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Research Article

Establishing A Virtual Planning Protocol for Functional Maxillomandibular Reconstruction in Oral Cancer Patients

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ABSTRACT

Background: Virtual surgical planning (VSP) helps optimize vascularized bone flap reconstruction and dental rehabilitation in maxillomandibular defects, improving accuracy, reducing errors and reducing the time required for surgery. In this manuscript, we describe a robust but flexible virtual protocol for functional maxillomandibular reconstruction optimized for oral cancer patients using in-house digital planning and provide templates to streamline communication among the team members.

Methods: Based on our previous experience of VSP in oral cancer (n=17), we derived a workflow to improve efficiency. It included a virtual surgical template and a protocol focused on the minimal time requirements for three different reconstructive approaches: prefabrication/prelamination, primary implant placement using the SM-ART approach, and digital planning without primary implant placement. We performed a prospective validation (n=4) to determine its validity and if the proposed timelines could be adhered to.

Results: The protocol allowed a smooth and coordinated framework for team members to communicate and plan the patient's treatment. The time period required for VSP was described for patients undergoing bony reconstruction with primary dental placement in those with and without custom plates, drill guides and for patients with prefabrication (Rohner's procedure). The minimum time required for VSP ranged between 17 and 30 days. The protocol could be reliably applied to the prospective group without any modification.

Conclusion: Bony reconstruction with primary dental implant placement in the context of oral cancer can be performed successfully with good functional outcomes. By adopting this protocol, virtual surgical planning can be performed efficiently, avoiding potentially costly delays in treatment.

Introduction

Vascularized bone flap reconstruction is the standard of care for large defects of the maxilla and mandible following ablation; the functional and aesthetic outcomes achieved are essential determinants of the patient's quality of life [1]. Dental rehabilitation is an important component of both function and aesthetics and requires a specialized multidisciplinary team. Successful dental rehabilitation requires both expertise and an integrated planning phase before surgery [2].

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Due to its challenges, dental rehabilitation is often only achieved following ablation and bony reconstruction of benign disease. In malignant tumors, dental rehabilitation remains a significant challenge [3]. The reasons for this are multiple. Traditional planning for dental rehabilitation requires considerable time, delaying surgery and allowing the tumor to progress. Primary dental implant placement increases surgical duration and complexity, with surgeons fearing that healing issues can delay radiotherapy and the likelihood of cure [4]. Another concern is that early recurrence may prevent the use of implants. Finally, following radiotherapy, secondary dental implant placement also has unique challenges related to osseointegration, osteoradionecrosis, and soft tissue contouring [5].

This paper aims to describe a planning and communication protocol for functional maxillomandibular reconstruction optimized for oral cancer patients. It leverages in-house VSP and printing technology to minimize the time required and is relevant to three different reconstructive approaches: prefabrication/prelamination (Rohner/Alberta Reconstructive Technique), primary implant placement using the SM-ART (Sydney Modified Alberta Reconstructive Technique) method and digital planning without primary implant placement.

Methods

The protocol design described here was based on our experience of oral cancer cases (squamous cell carcinoma, sarcoma and salivary gland malignancy) where successful bony reconstruction with primary dental implant placement was performed. This technique has two significant components, planning and surgery. Although the same process is applied for maxilla or mandible reconstruction with any osseous flap (fibula/deep circumflex iliac artery/scapula free flap), for simplicity of discussion, we are describing the process of mandible reconstruction using the fibula free flap. The Rohner's technique is a two-step technique involving prefabrication of fibula flaps, where the first step is fabrication within the fibula bone and the second step is the resection with prefabricated fibula flap transfer [6].

The Alberta Reconstructive Technique (ART) involves occlusion-driven and digitally based jaw reconstruction where there is virtual surgical planning performed for immediate osseointegrated implant placement and subsequent loading after around six months [7]. Individual institutions have different practices regarding responsibility for various aspects of the surgery and planning. We define the specific roles of each clinician as follows: the ablative surgeon, the reconstructive surgeon, the implant surgeon, the prosthodontist and the digital design engineer. The workflow is as shown in (Figure 1), while the timelines are shown in (Figure 2).

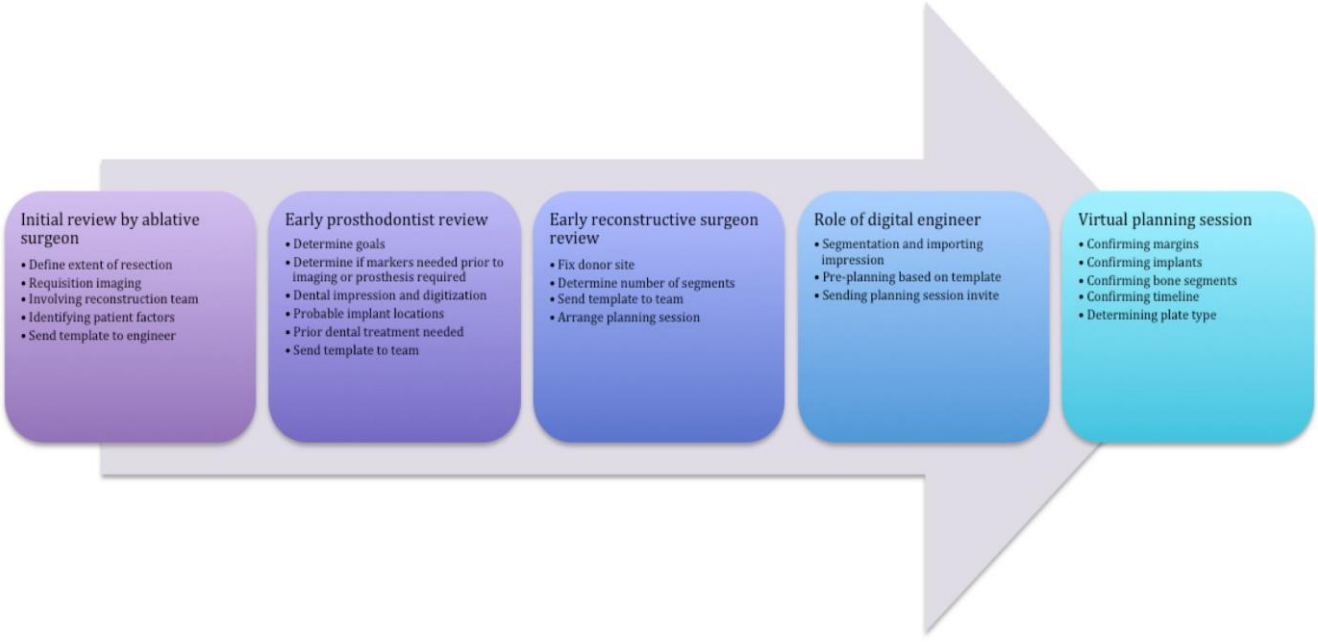

Figure 1: Virtual surgical planning overview.

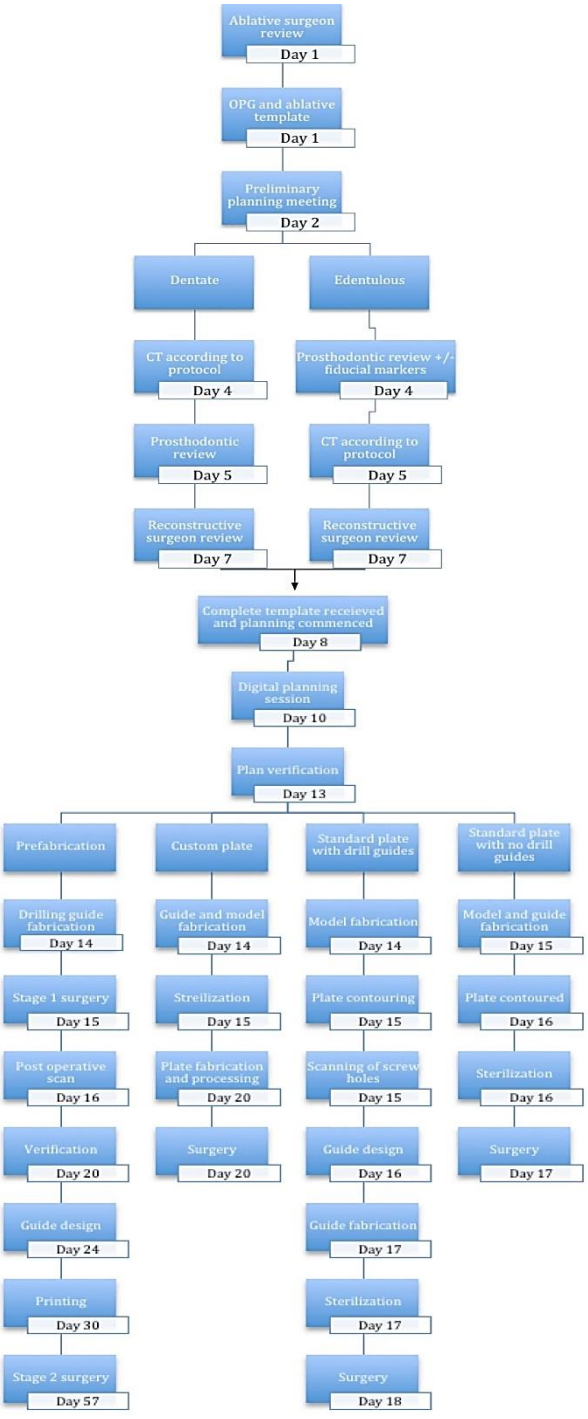

Figure 2: Virtual surgical planning workflow showing the estimated time required from initial evaluation of the patient to date of surgery.

Step I: Initial Review by Ablative Surgeon

i Defining the Extent of Resection

The ablative surgeon makes a clinical assessment of the extent of soft tissue and bony resection that will be required. The surgeon then decides if bony reconstruction is suitable for the patient.

ii Requisitioning Imaging as per Standard Protocol

Based on the initial evaluation and preliminary discussion with the patient, once the ablative surgeon decides that the patient is a candidate for bony reconstruction, they order imaging as per the standard protocol. All the potential donor sites are imaged. High-resolution computerized tomography (CT) of the patient's maxilla, mandible, and fibulae are acquired with fine slice thickness (minimum 1 mm). CT angiography of both lower limbs is performed to ensure that fibula can be safely harvested and to identify perforator location for the skin paddle. Based on these images, the 3D reconstruction of the maxilla, mandible and the potential donor sites are generated.

iii Early Involvement of the Reconstructive Surgeon and Prosthodontist

When a patient is identified as a candidate for bony reconstruction with dental rehabilitation, the reconstructive surgeon and prosthodontist are informed immediately without delay.

iv Identifying Factors that can Alter Treatment Outcome and Determining Patient Preferences

During the initial consultation, the ablative surgeon must consider if adjuvant radiotherapy may be required. Extensive disease requiring radiotherapy may warrant a simplified reconstructive plan to avoid delays in wound healing. A history of comorbid illness, especially peripheral vascular disease, is crucial. This allows a quick evaluation in the clinic that may alter reconstructive choice; for example, a patient with absent anterior and posterior tibial pulses is a poor choice for a fibula flap and a DCIA may be a more reliable choice. If the patient smokes, counselling to discontinue and access to cessation therapy is a must, as perioperative smoking is associated with higher flap complication rates and loss. History of previous trauma or surgery to a donor site can also preclude flap harvest from the area. If the patient has a preferred activity or sport, the donor site least likely to interfere with activities of daily living can be chosen.

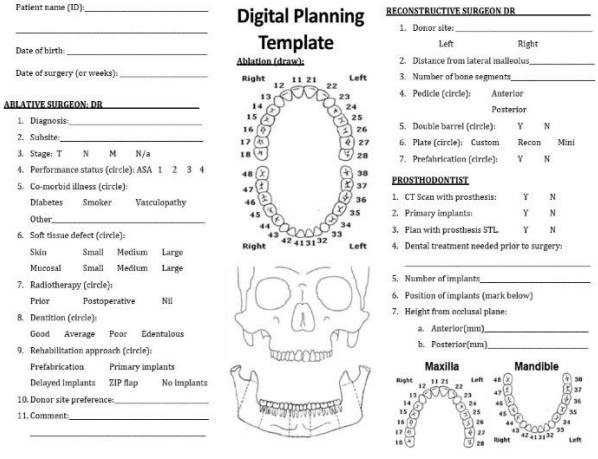

Figure 3: Virtual surgical planning template to be circulated amongst the surgical and rehabilitative team.

v Template Sent to Engineer

At the initial consultation, the extent of the bone and soft tissue excision will be marked on a template (Figure 3). This is forwarded to the design engineer, reconstructive surgeon and prosthodontist electronically. All team members are aware that modifications may be required following imaging review.

Step II: Early Prosthodontic Review

i Determining Realistic Goals Based on Patient Factors, Defect and Hygiene

The prosthodontist must now evaluate the patient and decide the most feasible dental rehabilitation plan for the patient. The prosthodontist meets the patient and can now discuss the goals and process of dental rehabilitation. Some patients are not desirous of dentition, especially if they have been edentulous for some time. For those seeking dental rehabilitation, the prosthodontist decides if the patient is a candidate for dental rehabilitation, and if so, if it should be implant-retained. Implant retained prosthesis requires multiple prosthodontics appointments and minor procedures; this renders it unsuitable for some patients. Regardless of the initial plan, the prosthodontist remains involved in digital planning to optimize bone position for implants to allow for plan changes after surgery.

ii Determining if Markers need to be Placed before Imaging

Edentulous patients may require markers to be placed prior to CT image acquisition. This ensures that there are landmarks for dental restoration and is particularly useful in edentulous patients.

iii Dental Impressions, Occlusal Records and Photographic Records are Taken and Digitized

Once the prosthodontist determines that the patient is suited to bony reconstruction and implant placement, patient's dental records are obtained. A diagnostic wax-up is carried out to ascertain the ideal teeth position. An intraoral or extraoral scanner is used to scan the plaster model and wax-up. The acquired images, in STL format, are exported and integrated with the remainder of the virtual plan.

iv Defines Probable Implant Locations on the Template

The number and position of implants are determined by the missing teeth and remnant bone and are marked on the template. This is important to allow the design engineer to start the planning process in advance of the team planning meeting.

v Sends Template to Team

The template is then shared with the team to allow for further planning.

Step III: Early Reconstructive Surgeon Review

i Examination and Confirmation of Probable Donor Site

Preoperative evaluation is important to confirm the donor flap selection. Choice of the left or right fibula is determined based on the donor site's clinical findings, orientation of the skin paddle, and pedicle length requirement.

ii Determining the Number of Bone Segments on the Template

During this initial review by the reconstructive surgeon, the number of bony segments required to span the defect is estimated and marked on the template.

iii Sends Template to Team

This reconstructive template is then shared with the design engineer.

iv Arrange Planning Session

Once the design engineer sees the three templates, they can commence a preliminary digital plan and set a time for the team planning session.

Step IV: Role of the Digital Engineer

i Segmentation of the Mandible and Fibula with Importing of the Digital Impression

Using high-resolution CT DICOM data, segmentation of the desired anatomical structure is performed by volume rendering, extraction of the chosen region of interest (ROI), crop volume, thresholding, region growing and a tessellated surface model is generated. The models can be edited using proprietary or open-source software.

ii Pre-planning the Resection, Reconstruction and Implants Guided by the Template

Combining the surgical margins as determined by the ablative surgeon; the choice of donor osseous flap determined by the reconstructive surgeon and the ideal teeth position determined by the prosthodontist; the design engineer begins the process of virtual surgical planning. For patients undergoing primary dental implant placement, a 'reverse' planning strategy is adopted, wherein the occlusal plane and the number of dental implants required for rehabilitation are determined first. Based on the optimal implant positions, the position of the fibula segments can be planned. This can be done using a multi-interface slicing programme, which helps precise positioning and angulation of the osteotomy segments.

iii Sending the Invitation for the Virtual Planning Session

Once the design engineer completes segmentation and preliminary planning, a virtual meeting with the surgeons and prosthodontists is held.

Step V: Virtual Planning Session

i Confirming of the Resection Margins

By the time the virtual planning session is underway, the ablative surgeon is expected to have studied the scans in detail and confirm the margins and extent of bony and soft tissue loss with certainty.

ii Confirming the Implant placement

The prosthodontist confirms the position of the implants in the virtual plan. In dental rehabilitation, this forms the central focus of planning; hence, the implants' angulation and spacing needs to be fine-tuned. Additional considerations, including spacing between implants, the number of implants within a bony segment and the potential for implants and the fixation screws collision, require special attention and are discussed.

iii Confirming the Bony Segments in Reconstruction

Similarly, the reconstructive surgeon is expected to have reviewed the angiography and imaging and decided on their choice of the donor site. If a significant deviation from the previously submitted template is required, the design engineer requires notification prior to the virtual planning session. Timely communication allows for a virtual comparison of two potential donor sites and other considerations during the virtual planning session. In general, we avoid segments shorter than 1.5 cm due to concerns about vascularity.

iv Confirming the Timelines

The time required for various reconstructive approaches is summarized in (Figure 3). The timelines may vary further depending on the need for adjustments in the plan, time taken for approval, models required, type of fixation plate (e) and complexity of the plan. To achieve a complete digital plan within a timeframe, suitable for a patient with malignancy, the process must be highly efficient with minimal unnecessary delays.

v Decision on Custom Versus Standard Plate

The team now decides if a custom or standard plate will be used. A traditional reconstruction plate is more cost and time-effective. However, a custom plate is preferred for complex reconstructions and provides a more precise replication of the digital plan.

A Custom Plate

a Verification of Plan

The plan is shared with the team and all the members have a working day to review and finalize it.

b Printing of Surgical and Implant Guides

The purpose of the 3D printed models is to help visualize and review the plan before the surgical procedure. The reconstructed lower alveolus model is used to plan the relation of the proposed dental prosthesis to the model of the maxillary dentition. If the reconstructed alveolus or denture positions are unsatisfactory, the plan is adjusted. After the surgeons and prosthodontist are satisfied with the 3D printed model, the surgical guides can be designed. The guides allow accurate positioning and angulation of the bone cuts in the maxilla/mandible and fibula and precise positioning of the dental implants. These guides are 3D printed with dental model resin, which allows a good level of detail and sterilization. The time required for the fibula cutting guide design, 3D printing and post-processing varies with size and the number of osteotomies; 1-2 segments, 3 segments and 4 segments require 1.5, 2 and 3 days respectively.

c Print/Mill Plate/Processing

The custom plate is now printed or milled, depending on whether a plastic or metal reconstruction plate is used. A custom plate allows for the development of drilling guides for the placement of screws, ensuring a very precise implementation of the surgical plan.

d Sterilization

The surgical guides and plate require sterilization before surgery; hence they are to reach the Central Sterile Services Department by at least the afternoon before surgery.

e Surgery

The advantage of meticulous planning is that it dramatically reduces intraoperative time and facilitates a smooth workflow. Potential sources of difficulty like inadequate pedicle length and malpositioning of the dental implants in relation to the reconstruction plate screws can be avoided.

- Raising the flap: The fibula flap is raised in the usual fashion. After the superior and inferior osteotomies, to release the fibula bone, the cutting guide is placed on the fibula to guide the position of the osteotomies. The cutting guide ensures that the length of the osteotomized segments and angulation of the osteotomies align with the surgical plan. It also allows for drilling of the plating surface to fix the positions of the screw for the reconstruction plate.
- Ablation of the mandible: After adequate soft tissue exposure, the cutting guides are applied to accurately osteotomies the mandible/maxilla and facilitate good alignment with the fibula segments. It also allows the surgeon to drill holes in the remnant mandible to pre-determine the position of the reconstruction plate screws and condylar position.
- Flap detachment, plating, inset and microvascular anastomosis: The fibula flap is detached and can be fixed with the customized reconstruction plate. This plate is placed within the defect and screwed are placed on the remnant bone for rigid fixation. The microvascular anastomosis is then performed to reperfuse the flap.
- Dental implant placement: The dental implants are now inserted into the vascularized fibula flap using the guides.
- Implant abutments are placed, and positions registered.
- Abutments are then covered with the flap skin paddle to be exposed later for denture placement.

B Standard Plate

a Verification of Plan

As above.

b Print Reconstructed Model and Guides

As above.

c Bend Plate to Model

Here, the reconstruction plate is adapted to the 3D printed neo-mandible the day before surgery to reduce intraoperative time. Once the adaptation of the plate is deemed satisfactory, it is sterilized.

d Sterilization

As above.

e Surgery

Is performed as is with custom prosthesis; however, drilling guides are usually not constructed for the placements of screws. If required, the adapted reconstruction plate must be screwed to the 3D printed neo-mandible in the desired position and scanned using the 3D scanner. This allows the holes in the reconstruction plate to be superimposed to create a drilling guide.

f Implant Management

As above

This protocol has been validated prospectively on a cohort of patients (n=4) to determine if the proposed timelines could be adhered to.

Results

I Clinical Outcomes

The protocol was derived based on our oral cancer patients' experience (n=17) who underwent ablation and reconstruction with primary dental implant placement (Table 1). The median follow-up was 30 (range 3-108) months. 13 patients underwent segmental mandibulectomy while 4 underwent maxillectomy, and all underwent reconstruction with the fibula free flap. There were no significant complications such as flap failure. 2 patients (12%) had plate exposure, which required minor secondary procedures to correct. Figures 4-7 showcases 17, 9, 13 and 12 (Table 1), which each represent a different case profile and approach.

Figure 4: Case 17, a central arch mandible carcinoma for which free fibula reconstruction was performed with primary implant placement **A)** virtual surgical plan **B)** reconstructed fibula within the pre-bent reconstructed plate **C)** final reconstructed neo-mandible with dental implants *in-situ*.

Figure 5: Case 9, a left mandible carcinoma with involvement of the overlying skin for which free fibula flap reconstruction with primary implant placement with radial forearm free flap reconstruction for the external skin defect **A)** preoperative appearance **B)** tumor exposed completely intra-operatively **C)** free fibula flap with dental implants in the leg **D)** free fibula flap and radial forearm free flap *in-situ* **E)** final reconstructed appearance.

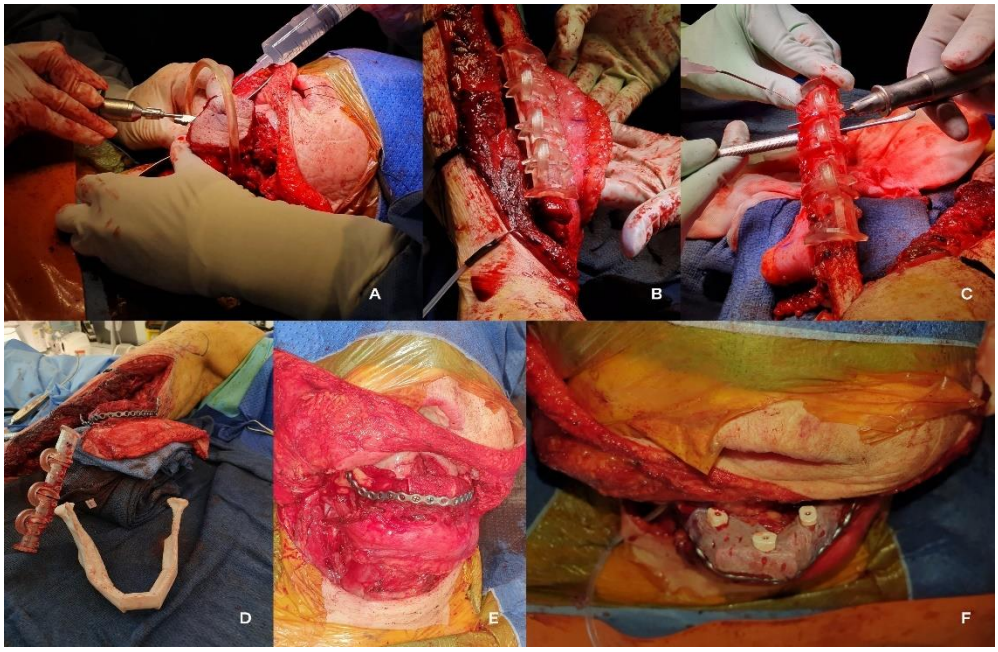

Figure 6: Case 13, a left mandible carcinoma with involvement of the overlying skin for which free fibula reconstruction was performed with primary implant placement **A)** intraoperative picture showing the cutting guides for the tumor **B)** fibula free flap with cutting guides in place **C)** osteotomies being performed with the guide **D)** printed 3D model of the reconstructed neo-mandible **E)** reconstructed neo-mandible *in-situ* **F)** final appearance of the neomandible with the implants *in-situ*, with a split skin graft which will form the neo-gingiva.

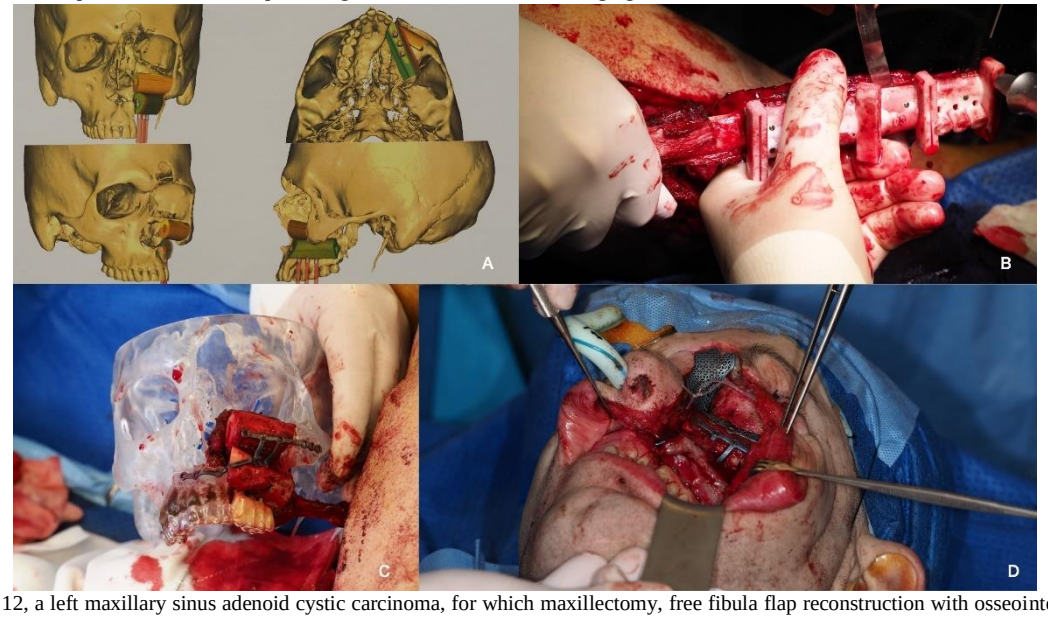

Figure 7: Case 12, a left maxillary sinus adenoid cystic carcinoma, for which maxillectomy, free fibula flap reconstruction with osseointegrated implants (Rohner's procedure) and titanium orbital mesh placement was performed **A)** the virtual surgical plan showing the reconstruction plan **B)** fibula free flap with the cutting guide *in-situ* **C)** the 3D printed model with the fibula free flap and custom plate showing an accurate reproduction of the virtual surgical plan prior to implantation **D)** reconstructed image showing the flap with loaded dental implants and titanium mesh *in-situ*.

Table 1: Clinical and treatment characteristics of cohort.

S. No.	Age	Gender	Surgical defect	Free flap used	Complications	Period of follow-up
1	69	M	Right segmental mandibulectomy	Right fibula free flap	No	9 months
2	47	F	Central arch mandibulectomy	Right fibula flap	No	12 months
3	78	M	Central arch mandible	Right fibula flap	No	30 months
4	40	M	Right segmental mandibulectomy	Left fibula flap	No	84 months
5	69	F	Right segmental mandibulectomy	Right fibula flap	No	48 months
6	64	F	Left maxillectomy	Left fibula free flap	No	48 months

7	77	M	Right segmental mandibulectomy	Right fibula flap	No	36 months
8	56	F	Central arch mandibulectomy	Right fibula free flap	No	36 months
9	52	F	Left segmental mandibulectomy	Left fibula free flap	No	60 months
10	51	M	Pre-maxilla	Right fibula free flap	No	24 months
11	45	M	Left segmental mandibulectomy	Left fibula free flap	No	30 months
12	51	M	Left maxilla	Right fibula free flap	Plate exposure	12 months
13	81	M	Left segmental mandibulectomy	Left fibula free flap	No	8 months
14	73	F	Central arch mandibulectomy	Right fibula flap	No	15 months
15	56	F	Pre-maxilla	Left fibula free flap	No	108 months
16	58	M	Central arch mandibulectomy	Right fibula free flap	Plate exposure	6 months
17	61	M	Central arch mandibulectomy	Right fibula free flap	No	3 months

II Validation of the Protocol

To prospectively validate our protocol's timelines, we applied it to a distinct cohort of patients undergoing ablation and bony reconstruction with primary dental implant placement (n=4). These cases represented one from each case type shown in (Figure 2). Planning for all these cases was completed within the described timeframe (range 14-57 days).

Discussion

Bony reconstruction of the craniofacial skeleton following ablation for malignancy is an integral part of restoring quality of life. However, in the absence of dental restoration, functional reconstruction is incomplete. Virtual surgical planning plays a vital role in restoring occlusion, which is otherwise difficult to achieve, especially in complex defects [8]. Many patients with oral malignancy do not receive primary dental implant placement for reasons enumerated previously. The purpose of this study was to demonstrate that routine dental implant placement and reconstruction is feasible and can be achieved successfully in the context of oral malignancy, and not just benign disease. All patients underwent successful primary dental implant placement with no major complications and good functional outcomes in our cohort.

Our protocol's major advantage is that it is robust yet flexible and allows for variations in technique, such as the use of standard reconstruction or customized plates. It adopts early and streamlined communication between team members, to facilitate parallel working of the team, saving time compared with traditional, serial workflows. This model is well suited to a unit where complete 'in-house' virtual surgical planning is available. Another major benefit of using such 'in-house' VSP and printing is to reduce costs compared to outsourcing to commercial products [9]. VSP allows for more complex reconstruction with shorter surgical durations and hospital stay, even when prices are comparable with those without virtual surgical planning as part of their surgical plan [10]. For other institutions to adopt this protocol, modifications may be required to reflect their logistics and systems.

Our protocol showed that it is possible to predictably operate within 18 days of first evaluating the oral cancer patient, using a concurrent workflow pattern and in-house VSP. Reconstruction is achieved in a time frame we believe is reasonable and within which significant disease progression is unlikely. Patients with low-grade or less aggressive disease may be candidates for more elaborate and time-demanding plans, such as using custom plates or Rohner's procedure [6]. Future refinements in design and fabrication may further reduce the time required for virtual surgical planning.

Conclusion

Bony reconstruction with primary dental implant placement in the context of oral cancer can be performed successfully with good functional outcomes. By adopting this protocol, virtual surgical planning can be performed efficiently, avoiding potentially costly delays in treatment.

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None.

Conflicts of Interest

None.

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