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Research Article

Evaluation of the Accuracy of computer-assisted technique in Maxillary Reconstruction with Free Fibular flap

Khaled Ibrahim Barakat [1], Omar Mansour[2] and Diaa Ahmed Elsaied[1].
[1] Department of Oral and Maxillofacial Surgery, Faculty of Dentistry, Minia University, Egypt.
[2] Maxillofacial surgeon king Fahd Hospital – Mainah- KSA

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Abstract
Objective: The precise three-dimensional positioning of the free fibular flap (FFF) in maxillary reconstruction is challenging in conventional, experience-based surgeries. This study explores the use of computer-assisted techniques to improve surgical accuracy. **Methods**: Ten cases were indicated for primary or secondary maxillary reconstruction. Virtual planning was carried out for all cases. We evaluate and compare the three-dimensional fibular positions after the operation with the virtual plan, including the following parameters: horizontal position of the fibular segments, and maxilla and mandible vertical distance. **Results**: The fibular segments 3D positions of the studied patients revealed that 80% of patients exhibit a horizontal shift of ≤ 5 mm, whereas, (20%) had >5 mm horizontal shift.. **Conclusion**: The utilization of virtual planning significantly enhances the precision of maxillary reconstruction with free fibular flaps, particularly in optimizing the three-dimensional alignment and positioning of the fibular segments

Key words: Computer - assisted technique- Maxillary Reconstruction – free Fibular flap

Introduction
The maxilla is a pivotal anatomical structure within the midface, serving as a barrier between the oral, antral, and orbital cavities. It provides essential support for the ocular globes, lower eyelids, cheeks, lips, and nose. Additionally, the maxilla is integral to functions such as speech, swallowing, and mastication, while also playing a significant role in facial aesthetics. Given its central position and function, the maxilla constitutes the primary bony support of the midfacial skeleton. Consequently, defects in the maxilla, resulting from tumor resection or traumatic injury, can lead to profound functional impairments and significant cosmetic deformities.[1]

Accordingly, reconstruction of maxillectomy defects is one of the most difficult challenges faced by surgeon working in this area [2]. Maxillectomy defects are commonly managed through either obturator or reconstruction using autologous tissue, with both approaches remaining topics of ongoing debate in terms of their efficacy and clinical outcome [3].

Various local and regional flaps have been employed in the reconstruction of maxillary defects, yielding variable success rates. However, these techniques are often constrained by limitations such as insufficient tissue availability, restricted vascular pedicle reach, and the frequent requirement for multiple staged procedures to achieve optimal outcomes[4].

The introduction of microvascular free tissue transfer has revolutionized maxillary reconstruction by providing sufficient tissue for repair, allowing for precise orientation, shaping, and placement of the flap to match the specific defect, and enabling reconstruction to be completed in a single-stage procedure.[5]

The free fibular flap, pioneered by Hidalgo in 1989 for mandibular reconstruction,[5] has since established itself as a critical technique in maxillofacial reconstructive surgery. Its application in midface reconstruction was first reported by Schusterman et al., in 1993, representing a significant advancement in the field of reconstructive surgery. [6]

In contemporary practice, computer-assisted techniques have become integral across various fields, including surgery.[6] Advanced computer-assisted technologies enable surgeons to perform preoperative virtual simulations, allowing for the exploration of nearly any conceivable surgical scenario.[7] Utilizing preoperative computed tomography (CT) data of the facial skeleton and donor site, virtual three-dimensional models can be generated to precisely define the dimensions of the defect and assess the availability of donor-site bone, thereby enhancing surgical planning and accuracy.[8]
This study aimed to evaluate the accuracy of computer-assisted technique in maxillary reconstruction with free fibular flap.

Patients and Methods

The current prospective study was carried on ten cases of maxillary pathology or a defect, resulting from a previous maxillary surgery, so primary or secondary reconstruction was done, from those patients presented to the outpatient clinic of the Minia University Dental hospital maxillofacial surgery department.

Patient demographics

Ten cases were included in this study six males and four females, the age ranged from 18-45 years, based on the Brown classification for maxillary and midface reconstruction, six patients were categorized as requiring class II reconstruction, while four patients were classified as needing class III reconstruction. (Table 1) six of these cases had benign tumors and four had malignant ones, primary reconstruction was done in six cases (four benign and two malignant cases) and secondary reconstruction was done in four cases (two benign and two malignant cases)

The inclusion criteria were:

1. Maxillary pathology either benign or malignant lesions.
2. Age ranges from 15 to 60 years, both genders were involved
3. Maxillectomy defects larger than 6 cm where obturator is unsuitable solution
4. Patients need surgical reconstruction after tumor resection.

The exclusion criteria were:

1) Bilateral maxillary defects.
2) Medical condition is unsuitable for prolonged surgical procedure.
3) Medical history of hypercoagulable state or morbid obesity.

I- Preoperative Evaluation

- Clinical examination included complete head & neck and lower limb examination for any history of deep vein thrombosis, lower limb trauma or fractures.
- Necessary laboratory investigations were done
- CT of the head & neck, and CT angiography or plain CT of the lower
- **Virtual planning**; was conducted Preoperatively using DICOM CT data, which were imported into Mimics software for precise surgical planning
- The tumor margins were delineated using the software, allowing for precise visualization of the tumor's three-dimensional position and its spatial relationship with adjacent anatomical structures.. (Figure 1)
- Subsequently, a virtual maxillectomy was executed using Mimics software, based on clinical assessments and three-dimensional radiographic data.

- Resection guides were also designed and printed to be used intraoperatively in tumor resection. (Figure 2)
- An osteotomy guide and a three-dimensional stereolithographic model were printed, after performing the virtual maxillary resection and reconstruction by fibula using a rapid prototyping technique, this model was used intraoperatively as a guide for prebending of plates (Figure 3 - 4).
- In cases of secondary reconstruction where maxillectomy was already done, CT of the head &neck and that of lower limb were also done and imported to mimics software and fibular segments were created accordingly (Figures 5-8).
- For Brown class II defects, a fibula reconstruction plan was generated using computer-assisted techniques. In contrast, more complex procedures were required for Brown class III defects. For most patients presenting with asymmetry, mirror-image planning based on the contralateral side prior to simulating the fibula reconstruction. A three-dimensional resin stereolithographic model was produced using rapid prototyping methods based on the mirrored plan. This model facilitated the pre-bending of the titanium mesh, which was subsequently used to support the orbital floor and restore the maxillary contour. (Figure 3c).

II- Intraoperative procedures

- Under general anesthesia the patient was put in supine position with endotracheal intubation, tumor resection with safety margins was performed according to the virtual plan,
- In all cases, the donor leg was ipsilateral to the maxillectomy site. The fibula flap (Figure 9) was harvested concurrently with the maxillectomy, following the technique described by Hidalgo (1989).

❖ **Osteotomies of the fibula**

- The fibular flap was osteotomized insitu while still attached to the pedicle using a surgical guide based on preoperative planning.
- Osteotomy guides that were designed preoperatively were used intraoperatively for cutting of the fibula to the desired segments (figures 10).
- The osteotomy guides confirmed that the segments were cut to the desired length and that angular wedge osteotomies were created as planned preoperatively, taking care to protect the vasculature.
- The pedicle was usually separated after the recipient site, was prepared, including the defect site and recipient vessels in the neck.
- The fibular flap was transferred to the recipient site, and the pedicle (peroneal artery and the two venae comitantes) was placed within a tunnel through the cheek, using a surgical glove to reach the submandibular region to promote anastomosis with neck vessels
- Facial artery was mostly used for arterial anastomosis, sometimes, in malignant tumors where neck dissection was performed; the superior thyroid artery was selected for anastomosis.
- The common facial vein was used in venous anastomosis and sometimes the internal jugular vein was also used as end to side anastomosis.

III- Postoperative evaluation

- A post-operative CT scan of the maxillofacial region, (Figure 11) was done after one month and its DICOM file data was imported to the mimics software to be analyzed and compared to the virtual plan.

Results

This prospective study was carried out on ten cases of maxillary pathology or a defect, resulting from previous maxillary surgery, from those patients presented to the outpatient clinic of the department of oral and maxillofacial surgery, faculty of dentistry, Minia University.

Ten cases were included in this study 6 males and 4 females with age range of 18-45 years. (Table 2)

- Distribution of cases between class II and class III is showed in (Table 3)
- Maxillary pathology of the studied patients, showed in (Table 4):
- Type of reconstruction of the studied patients showed in (Table 5):

The three-dimensional positioning of the fibular segments was assessed (Table 6). The results indicated that approximately 80% of patients exhibited shift ≤5 mm horizontally, which contributes to improved alignment between the reconstructed maxilla and the lower dentition, thereby enabling dental restoration and implant placement.

- Regarding complications, (Table 7) 1(10%) patient had infection, 1(10%) patient had enophthalmous, and 1(10%) patient had flap failure (Table 7)
- Regarding satisfaction; 8 (80%) patients were very satisfied, 1(10%) patient was satisfied, and 1 (10%) patient was dissatisfied (Table 8).

Table 1: Patients demographic

Pt No	10
Gender M\F	6\4
Age range	18-45 years
Benign tumors	6
Malignant tumors	4
Class II defect	6 cases
Class III defect	4 cases
Primary reconstruction	6 cases
Secondary reconstruction	4 cases
Right sided defect	5 cases
Left sided defect	5 cases

Table 2: Demographic data of the studied patients

		n=10
Age (years)	**Mean ± SD**	31.2 ± 8.15
	Range	18 - 45
Gender	**Male**	6 (60%)
	Female	4 (40%)
Weight (kg)	**Mean ± SD**	82.7 ± 8.07
	Range	66 - 93
Height (m)	**Mean ± SD**	1.71 ± 0.07
	Range	1.6 - 1.82
BMI (kg/m2)	**Mean ± SD**	28.34 ± 2.6
	Range	23.85 - 32.41

Table 3: distribution of cases between class II and class III defects

	Class II defect	**Class III defect**
No .of patients	**6** patients (60%)	**4** patients (40%)
Gender	**3** males and **3** females	**3** males and **1** female
Reconstruction	**2** cases primary reconstruction	4 cases 1ry Reconstruction
	4 cases secondary reconstruction	0
Number of benign cases	**4** cases	**2** cases
Number of malignant cases	**2** cases	**2** cases

Table 4: Showing Maxillary pathology of the studied patients

		n=10
Maxillary pathology	**Benign**	6 (60%)
	Malignant	4 (40%)

Table 5: Type of reconstruction of the studied patients

	n=10
Free fibular flap	6 (60%)
Fibular flap and pre-bent titanium mesh	4 (40%)

Table 6: Three-dimensional position of the fibular segments of the studied patients

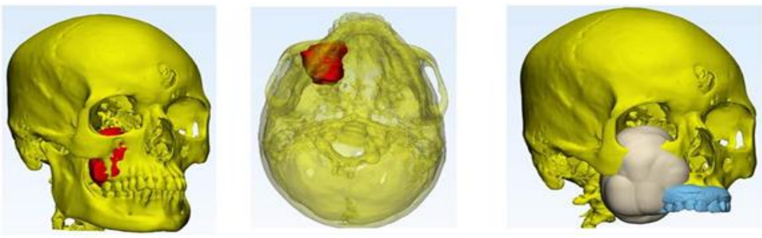
		n=10
Change in vertical distance between maxilla and mandible (mm) between operated and healthy sides	**Mean ± SD**	2.14 ± 0.55
	Range	1.22 - 2.82
Horizontal shift of the fibular segments	**>5 mm**	2 (20%)
	≤5 mm	8(80%)

Table 7: Complications of the studied patients

	n=10
Infection	1 (10%)
Exposure of titanium mesh	0 (0%)
Diplopia	0 (0%)
Enophthalmous	1 (10%)
Flap failure	1 (10%)

Table 8: Satisfaction of the studied patients

	n=10
Very satisfied	8 (80%)
Satisfied	1 (10%)
Dissatisfied	1 (10%)



Marking of the tumour extensions Resection margins

Figure (1): Preoperative planning for class III defect

Figure 2: (A)and (B) intraoperative view showing the use of resection guides in tumor resection.

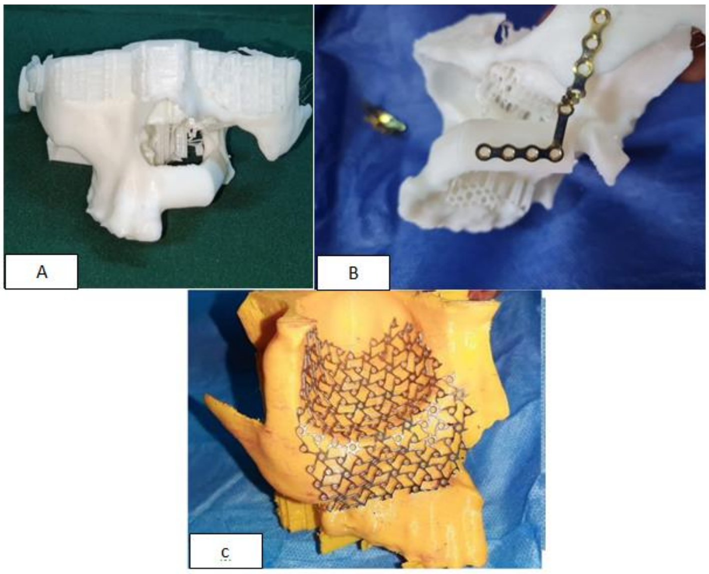


Figure 3: (A) showing 3D printed model with fibular segments in place, (B) pre-bending of titanium plate for fibula fixation and (c) pre-bending of titanium mesh

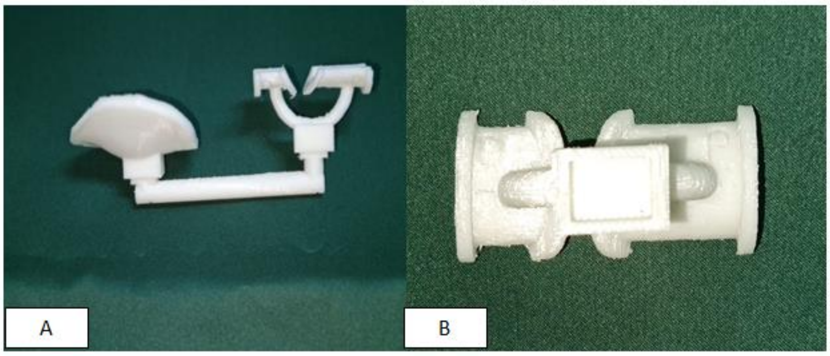


Figure 4: (A) Showing the 3 D printed an osteotomy guide for fibula with attached the lateral malleolus part, and (B) showing the fibular osteotomy guide only

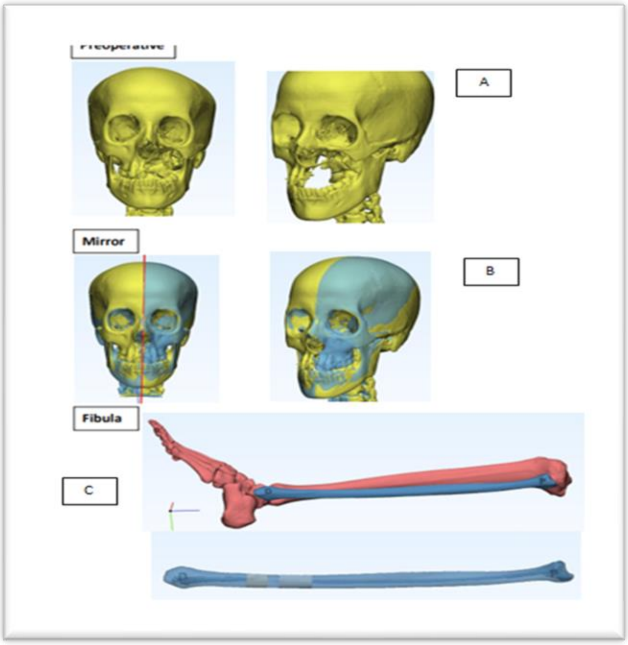


Figure 5: (A, B and C) digital workflow for a class II Lt. maxillary defect reconstructed with free fibular flap

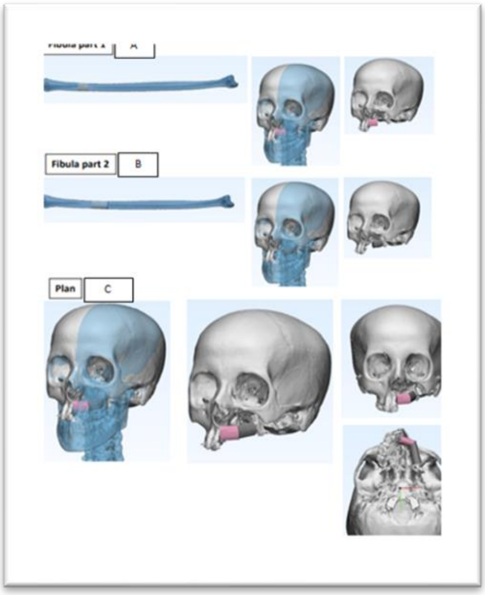


Figure 6: (A, B and C) continuation of digital work flow for the same case in figure

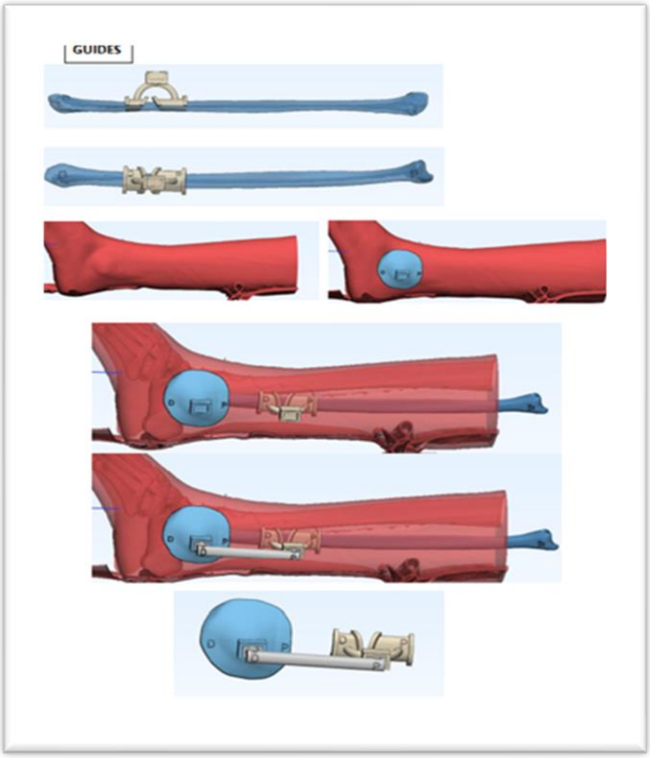


Figure 7: continuation of digital work flow showing fibular guide design

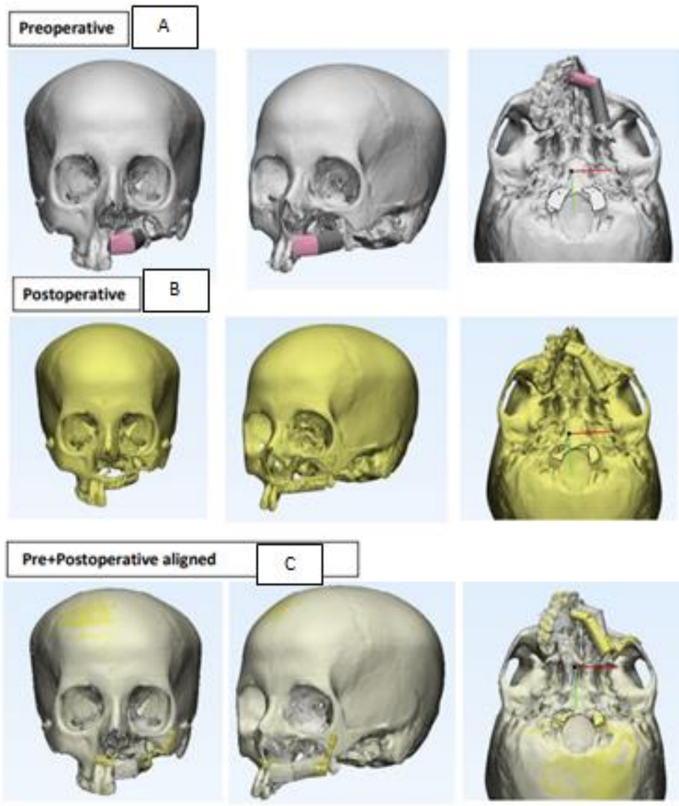


Figure 8: (A, B and C) continuation of digital work flow

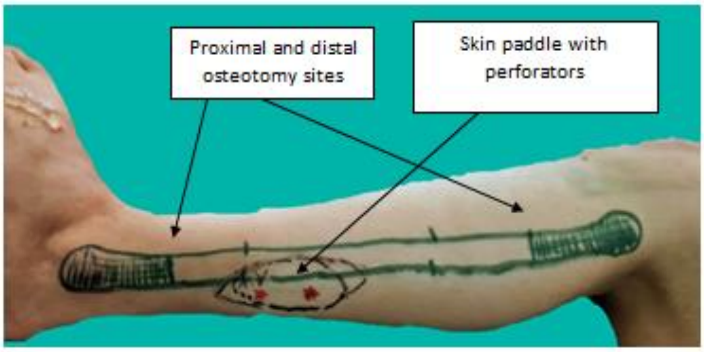


Figure 9: Intraoperative view showing fibula design

Figure 10: showing intraoperative use of cutting guides for fibula

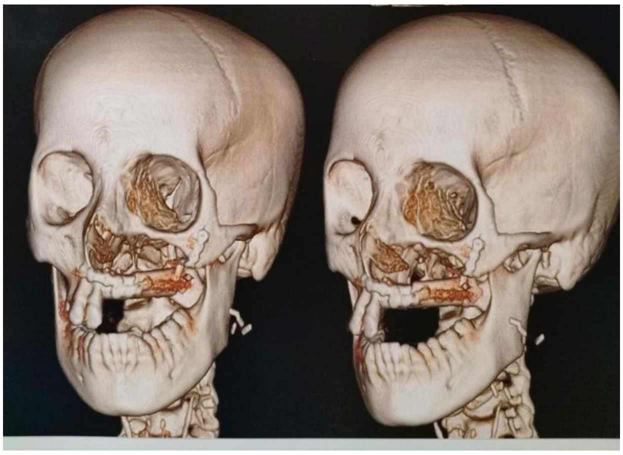


Figure 11: postoperative CT of class II defect

Discussion

Maxillary defects resulting from tumor ablation or trauma often lead to significant functional and aesthetic deformities, presenting a complex challenge for reconstruction.[13], Sadove and Powell ,[14]In 1993 pioneered the use of free fibula flaps for the reconstruction of both maxillary and mandibular defects When the goal of maxillary defect reconstruction is solely to close an oroantral fistula, the procedure is relatively straightforward, with the submental flap being the most appropriate technique for this purpose.[16]

When the objectives of maxillary reconstruction are more complex, aiming to restore a three-dimensional skeletal structure that closely resembles the native anatomy and ensure adequate replacement of excised soft tissues, the procedure becomes more intricate. In such cases, the fibula free flap represents a highly viable reconstructive option.[15] By utilizing a fibula free flap, the fibula can be osteotomized into multiple segments, facilitating the three-dimensional reconstruction of the resected maxilla, closely approximating its original anatomy. This technique also allows for the inclusion of an osteomyocutaneous flap, providing both skin and, when necessary, muscle tissue to repair excised mucosal tissues.[11]

Numerous studies have confirmed the fibula's suitability for dental implants due to its dense bone structure, making it a preferred option for functional maxillary reconstruction.[10] Consequently, free fibular flaps are widely utilized in this regard. However, achieving precise control over the fibula's positioning based purely on the surgeon's expertise remains challenging. In certain cases, the vertical distance on the reconstructed side was inadequate compared to the contralateral side, limiting the available space for dental implants or other prosthesis.[12] On the other hand, excessive spacing between segments can complicate functional rehabilitation. Our study analyzed the vertical distance discrepancies between the reconstructed and healthy sides, as well as the horizontal displacement of fibular segments.

Recent advancements in computer-assisted surgery (CAS), particularly in computer-aided design/computer-aided manufacturing (CAD/CAM) technology, have significantly enhanced the approach to craniofacial reconstructive surgery. Virtual planning offers a precise and quantifiable design that can be applied to both tumor resection and subsequent bone reconstruction, leading to improved surgical outcomes.[17]

Computer-assisted surgery now the landmark technique for succeeding the most precise and symmetric bone restoration than conventional techniques.[18]

Commercially available software are widely utilized in maxillofacial reconstruction procedures. These platforms offer comprehensive capabilities, including segmentation, osteotomy, repositioning, data analysis, and reconstruction.[19] Numerous studies have demonstrated in mandibular reconstruction the effectiveness of computer-assisted techniques, particularly with free fibula and other illiac flaps. These techniques have been shown to achieve a high degree of precision and aligning the reconstructed maxillofacial area.[20]

Modabber et al., reported the use of virtual planning and template models for maxillary and zygomatic reconstructions utilizing iliac artery flaps, noting significant improvements in clinical outcomes.[21] In a more recent study, Rohner et al., presented a case involving have extensive defect following radical tumor resection of the left cranio-maxillofacial area and a prefabricated fibula flap, along with a reconstruction plate, was used in conjunction with computer-aided design and models for reconstruction. These techniques contributed to enhanced patient outcomes and increased intraoperative efficiency.[22]

Our study included ten patients, in the six Cases with class II defect, only a free fibular flap was used in reconstruction, where the four patients with class III defect, reconstruction done with the free fibular flap and titanium mesh. The titanium mesh was pre-bent on the model to fit the individual contour of the orbital floor and infraorbital area. The mesh maintained the volume and orbital contents which covered anterior wall of the maxilla to reestablish infraorbital and perinasal areas contour.

Regarding the position of the fibular segments in the operated patient the maxilla and mandible vertical distance in the operated side was comparable with the healthy side, with only a range of 1.22-2.28 mm of difference between healthy and operated sides.

Two cases (class II defect) with horizontal shift of fibular segments that was more than 5 mm (about 6mm), with the fibular segments deviated either buccal (1 patient) or palatal (1 patients) side this may be due to intraoral fixation of the flap which was quite difficult than extra oral fixation.

The infection that occurred in one case (**class III defect, malignant lesion**) was minimal and resolved within few days of frequent irrigation with saline and chlorhexidine mouth wash along with the prober antibiotic administration according to culture and sensitivity test.

Enophthalmous that occurred in one case **(class III defect, benign lesion**) was not severe and did not affect the esthetic appearance of the patient.

The flap failure that occurred in one case (**class III defect, malignant case**), this is because of venous thrombosis that occurred in the third day postoperatively with failure of flap salvage. The defect was closed later on with temporalis muscle flap.

In our study, tumor mapping was conducted on a slide-by-slide basis using Mimics software for all six patients undergoing primary reconstruction. This process generated a three-dimensional tumor and surrounding structures representation. Based on this imaging, a virtual resection plan was developed. In all cases, the safety margins were confirmed to be clear of the tumor, ensuring adequate tissue removal.

The application of computer-assisted design has demonstrated significant advantages, in tumor diagnosis and resection.[22] As the complex anatomy of the mid-face, accurately defining tumor margins using conventional two-dimensional radiographs, especially in malignant cases, is challenging. Computer-assisted surgery has shown improvements in postoperative outcomes, including reduced tumor recurrence and better achievement of aesthetic goals in maxillary reconstruction.

In our study, 80% of patients expressed satisfaction with the final results, and in the majority of cases postoperative images were markedly symmetric and acceptable. Therefore, our research supports the feasibility and benefits of computer-assisted techniques in maxillary reconstruction using free fibular flaps. However, this approach has limitations, including the potential accumulation of systematic errors during the step-by-step process. For instance, the mirror planning technique is inherently subjective and relies on the virtual surgeon's interpretation, and there is no definitive "correct" position for the fibular segments as virtual planning is based on the surgeon's experience. Additionally, while virtual planning relies on CT-derived bone data, soft tissue considerations are also critical during the surgical procedure, which may lead to discrepancies or errors in the postoperative evaluation.

In conclusion, our study indicates that computer-assisted techniques, such as virtual planning, enhance the precision of fibular segment positioning, thereby improving the functional and aesthetic outcomes in maxillary reconstruction with free fibular flaps.

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