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Delayed Maxillary Reconstruction with Free Osteocutaneous Fibula Flap Using CAD-CAM Technology

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Abstract

Background Maxillary reconstruction poses unique challenges for the reconstructive surgeon because of the complex three-dimensional (3D) anatomy of the maxilla. Undertaking this endeavor on secondary reconstruction makes it more difficult due to problems in recreating the true defect. This study is an attempt to demonstrate the role of virtual surgical planning (VSP), 3D printing, and mock surgery in reconstructing such defects using free fibula flaps.

Materials and Methods This was a prospective study involving 10 patients of maxillary defects who underwent delayed reconstruction with a free fibula flap. The planning was done preoperatively using computer-aided design and computer-aided manufacturing (CAD-CAM) technology. A mock surgery with 3D printed models was done before the surgery. After the surgery, the accuracy results were obtained by overlapping and measuring fixed point distances between preoperative virtual planning and postoperative computed tomography (CT) scan data.

Results and Discussion Nine patients underwent successful reconstruction and were satisfied with the outcome. One patient had flap loss. The mean shift along the horizontal, vertical, and 3D axes was less than 5 mm between the preoperative virtual planning and postoperative CT scan data, indicating accurate reconstruction. We also suggest strategies for soft-tissue and bony inset including inferolateral pedicle origin, anteriorly facing lateral fibular surface, and two bony struts for the alveolus.

Conclusion VSP and CAD-CAM technology in maxillary reconstructions help achieve an anatomically accurate neo-maxilla. The addition of mock surgery to the routine and the use of cutting guide avoid unpredictability and reduce the need for adaptation activities on the operating table. CAD-CAM technology despite its limitations is invaluable in maxillary reconstruction and is an important tool for a reconstructive plastic surgeon.

Keywords
- virtual surgical planning
- CAD-CAM
- free osteocutaneous fibula flap
- maxillary reconstruction
- mucormycosis

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Introduction

During the COVID-19 pandemic in India, mucormycosis cases increased, leading to maxillectomies. Such patients now seek permanent maxillary reconstruction for aesthetic and functional reasons. Such secondary reconstruction is challenging due to the scarred and contracted nature of the defects and the complex anatomy of the maxilla. Computer-aided design and computer-aided manufacturing (CAD-CAM) technology can address these challenges by facilitating accurate assessment of the defect and virtual surgical planning (VSP).[1–3] While widely used in mandibular reconstruction, VSP is now being adopted in maxillary reconstruction.[4,5] This study aims to demonstrate the benefits of VSP and mock surgery in delayed maxillary reconstruction, using free osteocutaneous fibula flap, which is widely regarded as the gold standard for reconstruction of complex maxillary defects.[6–8]

Aims and Objectives

The aim of the study was to assess the accuracy of secondary maxillary reconstruction using VSP, three-dimensional (3D) modeling, and mock surgery in terms of precision parameters and surgical and functional outcomes.

Materials and Methods

This was a prospective study involving 10 patients who were operated on between January 2020 and April 2023 at the Department of Plastic Surgery, PGIMER, Chandigarh.

Each patient was preoperatively assessed with 3D noncontrast computed tomography (CT) of the face and bilateral lower limbs. The Digital Imaging and Communications in Medicine (DICOM) data of both the scans were converted into the stereolithography (STL) format and fed into a 3D planning software. The normal side of the face was mirrored onto the visualized defect and the missing bony components were delineated. Virtual reconstruction was done by superimposing and osteotomizing the 3D reconstructed fibula onto the maxillary defect in such a way that the contour of the midface and the relation between the dental arches were maintained as much as possible. An example is depicted in ►**Video 1**.

Video 1

An example of virtual surgical planning. Online content including video sequences viewable at: https://www.thieme-connect.com/products/ejournals/html/10.1055/s-0044-1790602.

Using the measurements from VSP, a fibula cutting guide was designed. The maxillary model, the patient's fibula, and the cutting guide were 3D printed. A mock surgery was performed a day prior to surgery wherein the 3D printed fibula was osteotomized using the cutting guide and fixed on the 3D model of the maxillary defect. Any further modifications needed were identified and VSP was redone if needed. All the models were sterilized and kept ready for intraoperative usage. The scheme of methodology till surgery is outlined in ►**Fig. 1**, and an example is depicted in ►**Fig. 2**.

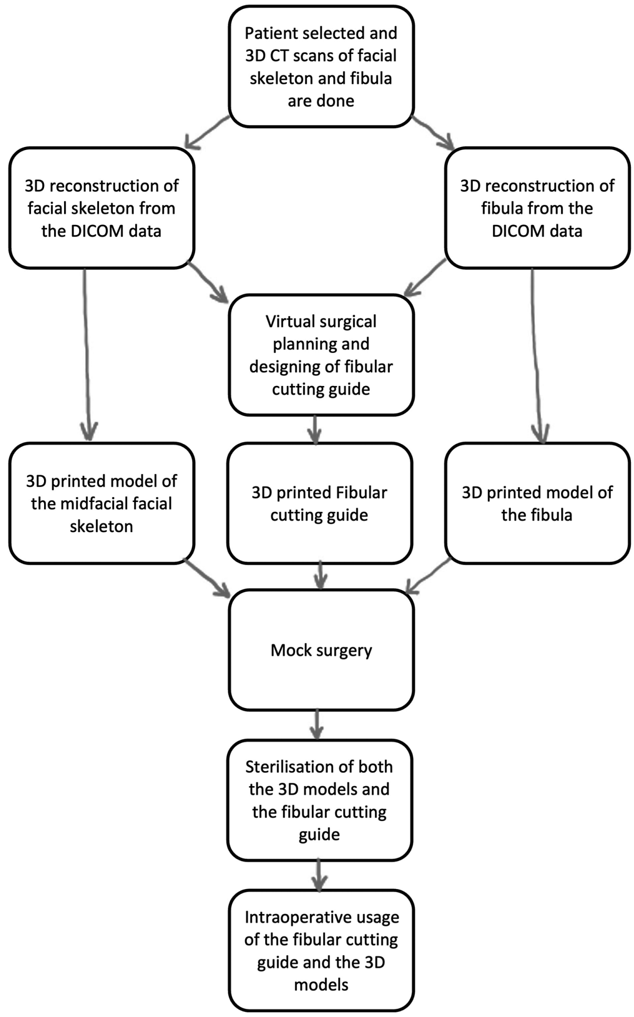

Fig. 1 Scheme of the process till surgery. 3D, three-dimensional; CT, computed tomography; DICOM, Digital Imaging and Communications in Medicine.

The surgeries were performed by the same surgeon. The fibular osteotomies were made using the cutting guide and the bony segments were fixed using miniplates. The fibular construct was then fixed to the zygoma and the maxillary remnant. The peroneal vessels were anastomosed to the facial artery and to a suitable regional vein.

At the 3-month follow-up after surgery, 3D CT scan was done. The precision results were determined by overlapping the postoperative CT images on preoperative virtual planning images. Various measurements such as horizontal shift, vertical shift, and 3D shift were noted at the individual bony struts, forming the neo-alveolus. An example is depicted in ►**Fig. 3**. If more than one bony strut was forming the neo-alveolus, the average of the measurements from each strut was calculated.

In all cases, except one, we used the Weber–Ferguson approach, which allowed complete exposure of the defect for soft-tissue release and implant fixation.[9] The ipsilateral facial artery, vein, and/or external jugular vein (EJV) were used as

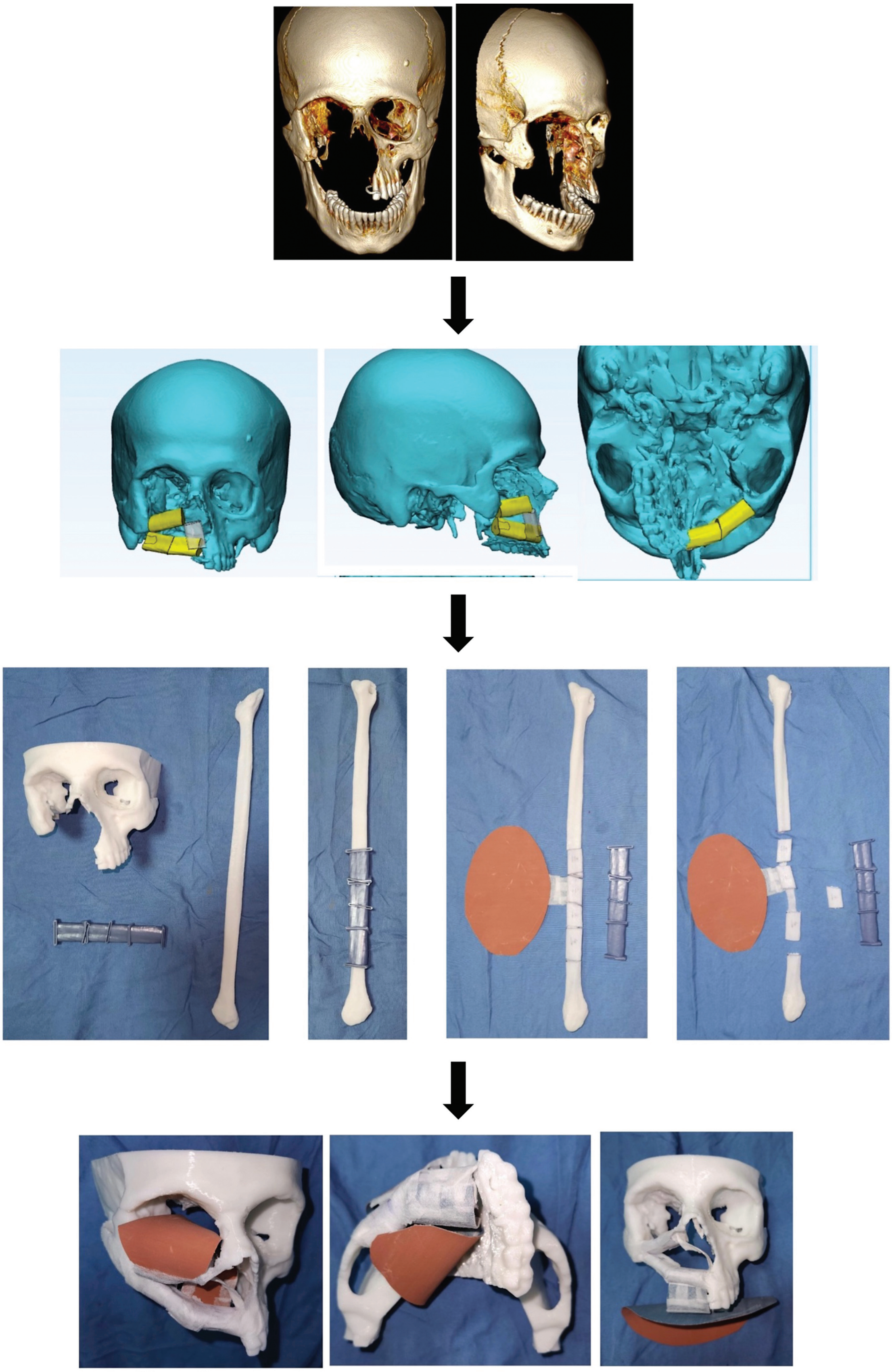

Fig. 2 A case showing preoperative three-dimensional (3D) computed tomography (CT), virtual surgical planning (VSP), and mock surgery.

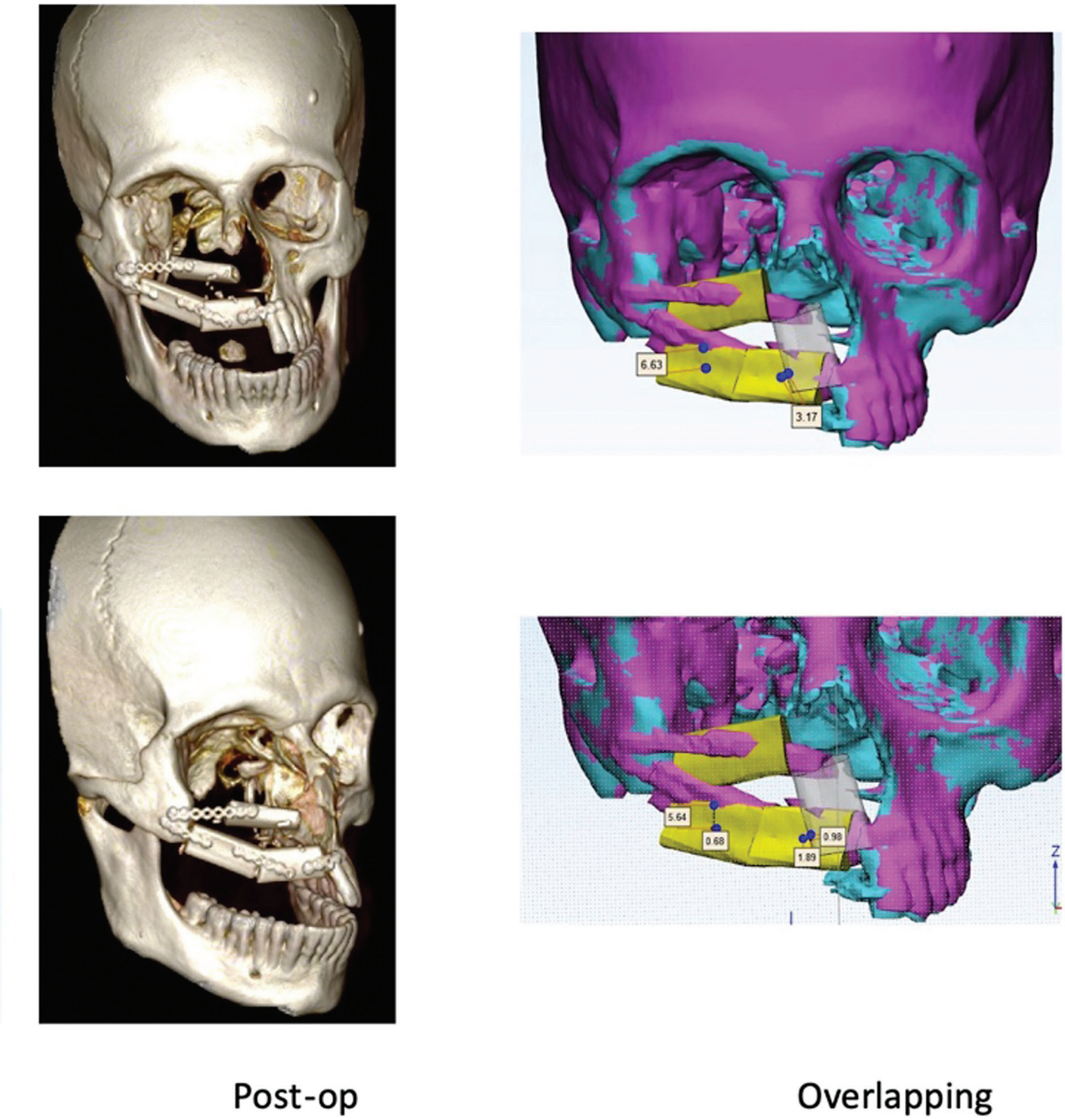

Fig. 3 Overlapping the virtual planning images on the post-op computed tomography (CT) images to measure the shift in various axes.

recipients in all cases. The EJV was preferred as the venous recipient owing to its caliber. When used, it was isolated, dissected out for a length proximally, and flipped medially to reach the flap pedicle near the arterial anastomosis as shown in ►**Fig. 4**. In all patients, the right fibula was used as the donor as the side of flap harvest is not of major concern. To increase the mobility of the skin paddle, the septum can be divided both proximal and distal to the area perforators as shown in ►**Fig. 5**.

In the cases where the inferior orbital rim (IOR) was also reconstructed, one or two struts were used to make the alveolus and another single strut was used to make the IOR. In all these cases, a segment of bone (~2 cm) was removed between the IOR segment and the alveolus segment while keeping the periosteal continuity intact (►**Fig. 6**). This is to prevent the abrupt bend in the flap pedicle as there is near 180-degree turn between the IOR and the alveolus segment. Ideally, in cases of total maxillectomy two bony struts are needed to form an anatomically accurate alveolus. However, if the second bony strut is less than 1.5 cm, a single strut is used. This was the case with patients 1 and 3 (►**Table 2**).

We also recommend that the lateral surface of the fibula be oriented forward, forming the anterior surface of the neo-maxilla. This is because it is the widest of the three fibular surfaces, which helps in restoration of the midfacial height, and it also facilitates easier implant fixation and later removal, if necessary, during dental implant insertion.

The operative time and ischemia time were noted. Functional outcomes were assessed regarding diet and speech. Aesthetic outcomes were measured using a subjective scale ranging from 1 to 10.

Technical pearls in surgical technique

- Each of the bony struts forming the neo-maxilla should be more than 1.5 cm.
- At least 2 cm of bone should be removed between the segments forming the IOR and the alveolus while keeping the periosteal continuity intact.
- The origin of the flap pedicle should be from the inferolateral aspect of the neo-maxilla when facial vessels are used as recipients.
- The septum of the skin paddle can be divided proximal and distal to the area of perforators, which increases the mobility of the skin paddle.
- The lateral fibular surface should face forward, forming the anterior surface of the neo-maxilla.
- Creation of the upper gingivobuccal sulcus, flap debulking, and split skin grafting over the neo-alveolus is necessary before dental implant insertion.

Results

The majority (7) of the patients in the study group were patients of mucormycosis (►**Table 1**) and had diabetes. All the patients had undergone maxillectomies and had presented later in the plastic surgery outpatient clinic. The mean age of patients was 36.4 ± 9.29 years.

In our study, half of the patients (5) belonged to type 3B Cordeiro defect[10] category, which indicates postorbital exenteration status with maxillectomy. The free osteocutaneous fibula flap (FOCF) flap can provide enough bone and soft tissue in the form of skin and muscle for obliteration of large maxillary and orbital defects.[11] Four patients belonged to the type 3a category and one patient to the type 2b category.

Fig. 5 On-table image of a harvested flap, depicting the excised septum on either side of perforators. The *area in blue grids* represents the divided septum.

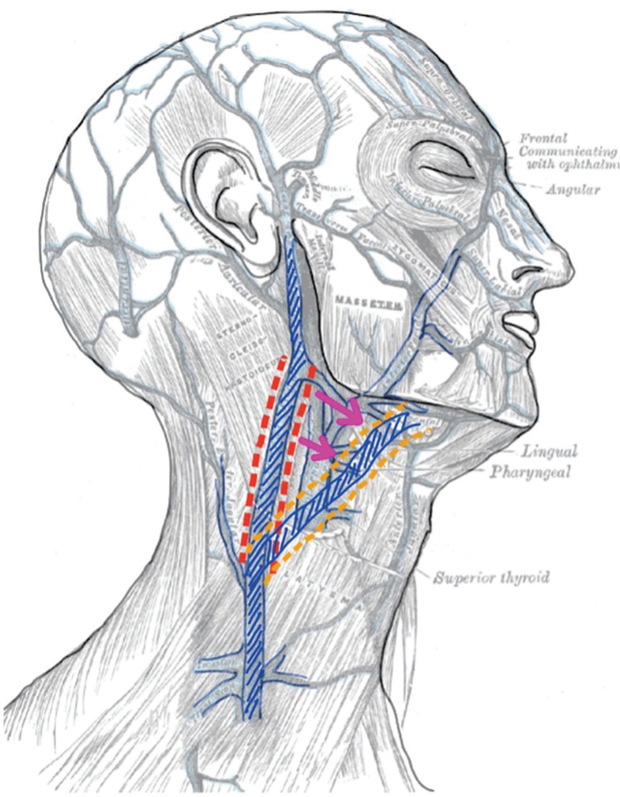

Fig. 4 Image depicting the extent of dissection when the external jugular vein was used as a venous recipient. The *area within the red line* shows its original anatomy and the *area inside the yellow lines* shows its modified location when used as a venous recipient.

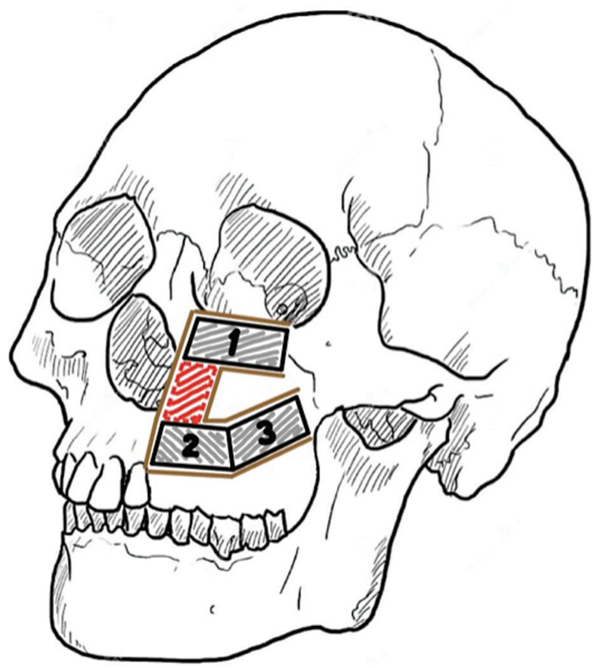

Fig. 6 Reference plan in a type 3 Cordeiro defect. The *brown lines* represent the periosteum. The *area in red* represents the removed bone while maintaining periosteal continuity. If either segment 2 or segment 3 is less than 1.5 cm, a single strut is used instead.

Table 1 Brief overview of all cases

Sl. no.	Age/sex	Diagnosis	Details	Intra-/postoperative details
1	30/M	Lt type 2b defect S/P debridement for maxillary osteomyelitis (►**Supplementary Fig. S1**, available in the online version)	No skin or palatal mucosal defect	2 × 3 cm skin paddle Single bone strut used to create maxillary alveolus
2	43/M	Lt type 3a Lt defect S/P maxillectomy following myoepithelial Ca of the palate, type 2 DM	Lt hemi-palate defect	7 × 7 cm skin paddle 3 bony segments used The patient developed venous congestion on the day of surgery. The flap was salvaged after re-exploration
3	41/F	Rt type 3b defect S/P Rt orbital exenteration and maxillectomy following mucormycosis, type 2 DM (►**Supplementary Fig. S2**, available in the online version)	Subtotal palatal defect and orbital defect	10 × 7 cm skin paddle 2 (+1) bony segments used
4	39/M	Lt type 3b defect S/P Lt orbital exenteration and maxillectomy following mucormycosis, type 2 DM	Subtotal palatal defect and orbital defect	9 × 7 cm skin paddle 2 (+1) bony segments used The patient had flap loss
5	49/M	Lt type 3b defect S/P Lt orbital exenteration and maxillectomy following mucormycosis, type 2 DM (►**Supplementary Fig. S3**, available in the online version)	Lt hemi-palate defect	5 × 6 cm skin paddle 3 (+1) bony segments used
6	35/M	Rt type 3b defect S/P Rt orbital exenteration and maxillectomy following mucormycosis, type 2 DM (►**Supplementary Fig. S4**, available in the online version)	Rt subtotal palate defect	15 × 5 cm skin paddle 3 (+1) bony segments used
7	28/F	Rt type 3a defect S/P Rt maxillectomy following osteosarcoma of the maxilla	Rt subtotal palate defect	8 × 9 cm skin paddle 3 (+1) bony segments used The patient had implant exposure, which was treated with implant removal and wound closure
8	18/F	Lt type 3b defect S/P Lt orbital exenteration and maxillectomy following mucormycosis, type 1 DM (►**Supplementary Fig. S5**, available in the online version)	Lt hemi-palate defect	5 × 6 cm skin paddle 2 (+1) bony segments used
9	35/F	Lt type 3a defect S/P Lt maxillectomy following mucormycosis, type 2 DM (►**Supplementary Fig. S6**, available in the online version)	Lt hemi-palate defect and external skin defect	16 × 6 cm skin paddle 2 (+1) bony segments used
10	46/F	Rt type 3a defect S/P Rt maxillectomy following mucormycosis, type 2 DM (►**Supplementary Fig. S7**, available in the online version)	Rt hemi-palate defect with external skin defect with vertical dystopia	17 × 6 cm skin paddle 3 (+1) bony segments used

Abbreviations: DM, diabetes mellitus; Lt, left; Rt, right; S/P, status post.
Note: (+1) indicates the segment of bone removed between inferior orbital rim (IOR) and the alveolus segment while keeping the periosteal continuity intact.

Nine patients underwent successful reconstruction. One patient suffered total flap loss. One patient developed venous congestion in the immediate postoperative period, which was salvaged after re-exploration. In the second patient, however, flap salvage was not successful.

In six cases, three fibular bony struts were used, four bony struts were used in three cases, and a single bony strut was used in one case. The mean operative time was 8.90 ± 0.84 hours (534 ± 50.5 minutes). The mean ischemia time was 97.5 ± 14.95 minutes.

Postoperative CT scans at 3 months of follow-up showed good contour of the fibular flap segments in eight out of nine patients. For each patient, objective measurements were taken at the neo-alveolus with respect to shift in horizontal, vertical, and 3D axes (►**Table 2**). The mean horizontal shift was 3.56 ± 2.55 mm, the vertical shift was 2.50 ± 1.22 mm, and the 3D shift was 5.68 ± 1.94 mm.

All nine patients were satisfied with the outcome. The mean improvement in aesthetic outcome was 1.77 ± 1.20 when graded by the patients themselves and

Table 2 Measurements obtained after overlapping post-op CT and VSP

Sl. no.	Horizontal shift (mm)	Vertical shift (mm)	3D shift (mm)	Comments
1	7.45	0.60	9.02	Single bony strut was used instead of planned two struts due to soft-tissue sufficiency at the defect
2	7.90	4.14	8.93	There is significant variation between the planning and postoperative result. This patient underwent re-exploration for venous congestion and miniplates had to be released
3	3.12	1.21	4.66	Single bony strut was used for the neo-alveolus here as the bony defect was of a smaller size
4	NA	NA	NA	Flap lost
5	1–2.67 2–3.34 Avg: 3.01	1–3.90 2–0.16 Avg: 2.03	1–8.34 2–3.34 Avg: 5.84	
6	1–1.89 2–0.68 Avg: 1.26	1–0.98 2–5.64 Avg: 3.31	1–3.17 2–6.63 Avg: 4.9	
7	0.88	4.07	4.86	These 2 cases were among the first cases included in the study. In these cases, the neo-alveolus was planned to be made of a single bony strut only
8	4.11	1.75	4.62	
9	1–1.29 2–1.82 Avg: 1.56	1–1.52 2–4.12 Avg: 2.82	1–3.71 2–4.59 Avg: 4.15	
10	1–4.43 2–1.08 Avg: 2.76	1–4.62 2–0.53 Avg: 2.58	1–6.52 2–1.70 Avg: 4.11	
Mean ± SD	3.56 ± 2.55	2.50 ± 1.22	5.68 ± 1.94	
p-Value	0.00279	0. 0003	0.0002	

Abbreviations: 3D, three-dimensional; CT, computed tomography; NA, not applicable; SD, standard deviation; VSP, virtual surgical planning.

Table 3 Aesthetic scoring by the patient

Sl. no.	Pre-op	Post-op	Difference
1	7	7	0
2	7	8	1
3	5	7	2
4	NA	NA	NA
5	4	6	2
6	3	6	3
7	5	6	1
8	2	6	4
9	5	7	2
10	3	4	1
Mean ± SD	4.56 ± 1.74	6.33 ± 1.12	1.77 ± 1.20

Abbreviations: NA, not applicable; SD, standard deviation.

1.472 ± 0.92 when graded by the clinicians (►**Table 3** and ►**Table 4**).

All the patients could tolerate soft diet 2 weeks after surgery and could have regular diet 2 months after surgery. Six out of nine patients reported improvement in speech. All the patients had perceptible speech.

Discussion

The maxilla has a complex 3D anatomy, and without CAD-CAM, it is difficult to assess the defect and plan reconstruction. The performance of a mock surgery and the use of a cutting guide both during mock surgery and intraoperatively avoid unpredictability and approximation involved in bone adaptation to the defect. Both are used in all cases. This reduces the operative and ischemia times.

Follow-up CT scans at 3 months showed good contour of the fibular flap segments in eight out of nine patients. After overlapping of planning and postoperative images, the mean horizontal shift, vertical shift, and 3D shift were 3.56 ± 2.55, 2.50 ± 1.22, and 5.68 ± 1.94 mm, respectively. The difference between postoperative result and virtual planning with respect to all three measurements was not significant as any variation of ≤5mm is assumed to be of good outcome. Accurate postoperative intermaxillary relationship helps in dental rehabilitation.[12] Also, deviation of greater than 5 mm is difficult to compensate during implant insertion.[13] Several studies have also shown good concordance with preoperative planning when VSP was used.[14–17] However, there is significant heterogeneity in the way accuracy outcomes are reported in all these studies.

Table 4 Aesthetic scoring by the clinicians

Sl. no.	Pre-op	Post-op	Difference
1	6.25 (5, 6, 7, 7)	6.25 (6, 6, 6, 7)	0
2	6.5 (6, 7, 6, 7)	6.5 (7, 6, 6, 7)	0
3	3.75 (4, 4, 3, 4)	5.25 (5, 6, 5, 5)	1.5
4	NA	NA	NA
5	3.75 (4, 4, 4, 3)	5.25 (5, 6, 5, 5)	1.5
6	3.5 (3, 4, 3, 4)	5.5 (5, 6, 5, 6)	2
7	4.75 (5, 4, 4, 6)	6.75 (7, 6, 6, 8)	2
8	2.75 (2, 3, 3, 3)	5.5 (5, 6, 5, 6)	2.75
9	4.5 (4, 5, 4, 5)	6.5 (6, 7, 7, 6)	2
10	2.75 (3, 3, 2, 3)	4.25 (4, 5, 4, 4)	1.5
Mean ± SD	4.28 ± 1.37	5.75 ± 0.81	1.472 ± 0.92

Abbreviations: NA, not applicable; SD, standard deviation.
Note: The clinician score was determined by pre- and postoperative clinical photographs by a team of four individuals who were not involved with care of the study population. They were a surgeon, two residents, and a senior nursing officer.

There were two flap complications in the study. We suspect that the improper positioning of the vascular pedicle of the flap was the reason for the complication in these cases. In both the patients, the origin of the flap pedicle was from the superolateral aspect emerging from the bony strut forming the IOR. This possibly led to a more acute angled turn at its origin, making it susceptible for vascular compromise. This orientation also necessitates a longer pedicle length, which is a technical challenge.

We recommend that the pedicle originate from the inferolateral aspect of the neo-maxilla, closer to the recipient facial vessels, reaching them in a linear fashion. This would decrease the bend of the pedicle and would also avoid a longer pedicle length. We also advocate against pedicle origin from the inferomedial aspect as this would also necessitate a longer pedicle length and a near 180-degree turn of the pedicle. All three instances are depicted in ►**Fig. 7**.

All nine patients were satisfied with the outcome. Reconstruction of the maxilla has been shown to have psychological benefits in addition to physical benefits.[18] The mean improvement in the aesthetic outcome was 1.77 ± 1.20 when graded by the patients themselves and 1.472 ± 0.92 when graded by the clinicians. Several studies have shown good aesthetic outcome with VSP when compared with the traditional surgery.[19–21]

All nine patients could have regular diet 2 months after surgery. Six patients reported improvement in speech. Modest et al performed a formal postoperative swallowing assessment, which showed earlier advancement to oral diet in VSP patients when compared with the traditional surgery.[21]

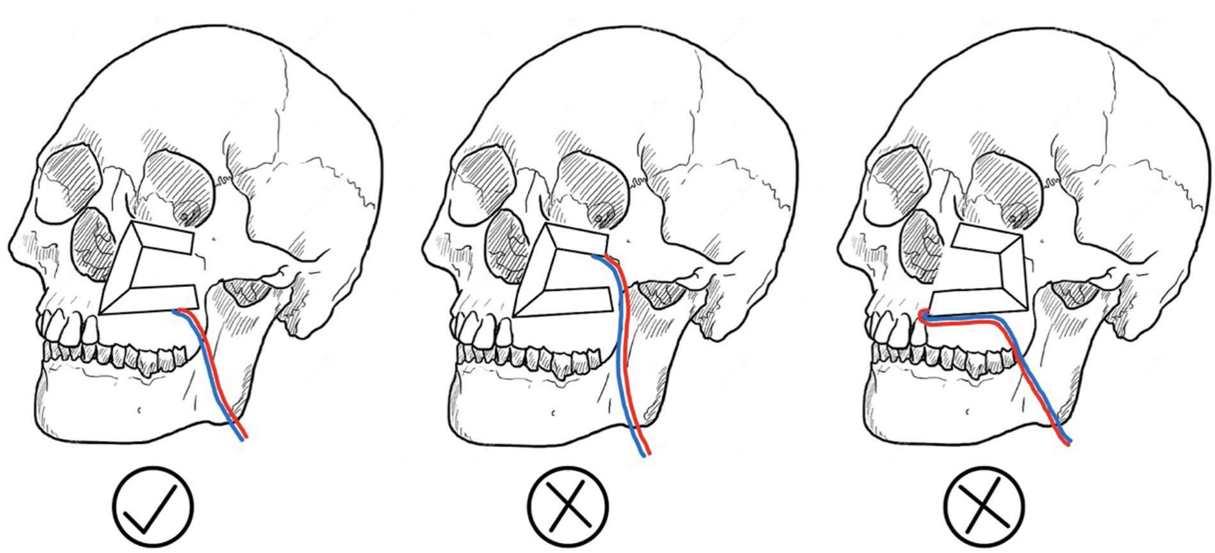

Fig. 7 Possible different orientations of the flap pedicle. The origin of the flap pedicle should be from the inferolateral aspect, which reduces the need for a longer pedicle and avoids any acute bend of the pedicle. The first image shows the same.

Fig. 8 Post-op radiograph and clinical photograph following dental rehabilitation in a patient with a type 2B defect.

Other studies did not find any significant advantage with respect to these two parameters.[14,19,20]

Four patients opted and completed dental rehabilitation. An example is shown in ►**Fig. 8**. Prior to insertion of dental implants, the bulky skin paddle forming the palate was debulked especially below the neo-alveolus and SSG was done. The upper gingivobuccal sulcus was also created. These procedures help in creating a firm bony platform needed for implant insertion. Dental rehabilitation can be considered during VSP before surgery as was shown by Swendseid et al[22] and Schepers et al.[13] VSP also offers the possibility of primary dental implant placements, which reduces the number of procedures and may reduce costs.[13,14,23,24]

There are few possible drawbacks of VSP and 3D modeling. It needs technical expertise and equipment, which may not be available in all centers. Also, the patient will have to bear the additional cost for the exercise. However, if the procedure becomes routine, the costs will decrease, and expertise will be easily available. Furthermore, when the advantages of VSP are considered, the overall cost might well be lesser than the traditional surgery as shown by Mazzola et al.[25]

There were few drawbacks in our study including a small sample size and the absence of a control group receiving traditional surgery to compare the results with. Larger multicentric randomized controlled trials are the need of the hour.

We also suggest two possible improvements in the way VSP is done and we plan to incorporate these suggestions in our further cases. First, we would like to get a CT angiogram of the lower limbs for visualization of peroneal perforator anatomy. This will allow for preoperative planning and designing of skin flap, alleviating the need for modifications on the operating table. Second, we also plan to involve the aspect of dental implants during VSP. Virtual implants can be placed in the fibula during VSP in normal occlusal relationship with the lower jaw and then the fibular position modified accordingly.

Conclusion

VSP, CAD-CAM, and mock surgery in secondary maxillary reconstruction helps achieve a more anatomically accurate neo-maxilla. The addition of mock surgery to the routine helps us to preoperatively identify any errors in the planning and gets the surgeon used to the defect before the actual surgery. This and the use of a cutting guide avoid unpredictability and reduce the need for adaptation activities on the operating table, which in turn can reduce the ischemia and operative times. This can lead to a better outcome, reduce hospitalization, and decrease the overall cost. These advantages can justify any additional costs of VSP.

Funding
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Conflict of Interest
None declared.

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