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The Role of Radiological Vascular Assessment and Computer-Aided Planning in The Outcome of Free Vascularized Fibula Flap for Bone Defects Reconstruction

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ABSTRACT

Background: Computer aided planning of free vascularized fibula flap is introduced for treating cases with bone defects.
Objective: The aim of the current study was to evaluate the effectiveness and benefits of planning and simulation in the outcome of free fibula flap (FFF).
Patients and methods: A total of 30 cases were managed in Menoufia University Hospital, Plastic and Reconstructive Surgery Department, between March 2020 and May 2023. The participants in our study were 15 consecutive patients (Group 1) who had free fibula flap mandibular reconstruction utilizing CAD-CAM technology and 15 more patients (Group 2) had free fibular mandibular repair using standard methods.
Results: In contrast to the conventional group (812 minutes), the CAD-CAM group's overall intraoperative duration was much less (662 minutes). In the CAD-CAM group, only 1 patient had postoperative malocclusion, compared to 6 individuals in the conventional group.
Conclusion: The computer aided planning is effectively allowing the procedure to be performed with less time, effort, complications and hospitalization time, moreover increased accuracy, better functional and aesthetic outcome.
Keywords: Computer aided planning, Free fibula flap, Bone defects.

INTRODUCTION

A highly difficult technique for the reconstructive surgeon is the restoration of discontinuity defects in the bone, especially the mandible, caused by benign or malignant tumors. To attempt to rebuild these flaws, several alternative strategies have been employed [(1)].

Alloplastic material, non-vascularized bone grafting, and vascularized bone transfers are some of the methods employed. The transfer of osteocutaneous free tissue with the use of microsurgical methods has been considered nowadays as the most common procedure in the context of mandibular reconstruction [(2)].

Owing to the emerging of novel procedures and the range of flap donor locations, there are many reconstructive choices available. However, the fibula continues to be the most popular donor location [(3)].

In the context of reconstructive head and neck surgeries, the bone restoration of the mandible using microvascular FFF following segmental mandibulectomy is a recognized conventional treatment. Owing to a lengthy vascular pedicle, a broad artery diameter, and the ability to create a skin island as well as a muscle cuff, it was found to be an excellent candidate for mandible restoration [(4)].

The bone transplant that enables restoration of the entire mandible by using a single flap is the fibula. To establish a harmonious and functioning neomandibular arch, however, surgeons must restore complicated abnormalities with one or multiple osteotomies [(5)].

To handle the critical functions of the mandible related facial harmony, speaking, mastication, and airway management and to duplicate it as closely as possible, the fibula must be precisely adapted, segmented, and formed. As a result, the actual osteotomy angles and bent plates are assumed in accordance with the simulation of the mandibular shape. In order to ease osteotomy and improve accuracy, VSP is increasingly used in the context of complicated defect reconstruction, particularly in situations of at least two segmental mandible restorations [(6)].

The perforator vessels that emerge from the fibula's posterior edge supply the skin paddle with nutrients via the peroneal artery. Regrettably, the anatomical route of these perforator arteries frequently exhibits substantial variability, which can make planning challenging [(7)].

Although Doppler ultrasonography, CTA, and MRA are frequently utilized in the context of presurgical assessment, the results are frequently not connected to CAD/CAM planning methods. Of note, the fibula's bony portion has a sturdy nature. Its incorporation into CAD/CAM logarithms with regard to surgical plan is a commonly utilized and largely appreciated tool as a result [(8)].

The aim of the current study was to evaluate the effectiveness and benefits of computer aided planning as tool in improving free fibula flap (FFF) results in bone defects reconstruction.

PATIENTS AND METHODS

A total of 30 cases were managed in Menoufia University Hospital, Plastic and Reconstructive Surgery Department, between March 2020 and May 2023. The participants in our study were 15 consecutive patients (Group 1) who had free fibula flap mandibular reconstruction utilizing CAD-CAM technology and 15 more patients (Group 2) had free fibular mandibular repair using standard methods.

Inclusion criteria: Patients of both genders (14 males and 16 females); their age ranged from 26 to 66 years old. All participants were patients with extensive bone

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defect can't be closed by bone grafts and will be fit for surgery.

Exclusion criteria: All patients with small defects that can be closed by bone grafts and not fit for surgery. Other exclusion criteria were old age (>70 years old), cardiac and diabetic patients.

Every patient was exposed to:

A. Preoperative Assessment: Full history taking (age, sex, occupation, special habit of medical or surgical importance, chronic illness,). Clinical examination. Patient Communication and explanation of the problem, procedure and post-operative management plan. Standardized color digital photography of the cases. Laboratory investigations e.g., CBC, Coagulation Profile.

B.

B. Preoperative virtual surgical planning: The right preoperative imaging is the first step in the VSP process. Mandibular and fibula high-resolution CT images with 1 mm interval cuts are acquired. The virtual scalpel is then turned over to the ablative surgeon to show where the osteotomies were made. The fibula is then placed on the screen to substitute the mandibular and maxillary regions that were removed. The same number and location of osteotomies are carried out as with the conventional templates previously mentioned. In addition, dental implants may be inserted into the fibula once the virtual fibula repair is finished. At this point, the position and depth of the implant are chosen.

After the conference call is over, additive printing is used to create acrylic cutting guides for the fibula and tumor removal.

To enable mesial and distal bone incisions that contain the tumor, cutting guides for the excision are positioned on the mandible or maxilla. The cutting guides must properly fit to the preoperative VSP's desired position. A guide based at occlusion with an extensions arm for the osteotomy may be the best way to guarantee exact placement. Once in place, the guide is screwed to the bone to prevent motion throughout the osteotomy. Through the cutting guide, the complete osteotomy must be carried out. It is insufficient to simply score the mandible's surface with the saw since the osteotomy plane is frequently angulated and not parallel to the buccal aspect. After the fibula is removed, the leg is treated in a manner akin to that. The fibula cutting guide is adjusted to the bone while the peroneal vessel is still connected. Similar to how the mandible/maxilla guide must be placed, it is crucial that the fibula guide be placed in the precise anatomical spot as planned during the VSP. If the guide is placed in the wrong anatomic location, the guide will not adapt to the bone as the fibula's form changes rather noticeably from proximal to distal. The two fibula osteotomies that are performed most proximally and distally complement the ablative team's procedures. After the guide is taken out, miniplates or a reconstruction bar are used for rigorous fixing. In order to assure precision with the virtual surgical planning, the contoured fibula could be contrasted with a 3D acrylic model of the intended repair. For insetting, the flap is pulled up to the head and neck deformity.

C. Technique:

Surface Markings and Skin Island Design: The septum between the lateral and posterior compartment muscles is always in the center of the skin island. By feeling the fibula's posterior edge and drawing a line along it, it is possible to locate this septum. The skin island is a great donor site because of its tiny transverse dimension, which is often closed if it is less than 3 to 4 cm.

Skin, the Lateral Septum, and Lateral/Anterior Muscle Compartments: Anterior Dissection: The dissection is commenced anteriorly after tourniqueting the limb to exsanguinate it slightly. The skin and fasciae are separated from the lateral compartment muscles after the incision is made into the subcutaneous tissues. The septum, that transports the blood flow to the skin, is very carefully avoided at all costs. The lateral compartment muscles are separated after the dissection reaches the lateral fibular aspect by leaving a cuff of muscle (2–3mm) on the bone to protect the periosteum. The septum between the lateral and anterior compartment muscles is cut after the lateral compartment muscles have been dissected. The anterior tibial nerve and the muscle-dwelling branches of the anterior tibial vessels must both be protected from damage. The interosseous membrane was recognized and incised over the whole dissection distally once the muscle has been separated from the bone.

Dissection of the Skin Island's Posterior border: Special care is given to avoid dissecting into the septum when the posterior skin border is incised. to prevent damaging the skin's blood flow and septum. Proximally, the major pedicle was recognized. The fasciae covering the flexor hallucis longus (FHL) muscle was cut once the majority of the pedicle has been located in order to remove the muscle from the incision.

Fibula Osteotomies: Proximal and Distal: A sagittal saw is used to make the distal osteotomy. The peroneal vessels situated immediately medial to the bone are handled with caution. It is typical to make the proximal osteotomy as high as feasible. It is beneficial to do the osteotomy slightly underneath the peroneal nerve level and the level in which the anterior tibial arteries penetrate the interosseus septum on their way to the anterior compartment, even if this piece of the bone is not required for the reconstruction. This makes it possible to dissect the pedicle with improved exposure.

Division of the Tibialis Posterior Muscle (TPM) and the Distal Peroneal Vessels: The distal peroneal vessels and the TPM are identified after the osteotomies are performed and the flap is pulled from the incision. The midline raphe and the TPM are both bipennate muscles. The bone fragment is extricated from the incision by ligating the distal vessels. A division exists in the FHL muscle.

Dissection of the Main Pedicle:

The posterior tibial vessels deeper in the wound and the peroneal vessels on the fibular surface are preserved by carrying out the dissection through the midline raphe. From distal to proximal, the dissection is performed. The posterior tibial veins and the peroneal vessels surround the tibial nerve. The posterior tibial and peroneal vessels are divided at the peroneal vessels bifurcation.

Ethical Consideration:

This study was ethically approved by the Institutional Review Board of the Faculty of Medicine, Menofia University. Written informed consent was obtained from all participants. This study was executed according to the code of ethics of the World Medical Association (Declaration of Helsinki) for studies on humans.

Statistical analysis

The collected data were introduced and statistically analyzed by utilizing the Statistical Package for Social Sciences (SPSS) version 22 for windows. Qualitative data were defined as numbers and percentages. Chi-Square test and Fisher's exact test were used for comparison between categorical variables as appropriate. Quantitative data were tested for normality by Kolmogorov-Smirnov test. Normal distribution of variables was described as mean and standard deviation (SD), and independent sample t-test/Mann Whitney test was used for comparison between groups. P value ≤ 0.05 was considered to be statistically significant.

RESULTS

In the CAD-CAM group, the average follow-up was 9.5 months (with a range of 6 to 15 months), whereas in the traditional group, it was 18 months (with a range of 16 to 33 months).

Out of the 15 cases in the CAD-CAM group, 9 were female and 6 were male, compared to 7 females and 8 men in the conventional group. In the CAD-CAM group, the mean age ranged from 12 to 67 years, whereas in the traditional group, it ranged from 22 to 72 years.

Both groups' mandibular abnormalities were categorized using Brown's categorization. It was discovered that the type 2 deficiency affected the majority of patients in both groups (conventional group 9/CAD-CAM group 10). The 2 groups also had comparable additional types of problems (**Table 1**).

Table (1): Mandibular deformities classified in 2016 using Brown's classification.

Brown's Classification	**Without CAD/CAM**	**With CAD/CAM**
Class I: Lateral defects excluding condyle and canine	2	2
Class Ic: Lateral defects with condyle	0	0
Class II: Hemimandibulectomy, ipsilateral canine or ipsilateral condyle included but not contralateral)	9	10
Class IIc: Hemimandibulectomy with condyle	0	1
Class III: both canines are removed during anterior mandibulectomy, although neither angle is	2	0
Class IV: Extensive anterior mandibulectomy, comprising removal of either one or both angles and both canines, 5 6	2	2
Class IVc: Extensive anterior mandibulectomy with removal of one or both condyles and both canines	0	0
Total	15	15

It should be observed that there are considerable differences between both groups in the number of fibular osteotomies and, consequently, the number of fibular segments used for mandibular reconstruction (**Table 2**).

Tables 2 and 3 show that most of cases in the conventional group (12 out of 15) received just one fibular osteotomy, resulting in the need of just 2 fibular segments for mandibular reconstruction. On the other hand, in the CAD-CAM group, 10 out of 15 patients required two fibular osteotomies, leading to the need of 3 fibular segments for mandibular reconstruction. Additionally, 3 cases in the CAD-CAM group required 3 osteotomies, compared to 0 in the conventional group. These findings demonstrate the complexity growth in CAD-CAM reconstruction.

Table (2): Osteotomies performed using CAD/CAM and the conventional method. .

No of osteotomies	Without CAD/CAM	With CAD/CAM
0	0	1
1	12	1
2	3	10
3	0	3
Total	15	15

Table (3): Number of Fibular Segments in the CAD/CAM Group and the conventional Group.

No. of Fibular Segments	Without CAD/CAM	With CAD/CAM
1	0	1
2	12	1
3	3	10
4	0	3
Total	15	15

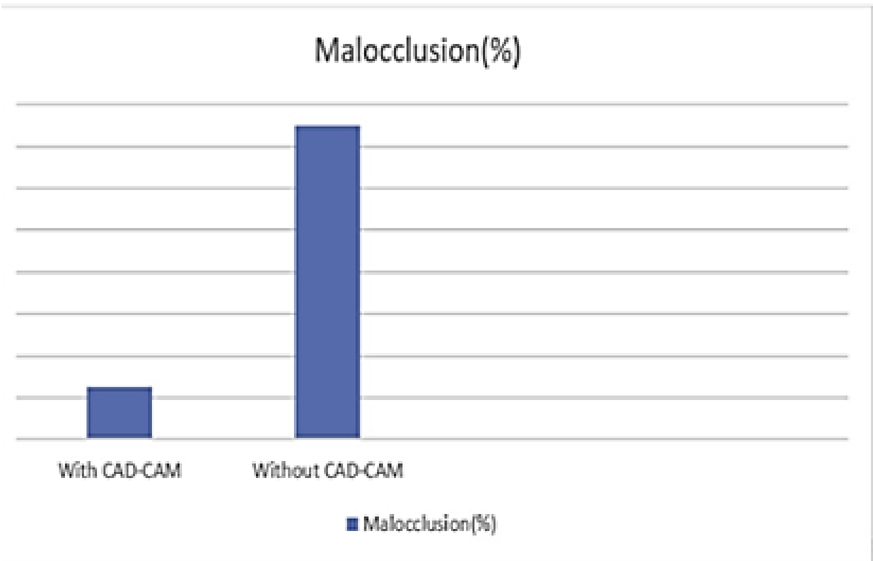
Operative time: In the CAD CAM group, the average procedure took 662 minutes (n=15), whereas it took 812 minutes (n=15) in the traditional group. This suggests that the usage of 3D printed cutting guides reduced the average operating time by roughly 150 minutes. With a p-value <0.0001, the outcome was statistically significant. It may be important to note that the shorter operating time was achieved despite the fact that the CAD-CAM group required more osteotomies than the traditional group (**Table 4**).

Table (4): Total operating time in the CAD-CAM and traditional groups is compared.

With CAD/CAM (Mean ± SD) (n=15)	Without CAD/CAM (Mean ± SD) (n=15)	Δ= Without - With (Mean ± SD)	95% CI of the Difference		t-test	P-value
			Lower	Upper		
662 ± 88	812 ± 88	150 ± 24	102	196	5.822	<0.0001*

*P-value <0.05, statistically significant.

Occlusion: With the use of CAD-CAM, there were considerably less occlusal abnormalities identified in 6.5% of patients (1 out of 15) compared to 27% of patients (4 out of 15) in the traditional group after surgery (**Figure 1**).



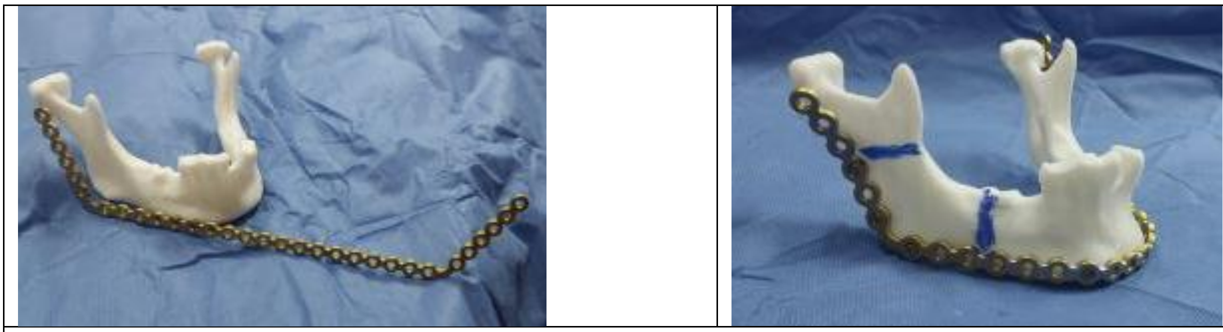
Graph 1

Figure (1): Comparison of postsurgical malocclusion in the CAD-CAM and conventional groups is shown in the graph.

Complications: In the prospective study group, neither group experienced a whole flap loss, nor the CAD-CAM group saw zero partial flap losses compared to one in the conventional group. In the CAD-CAM group, one patient required flap re-exploration, whereas three patients in the conventional group received flap re-exploration and recovered normally. In the CAD-CAM group, there was only one instance of plate fracture and plate extrusion, as opposed to two instances of plate fracture and four instances of plate extrusion in the traditional group (**Table 5**).

Table (5): Complications in the CAD-CAM and traditional groups are compared.

Complications	Number of Cases (n=15) with CAD-CAM	Number of Cases (n=15) without CAD-CAM
Total flap loss	0	0
Partial flap loss	0	1
Re-Exploration	1	3
Plate fracture	1	2
Plate Extrusion	1	4



A: Preoperative surgical planning

B: Preoperative marking

C : Tibioperoneal trunk

D: Free osseocutaneous fibula flap

E: Donor site primary closure

F: Flap in setting and microvascular anastomosis	G: Neomandible profile

Figure (2): Typical clinical images of patients receiving care using CAD-CAM technology.

DISCUSSION

The restoration of the mandible by utilizing a FFF has always been difficult and included a high learning curve. Despite using every trick in the book, traditional approach has frequently produced less than ideal outcomes. Virtual surgical planning and CAD-CAM have completely changed reconstructive surgeries in recent years. These methods enable precise intraoperative execution and accurate preoperative planning, potentially cutting down on operational time. A stereolithic model of the reconstructed mandible (in a virtual manner) was made after the mandible was virtually resected and rebuilt using CT technology in the early studies of computer-aided mandibular reconstruction [(9)].

In 2005, **Valentini *et al.*** [(10)] published a case series with 15 individuals who used this technique. They came to the conclusion that preoperative surgical planning resulted in shorter operating times, less flap failure, higher treatment efficacy, and the greatest functional and aesthetically pleasing outcomes.

The pre-surgical bending of reconstruction plates to meet the stereolithic model was the next significant development in terms of reducing operating room time. In a research by **Marchetti *et al.*** [(11)]**,** it was discovered that a well-contoured reconstruction plate pre-bent on stereolithic model might prevent abnormalities which include severe mental or gonial projection and mal-occlusion, as well as the condylar head torque. **Toto *et al.*** [(12)] discovered that the use of stereolithic models alone was insufficient to give a technique for predictably carrying out the surgical plan and did little to lessen the tedious nature of executing the osteotomies.

Prefabricated osteotomy guides based on a preoperative planning session were introduced to overcome these issues. The guides were created for intraoperative usage utilizing a variety of design softwares before being 3D printed. According to **Hirsch *et al.*** [(13)]**,** the guides are made to have precisely matched ends for both mandibular excision and fibular osteotomies. In many hospitals throughout the world, they are now considered standard of care. Additionally, titanium plates printed to order using CAD-CAM technology may be produced more quickly and efficiently. While the flap is still linked to the pedicle, the segments of the fibular flap are modelled to the plate using the custom-made plates. The titanium plate was subsequently fitted with flaps to accommodate the mandibular deformities [(14)].

In the context of the use of CAD-CAM technologies in mandibular repair, **Deek and Wei** [(15)] have brought up important difficulties. Pedicle reach to recipient vessels, anatomic variances, various soft tissue pedals, and intrasurgical revision of the surgical strategy and performance are a few of these.

In addition to these drawbacks, the benefits of using this method for less complex reconstructions, such as single segment fibula, are debatable. As demonstrated in our analysis, only a small number of patients-and only those in the traditional group-were repaired utilizing a single fibular segment. Therefore, our data cannot be used to make any conclusions about the effectiveness of CAD-CAM in single segment mandibular reconstruction. In complicated instances, those requiring numerous osteotomies, and in situations when concurrent dental rehabilitation is necessary, there is no question that this approach streamlines the mandibular reconstruction [(16)].

A study of 153 publications was conducted in 2019 by **Nicholas *et al.*** [(17)] to examine the function of VSP in mandibular reconstruction. In their study, they included 23 publications with 713 patients in total. Significantly less intraoperative time was related to VSP. Comparing VSP to traditional methods, there was a decreased orthognathic deviation from the optimum result. According to their findings, VSP significantly improves orthognathic accuracy, ischemia times, and operational timeframes.

In our investigation, we too found similar outcomes. **Hirsch *et al.*** [13] have shown that using virtual surgical planning; stereo lithographic models, operational guides, and pre-bending of reconstructive plates can reduce the error associated with the conventional surgery and shorten operating room time.

The precision of mandibular and fibular osteotomies carried out by utilizing cutting guides to be similar with virtual planning has been highlighted by **Roser *et al.*** [4]**.** Fibular osteotomies and neo mandible contouring in the current study's conventional surgery group mostly relied on the surgeon's skill and expertise, with minimal assistance from 2D imaging. On the other hand, in the other group, correct osteotomies of the mandible and fibula at predefined places could be easily completed with the aid of preoperative virtual surgical planning and use of intraoperative 3D printed cutting guides. The exact alignment of the cut ends of the osteotomies allowed for great bone contact, which in the current opinion will hasten union and warrant future research. The titanium plates were prebent and moulded on the 3D-printed model of the mandible after reconstruction, saving valuable intraoperative time.

Although osteotomized fibular segments could fit in the mandibular defects similar to a jigsaw puzzle, proper rebuilding of the neomandible remains the hallmark of the procedure [18–20]. The length, angulation, and location of the fibular osteotomies do not require intraoperative modification, which reduces the amount of time needed for surgery, which in the current series is close to 150 minutes on average [12,14].

The fact that the CAD-CAM group in the current series underwent more fibular osteotomies than the conventional group makes the lower operating time in that group all the more noteworthy. With 93% of cases in this group retaining pre-surgical occlusion at long-term observation postoperatively, in comparison with just 73% of cases in the traditional group, the perfection in osteotomy and fixation is observed to translate in the postoperative period. Similar to how the aesthetics are better preserved in the CAD-CAM group in comparison with the conventional group, greater scores obtained by cases in the first group in the current study clearly demonstrate this. Numerous writers who have mentioned benefits of CAD-CAM over traditional procedures in mandibular repair have confirmed these findings. According to **Weitz *et al.*** [20], the shorter operating time and better general results more than make up for the higher expense. We assessed the data for 15 consecutive cases in each group with the intention of including all possible flaws.

The clinical team also performed subjective measurements of occlusion during the preoperative and postoperative periods. This, in our opinion, would have lessened the impact of the learning curve on the higher results in the CAD-CAM group. In the current study, we employed reconstruction plates that were pre-bent on the operating table's accessible reconstructed mandibular model and then used to fixate fibular segments. Contrarily, many facilities in the West use custom-milled or 3D-printed plates, which increase efficiency and precision.

Sieira *et al.* [14] discovered that using titanium plates with bespoke pre-contoured shapes significantly reduced the overall surgical time. The expenses were too high for our situation, therefore we didn't utilize them. To more clearly define the mandibular contour, anterior, central, and lateral flaws were repaired using a 2.7 mm pre-bent reconstruction plate.

CONCLUSION

The computer aided planning is effectively allowing the procedure to be performed with less time, effort, complications and hospitalization time, moreover increased accuracy, better functional and aesthetic outcome.

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