series of consecutive cases operated at our institution and considered the management strategy of in-house planning in VSP/3D application.

Methods: In total, 11 cases were included from November 2016 to December 2021. Eight male and three female were included, with a mean age of 55.4 years old (range: 34–74 years old). Maxillary defects were classified according to Brown's Classification: two cases with IIB, one case with IIC, four cases with IID, three cases with III, and one case with IV. Preoperatively, facial computed tomography (CT) and lower extremity computed tomography angiogram (CTA) were performed in all patients. Osteocutaneous FFFs were planned, harvested, and customized according to the VSP/3D guide configuration. VSP and 3D printed cutting guides were performed by an external company in nine cases and were self-planned in three of them. Titanium 3D-printed fixation plates were used in four cases.

Results: All flaps survived, and the main reconstructive goals were achieved in 9 cases out of 11. Mean FFF length before osteotomy was 20.0 cm (17.5–22.5 cm). None of the cases experienced flap ischemia or venous congestion. At least one complication occurred in four cases: Prefabricated titanium plate exposure (two cases), loss of donor site skin grafts (one case), and ectropion (one case). One patient underwent a second FFF reconstruction. Two titanium printed plates became exposed after radiotherapy and needed to be removed. Mean follow-up time was 23.5 months (range 6–63 months). Dental rehabilitation was completed in eight of the 11 cases. Regarding functional recovery, five cases underwent delayed osseo-integrated dental implants

(ODI), and two cases had immediate ODI procedures. One case was treated with removal dentition.

Conclusion: VSP/3D printing technology is a new and helpful tool to successful restoration of craniofacial function and aesthetics. It can be used in the broad range of configurations offered by FFFs considering our suggested management strategy.

1 | INTRODUCTION

Currently, a revolutionary drift is occurring in head and neck reconstructive surgery by configuring the new technologies into the field. Virtual surgical planning (VSP) and three-dimensional (3D) printing technologies are altering the way surgeons perform trauma, oncologic and reconstructive procedures. These technologies make the procedures safer, faster, and more accurate resulting in lower morbidity and better aesthetic outcomes (Shenaq & Matros, 2018; Witjes et al., 2018). Mandibular reconstruction with osteocutaneous fibula free flaps (FFFs) using 3D printed cutting guides is the gold-standard for extensive mandibular reconstruction in most of the cases (Wang et al., 2016). Many times, designing and fabrication of guides and plates have to be performed by engineers and external companies which could lead to delay possibilities. Today, however, an in-house and self-developed manufacturing approach for mandibular cutting guides has been developed (Bosc et al., 2017; Ganry et al., 2017). This new approach is proved to be reliable and helpful tool in reconstructive surgery (Li et al., 2018; Zavattero et al., 2020).

Similar to mandibular reconstruction, middle and upper facial reconstruction could also benefit from VSP and 3D printing technologies. The complex 3D configurations, orbital volume and contour preservation, dental and phonatory rehabilitation, and favorable aesthetic outcomes are of critical importance to midface reconstruction. Before the introduction of VSP and guide printing, midface reconstruction with the FFF was considered a particularly difficult procedure. This hardship was due to the necessity of tailoring multiple bone fragments in a complex 3D space. Today, VSP allows a variety of configurations to be operated with high accuracy. Recently, there are some reports of in-house, surgeon designed VSP (Morita et al., 2017; Smithers et al., 2018).

The objective of this report is to demonstrate VSP/3D application in reconstruction of maxillary defects using the FFF by describing the different configurations available. We reviewed a series of consecutive cases operated at our institution and considered the management strategy of in-house planning in VSP/3D application. Moreover, our institutional transition to an in-house self-developed VSP is elaborated as well as the management strategy in VSP/3D application.

2 | PATIENTS AND METHODS

This report includes a retrospective review of all the patients who underwent reconstruction by FFF for maxillary defects. All the patients were admitted to our Plastic and Reconstructive Surgery Department of the Hospital Universitari de Bellvitge between November 2016 and December 2021. Maxillary defects were classified based on Brown's Classification (Brown & Shaw, 2010), which distinguishes between vertical (numbers I to VI) and horizontal (letters a to d) maxillectomy dimensions. The series comprised 11 cases in 10 patients, (two IIB, three IIC, two IID, three III, one IV according to Brown's classification). Seven males and three females were included by mean age of 55.4 years old (range: 34–74 years old). Patient data are summarized in Table 1.

2.1 | Virtual surgical planning

Data for facial computed tomography (CT) and lower extremity computed tomography angiogram (CTA) were obtained preoperatively in all patients. All cutting guides were designed and printed using selective laser sintering (SLS) in polyamide. Specific titanium plates were printed in four cases. Two cases underwent VSP by an external company (DePuy Synthes). For these patients, the CT files were sent to the engineers. The surgical plan and guides were designed and evaluated by the main surgeon (OBS), then were printed in polyamide and sent back to our institution for sterilization. Six cases underwent VSP with another external company (Avinent, Spain) by the same steps.

In one case of maxillary reconstruction and two cases of mandibular reconstruction, not included in this report, planning was conducted in collaboration between our team (SBV) and Avinent. We requested that the company printed both their cutting guides and ours. This enabled us to check whether our first designs required correction before clinical implementation and to compare and use those from the company if needed (Figure 1a).

In four cases, titanium prefabricated plates were printed. We conducted immediate dental rehabilitation with osseo-integrated dental implants (ODI) in cases suitable for implant-based dental rehabilitation requiring postoperative radiotherapy (RT). This seemed to improve long-term implant survival compared with delayed implantation into radiated FFFs (Pellegrino et al., 2018). In cases with no postoperative RT planned, delayed ODI was performed as immediate implantation prolongs the operative time. Also in these cases, a second delayed procedure may be required to perform minor correcting surgeries, such as debulking, lipofilling, or orbital canthopexy.

In three cases, using a self-developed approach, we performed VSP of the resection and FFF cutting guides. One surgeon designed SBV performed the VSP, using OsiriX software to transform the Digital Imaging and Communications in Medicine (DICOM) data from CT and CTA to stereolithography (STL) files. The resulting STLs were

TABLE 1 The patients' data and outcomes

Case	Age	Sex	Diagnosis	Defect type	Complementary therapies	Planification type	Fibula flap length (cm)	Recipient vessels	Vein grafts	3D printed plate	Follow-up (months)	Complications	Dental functional recovery	Secondary procedures
1	49	M	Odontogenic fibromyxoma	IIB	No	External	19	FV	Yes	No	63	No	Delayed ODI	Implants
2	43	F	Squamous cell carcinoma	IIC	Adjuvant RT/CT	External	17.6	FV	No	No	51	No	Removable dentition	Lipofilling
3	72	M	Squamous cell carcinoma	IID	Adjuvant RT	External	20.3	ECA, CFV	Yes	Yes	32	Plate exposition	Failed reconstruction	Contralateral fibula
4	53	M	Cocaine abuse	IID	No	External	22.5	ECA, EJV	Yes	Yes	28	No	Immediate ODI	Debulking, tracheostomy closure
5[a]	73	M	Clear cell carcinoma	IID	Adjuvant RT	External	20.1	ECA, EJV, CFV	No	Yes	27	Plate exposition	Failed reconstruction	-
6	44	M	Squamous cell carcinoma	IIB	Adjuvant RT/CT	In-house	17.5	ECA, EJV, CFV	No	No	18	No	Delayed ODI	Implants
7	37	M	Fusocellular sarcoma	III	Neoadjuvant RT/CT	In-house	22.4	FV	No	No	17	Ectropion	Delayed ODI	Implants, canthopexy
8[a]	74	M	Plate exposure	IID	Previous RT	In-house	19.7	ECA, EJV, CFV	No	No	16	No	Delayed ODI	Implants
9	52	M	Squamous cell carcinoma	IV	Adjuvant RT/CT	External	21.4	FV, EJV, CFV	No	No	9	No	Immediate ODI	-
10	41	M	Angiofibroma	III	No	External	20.7	FV, EJV, CFV	Yes	No	8	No	Delayed ODI	Implants
11	72	F	Mucosal Melanoma	III	RT	External	18.8	FV, EJV, CFV	Yes	Yes	6	Partial loss of skin grafts	ODI Pending	-

Abbreviations: CFV, common facial vein; CT, chemotherapy; ECA, external carotid artery; EJV, external jugular vein; FV, facial vessels; ODI, osseo-integrated dental implants.; RT, radiotherapy.
[a]Cases 5 and 8 correspond to the first and second FFF for the same patient.

processed into Meshlab and Meshmixer software. Using Blender software allowed to design the cutting guides. Once the design was evaluated by the main surgeon (OBS), STL files were sent to the external company to be printed in polyamide.

2.2 | Surgical technique

All cases were performed by the same surgeon (OBS). A multidisciplinary team including plastic surgeons, otorhinolaryngologists, and neurosurgeons was required in five cases to complete the tumor resection. An oncoplastic two-team approach was adopted for all other cases. The first team raised the osteocutaneous FFF without ischemia cuffs, applying cutting guides to the fibulae and performing osteotomies. Fibular fragment configuration was performed without autonomizing the flap, using the prefabricated or pre-bent titanium plates (Figure 1b–e). Immediate ODIs were placed in the same manner using specific drilling holes provided by the cutting guide. Meanwhile, the second team performed tumor resection or debridement using polyamide cutting guides for osteotomies and prepared the recipient vessels for anastomosis.

3 | RESULTS

Postoperative outcomes were summarized in Table 1. All flaps survived, and the main reconstructive goals were achieved in nine cases out of 11. None of the cases experienced flap ischemia or venous congestion. Mean FFF length before osteotomies was 20.0 cm (17.5–22.5 cm). Interpositional saphenous vein grafts were required in five cases. Complete tumor resection was achieved in most of the oncologic cases except one case, who had local recurrence 6 months after surgery.

At least one complication occurred in four cases: Prefabricated titanium plate exposure (two cases), loss of donor site skin grafts (one case), and ectropion (one case).

One patient underwent a second FFF reconstruction. Two titanium-printed plates became exposed after radiotherapy and needed to be removed.

Mean follow-up time was 23.5 months (range 6–63 months). Dental rehabilitation with ODI or removable denture was achieved in 8 of 11 maxillectomies. Regarding functional recovery, five cases underwent delayed ODI, and two cases had immediate ODI procedures. One case was treated with removal dentition. ODI One patient was still pending for future dental implants. All FFF configurations used in maxillary defects discussed in this series of cases are shown in Figure 2.

3.1 | Case reports

3.1.1 | Case 1

Forty-nine-year-old male presented with a right maxillary mass and loss of two teeth. CT scan showed an odontogenic keratocyst of the left maxilla. Brown IIB maxilectomy and reconstruction with FFF were

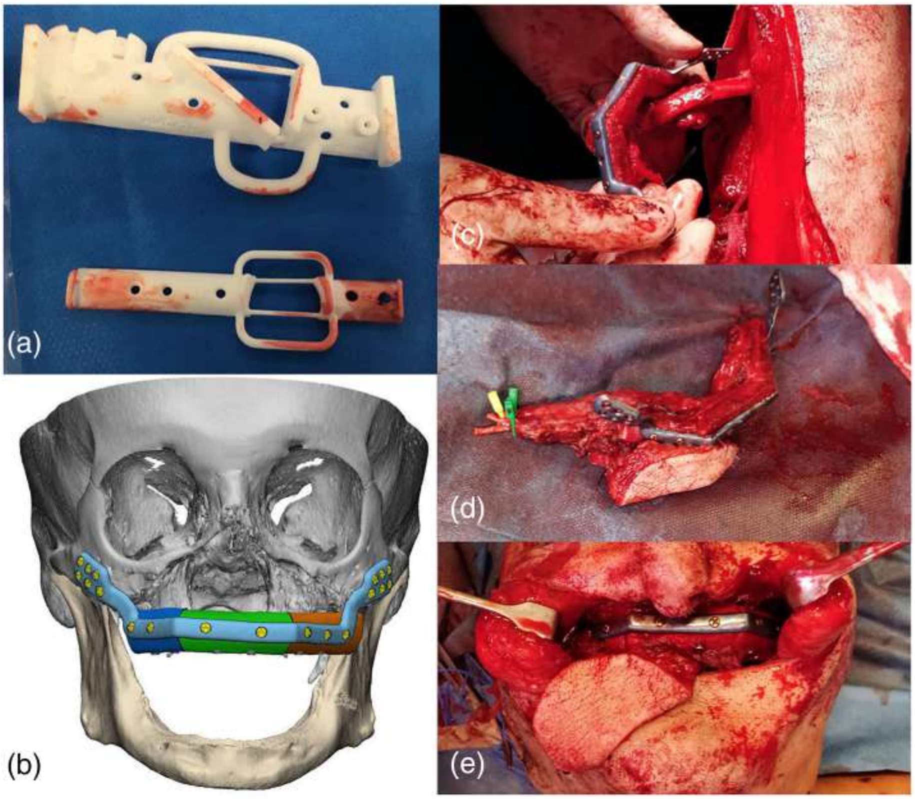

FIGURE 1 Polyamide guides and titanium printed plates. (a) Company designed (above) and self-designed (below) guides were shown after applying them on the ~~patient's~~ fibula. This allowed error correction in design without compromising the results. The contact surface with the fibula on self-designed guide was narrower compared with the company guide and this could lead to incorrect angulations while performing the osteotomies. (b) An example of VSP including titanium-specific plate used for patient 4. (c) Titanium prefabricated plate allowed configuration of the fragments and implant placement without autonomization of the flap, decreasing ischemia time. (d) FFF 3D configuration with titanium prefabricated plate. (e) The use of titanium plate facilitated the insetting when sufficient space existed to allow the whole preconfigured flap

planned. Class IIB defects include complete unilateral maxillectomy without orbital floor or rim involvement and require dental rehabilitation, facial contour correction, and oronasal fistula repair. In this case, a two-fragment, L-shaped FFF reconstruction was performed with the pedicle placed posteriorly and facing toward the oral cavity and the skin paddle as the neopalate. The anterior fragment houses ODIs and should be placed horizontally for this purpose, while the posterior fragment contacts the zygoma to assure proper osteosynthesis. This configuration also provides adequate facial contour restoration. In this case we opted to Weber-Ferguson approach and right cervicotomy for the anastomosis. Before osteotomies, the FFF length was 19.0 cm. Facial artery and vein were used as the recipient vessels with interpositional saphenous vein grafts. The patient did not develop any complications or recurrence during 63 months of follow-up. In this case, dental rehabilitation was achieved with delayed dental implants (Figure 3).

3.1.2 | Case 2

Seventy-two-year-old female was referred to our department by an otorhinolaryngologist after the diagnosis of a mucosal melanoma in the specimen of an endoscopic pollipectomy. CT and MRI were performed. The residual tumor was a mass after the pollipectomy that involved the maxillary and frontal sinuses as well as the ethmoid bone. Brown's class III maxilectomy and reconstruction with FFF were planned. The orbital floor was in contact with the tumor but the orbital contents were preserved. To assure the complete resection, a multidisciplinary team was established. Bicoronal approach and frontal craniotomy were necessary to perform the frontal and ethmoidal resection (Figure 4). Weber-Ferguson incision and cervicotomy were also performed.

In this case we performed VSP with customized 3D-printed miniplates and orbital plate. A three-fragment FFF was designed (Figure 4). The proximal fragment was positioned from the zygoma to the premaxila without directly contacting neither the zygoma nor the third fibula fragment. The pedicle faced inwards, the second fragment reconstructed the medial orbital rim, and the distal fragment reconstructed the inferior orbital rim, articulating with the zygoma. Two skin paddles were designed, one to cover the skin defect on the cheek and the other provided the palate. To assure the optimal orbital volume restoration, we transferred our VSP files to computer-assisted intraoperative navigation software (Brainlab AG, Germany) and performed the fibula insetting under intraoperative stereotactic control. Complete resection of the T3 mucosal melanoma was achieved and the patient underwent adyuvant radiotherapy. The FFF length was 18.8 cm before osteotomies. The recipient vessels were the facial artery, external jugular vein and common facial vein using interpositional vein grafts. Complications included partial loss of skin grafts on the fibula donor site and mild ectropion that will be corrected in a second procedure alongside with the delayed ODI placement.

4 | DISCUSSION

Maxillary defects are presented hereunder according to Brown's classification and the available choices for our reconstruction strategies. It

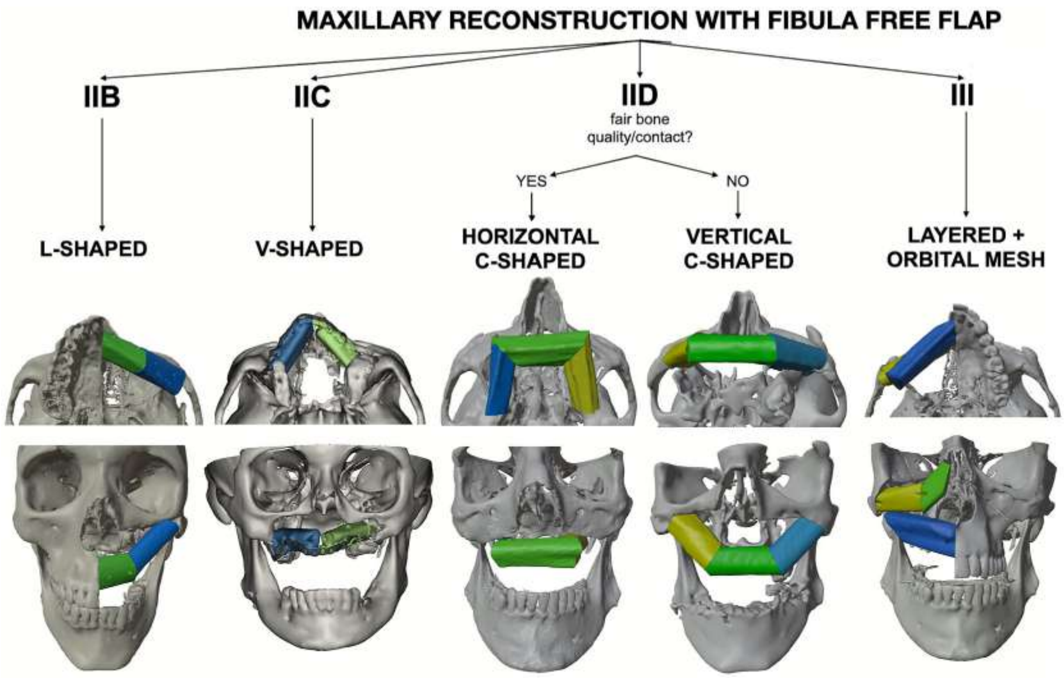

FIGURE 2 Fibula free flap configurations for maxillary reconstruction according to Brown's classification. Brown's defects commonly suitable for bone reconstruction were included. Case numbers related to each of the defects were listed below the images. All images corresponded to virtual planning reconstructions, except the image of one patient, which corresponded to a postoperative 3D tomography reconstruction because the virtual planning files were not available. Proximal (closer to the knee) fragments were represented in blue. Distal (closer to the foot) fragments are represented in green or yellow, depending on the total number of fragments. In case of IID defects, the authors preference was to perform the vertical C-shaped configuration in poor bone quality, extensive resections, salvage procedures or irradiated areas. This assured fair bone quality contact with the zygomas

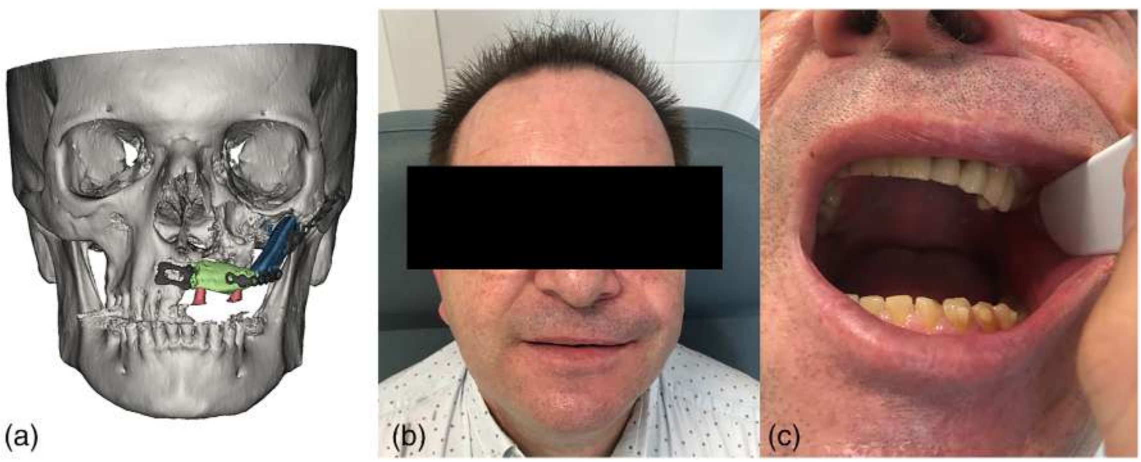

FIGURE 3 (a) Postoperative 3D reconstructions using CT scan. ODIs were depicted in red. (b) The latest postoperative image taken from the patient, demonstrating satisfying aesthetic outcomes. (c) Intraoral image showed dental rehabilitation with implants

is noteworthy that Brown's Class I, V, and VI were not considered in this report. First, Class I defects in the vertical dimension and Class A in the horizontal dimension rarely required osseous reconstruction with FFFs. Second, Class V defects, which involve orbitomaxillary resection with palate sparing rarely require the bone reconstruction (Brown & Shaw, 2010). It is noteworthy to report that although a case involving Class IV defect is included in this study, it is not common practice of the authors to perform FFF in these patients. Class IV defects, which include total maxillectomy and orbital enucleation or exenteration and often skull base resection, frequently have a poor prognosis and are of advanced stage disease. The authors tend to favor skin and soft tissue coverage over dental rehabilitation in these patients, using the deep inferior epigastric perforator (DIEP) free flap as the first choice (Miyamoto et al., 2019). However, Case 9 was

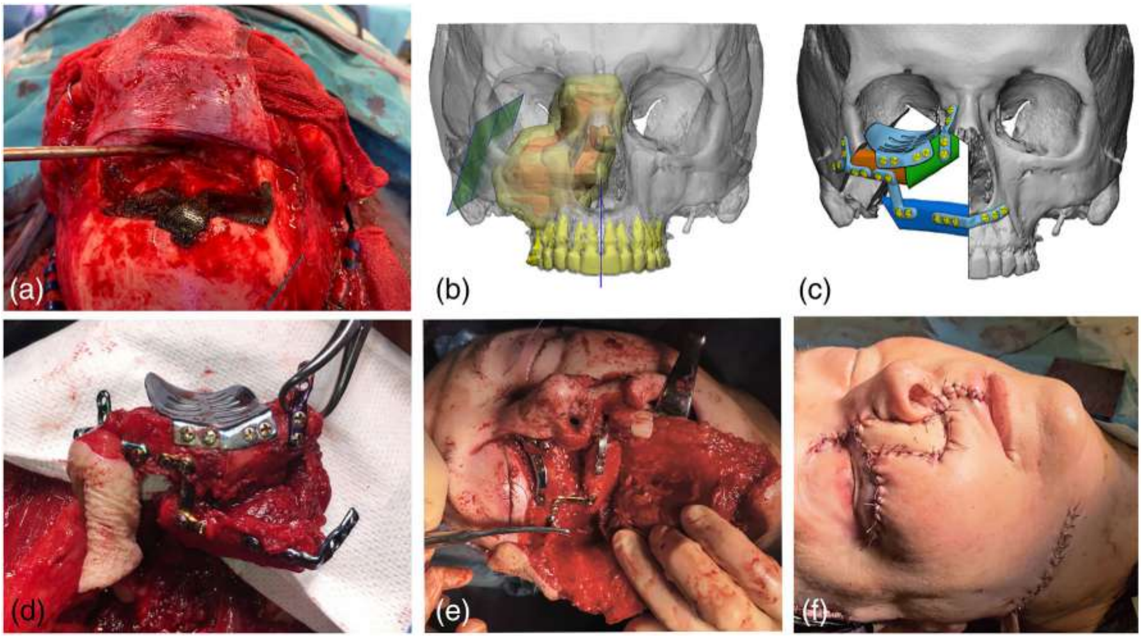

FIGURE 4 (a) Frontal craniotomy using bicoronal approach allowed access to the superior part of the tumor. (b) 3D reconstruction of the tumor volume obtained from the fusion of MRI and CT data. The orange color manifested the actual volume of the tumor and the yellow color showed 5 mm resection margin. (c) VSP of the case, including the patient's specific implants: four miniplates and one orbital floor reconstruction plate. (d) Actual configuration of the fibula flap before in-setting. (e) Intraoperative photo after the insetting of the flap. (f) Immediate postoperative photo

planned as a Class III maxillectomy underwent a FFF with immediate ODI, however, was reconverted to class IV due to unadvertised involvement of the orbital content.

Class IIB defects include complete unilateral maxillectomy without orbital floor or rim involvement and require dental rehabilitation, facial contour correction, and oronasal fistula repair. In these cases, we perform a two-fragment, L-shaped FFF reconstruction with the pedicle placed posteriorly and facing toward the oral cavity and skin paddle as the neopalate, as demonstrated in case report 1. The anterior fragment houses ODIs and should be placed horizontally for this purpose, while the posterior fragment contacts the zygoma to assure proper osteosynthesis. This configuration also provides adequate facial contour restoration. Class IIC cases include bilateral subtotal maxillectomy involving up to 50% of the transverse anterior palate. In these cases, we perform a two-fragment, V-shaped FFF reconstruction, with the pedicle facing toward the oral cavity and the skin paddle covering the palate. The midface collapse in class IIC cases could create superior labial retraction, and ultimately cause labial and salivary incompetence (Cuéllar et al., 2021). To avoid this complication, sufficient anterior projection of the premaxilla should be achieved. Class IID includes total or near total bilateral maxillectomy without orbital involvement. We encountered more difficulties reconstructing these maxillectomies than any other described in this report. In the first three cases, we opted to a three-fragment C-shape configuration in which the skin paddle served as the neopalate and the fragments traced the previous alveolar ridge. This ensured adequate implant placement and restored facial height and projection. Bone-to-bone contact from the fragments with the lateral pterygoid plate was intended in the cases of total palate resection. Fixation was achieved with a 3D-printed titanium plate contacting both zygomatic bones in each case. Patients with poor bone quality and/or those who are likely to receive adjuvant RT are prone to collapse and plate exposition complications. In these cases, we prefer to design the three-fragment FFF to fit in between the zygomas, sacrificing the possibility to locate dental implants in the posterior aspects of the dental arch but assuring a satisfactory bone-to-bone contact, which is paramount for long-term stability of the FFF.

Class III defects include globe-sparring total maxillectomy with orbital floor and rim resection. Our preference for reconstructing these defects is a variation of Trosman et al.'s layered technique (Trosman et al., 2018), elaborated in case report 2. Intraoperative surgical navigation for Class III defects is recommended. Minimal orbital volume changes may cause diplopia, enophthalmos, or exophthalmos and the use of intraoperative surgical navigation can assure orbital volume retention (Kang et al., 2020; Schmelzeisen et al., 2004). Additionally, most navigation software can be fused with the planned reconstruction files to provide a hybrid approach for navigating the surgery and assessing the correct position of the FFF.

Besides, maxillary reconstruction, the authors have used VSP for FFF in frontal reconstruction cases. Frontal and calvarial defects could be reconstructed using the free flap transfer although it became uncommon due to the extensive use of cranioplasties. Free flap transfer has been used to treat chronic frontal sinus infections when other strategies have already failed (Bluebond-Langner et al., 2007) or in cases with extensive tumor resection affecting the superior orbital rims. These cases are not included in our case series as the authors did not consider VSP to be necessary in frontal defects and they usually involve one fragment that could be easily accommodated without VSP.

We consider VSP and 3D printing technologies as helpful tools in configuration to successful maxillary FFF reconstruction. In our surgical setting, the level of precision and the complexity of applied configurations would be difficult to be achieved by a conventional approach. Traditionally, craniofacial VSP has been used most commonly in mandibular reconstruction as occlusion, mandibular symmetry, and implant planification are of importance. Although literature is scarce in this matter, it is our opinion that maxillary reconstruction with FFF could benefit from VSP. Maxillary reconstructive surgeries should be millimetric accurate when dental implants are planned, or/and when orbital volume should be preserved, accounting for the vast majority of Brown's defects. In cases where neither dental implants nor orbital volume are involved, VSP may lose its necessity to be involved, especially when 1 fibula fragment is used. The cost-effectiveness of VSP in these cases would be an interesting objective for future research.

It has been reported satisfactory results with the use of large, one-piece 3D printed plates for maxillary reconstruction (Melville et al., 2019). We use this approach routinely for mandibular reconstruction as they facilitate the exact fragment placement. However, since experiencing two plate exposures after RT, we no longer use this approach for maxillary reconstruction in patients who have received or are likely to receive RT. We prefer pre-bent or 3D printed miniplates instead because they have lower profiles and are less prone to exposure. Moreover, if one plate is exposed or infected, it is easier to remove.

Regarding the use of immediate or delayed ODI, we tend to favor immediate implantation to improve long-term implant survival whenever RT is likely to be required afterward. However, when there is uncertainty about resection margins, it is better to wait for a delayed placement. Uncertain situations potentially could mean that FFF length or the fragment position may differ and cause implant mispositioning. Even though postoperative RT is scheduled, the delay is considered necessary because implant misplacement might compromise dental rehabilitation.

In our experience, transition to in-house VSP is applicable and could lead to fast and efficient reconstructive surgeries. A motivated team is needed to withstand the hours of dedication and to overcome the frustration in trying to master this software. Despite further opening the door for greater engineering input in reconstructive surgery, we should remember that medicine is not an exact science. It is important for both surgeons and engineers to understand that a degree of flexibility should be retained in designs because situations may arise that require a different plan to that initially developed.

In our institution, we currently have neither a polyamide 3D printer nor the corresponding accreditations to print sterilizable cutting guides. We hope to have a 3D printing laboratory established and run it by a bioengineering team in the mid-term future. Thus, we cannot consider the present approach to have been strictly in-house due to the reliance on external companies to print the guides.

5 | CONCLUSIONS

Our report showed that 3D-design and printing technologies could be utilized in the improvement of maxillary reconstructive surgeries. This can be achieved by either external companies or in-house planning to provide customized reconstructive surgery. These technologies enable the surgeon to perform a wider range of FFF configurations to restore the function and aesthetics. These features make FFF to be the most versatile for frontal and maxillary defects.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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