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Virtual Surgical Planning in Subscapular System Free Flap Reconstruction of Midface Defects

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ABSTRACT

Objectives: Reconstruction of the midface has many inherent challenges, including orbital support, skull base reconstruction, optimizing midface projection, separation of the nasal cavity and dental rehabilitation. Subscapular system free flaps (SF) have sufficient bone stock to support complex reconstruction and the option of separate soft tissue components. This study analyzes the effect of virtual surgical planning (VSP) in SF for midface on subsite reconstruction, bone segment contact and anatomic position.

Materials and Methods: Retrospective cohort of patients with midface defects that underwent SF reconstruction at a single tertiary care institution.

Results: Nine cases with VSP were compared to fourteen cases without VSP. VSP was associated with a higher number of successfully reconstructed subunits (5.9 vs 4.2, 95% CI of mean difference 0.31–3.04, $p = 0.018$), a higher number of successful bony contact between segments (2.2 vs 1.4, 95% CI of mean difference 0.0–1.6, $p = 0.050$), and a higher percent of segments in anatomic position (100% vs 71%, 95% CI of mean difference 2–55%, $p = 0.035$). When postoperative bone position after VSP reconstruction was compared to preoperative scans, the difference in anteroposterior, vertical and lateral projection compared to the preoperative 'ideal' bone position was < 1 cm in 82% of measurements. There were no flap losses.

Conclusion: VSP may augment SF reconstruction of the midface by allowing for improved subunit reconstruction, bony segment contact and anatomically correct bone segment positioning. VSP can be a useful adjunct for complex midface reconstruction and the benefits should be weighed against cost.

Introduction

Bony reconstruction of the midface with free tissue transfer is complex and challenging due to structural considerations such as the need for orbital support, patency of the nasal cavity, restoration of the palate and alveolus and skull base support when needed. As a result, it is not uncommon for patients to experience diplopia, hypoglobus and enophthalmos postoperatively. Orocutaneous and nasocutaneous fistulae and hardware infection due to communication with the oral cavity or sinuses are also common in the chronic setting [1]. Finally, cosmetic deformities from inadequate projection is also a concern [2]. Cosmetic and functional outcomes are improved with bony reconstruction as it is able to provide rigid support of key structures, restoration of contour, affords the possibility of dental rehabilitation and is less likely to contract significantly following radiation treatment [3].

Subscapular system free flaps (SF) are uniquely suited to address the needs of midface reconstruction. A substantial amount of bone can be harvested from the lateral scapular border and scapular tip, each with different shapes and thicknesses [4]. Chimeric flaps can be harvested in various combinations, adding parascapular and scapular skin paddles, latissimus muscle (with or without skin), serratus muscle and rib. Additionally, due to the vascular organization of this network, these components can be harvested off separate pedicles, offering great flexibility and freedom of movement relative to each other [5].

The utilization of virtual surgical planning (VSP) is increasing in

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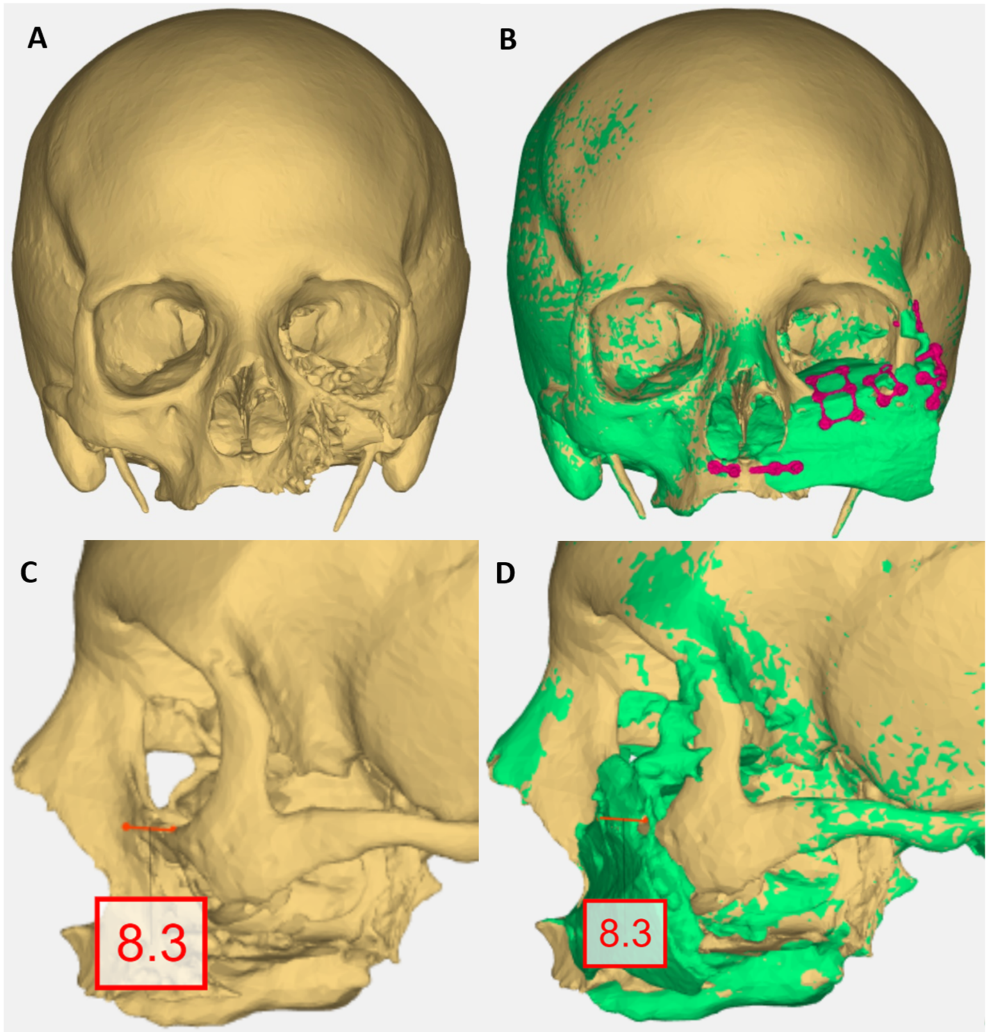

Fig. 1. An example of postoperative projection measurements in an 85-year-old woman with an adenoid cystic carcinoma of her maxillary sinus. The preoperative scan (tan) is shown in panel A, and the postoperative scan (green) is overlaid on the preoperative scan in panel B. A measurement can be taken from the preoperative to the postoperative scan, in this case the anteroposterior measurement (C and D). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

head and neck reconstruction, and is most commonly implemented for reconstruction of mandibular defects and in orthognathic surgery to plan maxillomandibular adjustments [6–8]. VSP allows reconstructive surgeons to conceptualize complex defects and better anticipate the specific reconstructive needs of each patient. The additional cost of VSP may be offset by increased precision as measured by rates of bony union and shorter operative times [9,10], which may decrease length of stay and overall cost of hospitalization [11]. With the anatomic challenges of midface reconstruction and the afforded complexity of the SF, both would appear to be ideal candidates for perioperative VSP. However, there is scant literature describing the use of VSP for SF, VSP for midface reconstruction, and few large series of SF midface reconstruction overall. This work describes a series of midface defects reconstructed with SF, compares the reconstructive complexity and success between patients with and without VSP, and details some of the nuanced challenges in which VSP was useful.

Materials and methods

Patient selection

Institutional board review was obtained from the Thomas Jefferson University Hospitals Office of Human Research. A retrospective review of a prospectively maintained database of free flap patients performed at a single tertiary-care institution between 2015 and 2019 was queried. Patients were included for analysis if they received a free flap of the subscapular system that included bone, and if the defect involved total maxillectomy, partial maxillectomy or orbital rim. Twenty-three patients met inclusion criteria. Reconstructive complexity was determined based on the Brown and Cordeiro defect classification systems [12,13], on the number of subunits resected, number of separate bone segments and number of bony appositions.

Virtual surgical planning

Nine patients underwent VSP prior to their procedure. The three major commercial options (Stryker/3D System, Rock Hill, SC; Synthes/ Materialise, Leuven, Belgium; and KLS Martin, Jacksonville, FL) were all utilized in this series (although only one system and plan were used for each patient). VSP consisted of: a surgical planning session, cutting guides, models and in some cases custom plate production. Three dimensional virtual models were reviewed by the reconstructive surgeon and used to plan the size and shape of scapular bone cuts. In all patients, surgical cutting guides were supplied and used during for the scapula harvest. In three patients, customized plates were also used. The operative steps to harvest SF were performed in standard fashion [14].

Subsite reconstruction analysis

Postoperative imaging scans, 3-dimensional reconstructions and operative notes were reviewed by three of the authors (BS, RG, JC) to determine which subsites were resected and which were reconstructed. The following were considered independent subsites: the zygomaticomaxillary complex, zygomatic arch, orbital roof/anterior cranial base, frontal bar, lateral orbital rim, orbital floor, inferior orbital rim, nasal bones, hard palate, alveolar ridge, nasomaxillary buttress and zygomaticomaxillary buttress. A subunit was considered resected if at least 25% of the subunit was removed, or in the case of the buttresses, if continuity was interrupted. A subunit was considered reconstructed if bone harvested from the scapula was used to recreate that subsite.

Bone segment contact and anatomic position

Postoperative imaging scans and 3-dimensional reconstructions were reviewed for evidence of bony apposition of the scapula segments to the native bone and to each other. A segment was considered to have appropriate apposition only if the segments were in direct contact with one another. Any space between the ends of bone segments resulted in being counted as noncontact. Images were also reviewed to determine whether the scapula segments were set into positions that mirrored the normal bony anatomy. All appositions and segments were scored independently.

Postoperative projection symmetry

Preoperative and postoperative imaging was uploaded to DePuy Synthes ProPlan TruView Post Op Analysis Application (Leuven, Belgium). This program allowed simultaneous viewing of the pre- and postoperative imaging with overlay graphics, and measurements could be performed to determine the distance by which the reconstructed bone deviated from the preoperative normal bone. This was measured in 3 dimensions, anteroposterior (AP), lateral and vertical. The measured positions were standardized whenever possible (Fig. 1). For patients in whom a defect was present prior to ablative surgery, a mirror image of the normal side of the preoperative scan was used for comparison and measurements.

Symptoms and quality of life survey

Postoperative shoulder dysfunction was measured with administration of the 11-point Quick-DASH (Disabilities of the Arm, Shoulder and Hand) Outcome Measure, a validated tool used extensively in orthopedic practice [15]. Quality of life was measured with the FACT Head and Neck Symptoms Index (FHNSI), which measures common patient symptoms and has been used in many head and neck studies [16]. The surveys were administered during routine postoperative visits.

Results

Comparison of VSP and non-VSP patients

Twenty-three patients underwent scapula reconstruction for midface defects. VSP was utilized in 9 cases. The patient, tumor, and flap characteristics are shown in Table 1. The median patient age was 67 (range 22–88) and 57% were male. There was an even distribution of Brown and Cordeiro defect classification between the VSP and non-VSP groups.

Subunit resection and reconstruction

Various factors identified as surrogates of case complexity and reconstructive success were compared between the VSP and non-VSP groups and are summarized in Table 2. A comparable number of separate subunits were resected as part of the ablation in both the VSP and non-VSP groups (mean of 6.0 subunits vs 5.7 subunits, p = 0.74). Reconstruction was able to restore a mean of 5.9 subunits in the VSP group compared to 4.2 in the non-VSP group (Mean difference 1.9, 95% CI 0.31–3.04, p = 0.018). Similarly, the percentage of subunits restored with VSP was 98% vs 78% in the non-VSP group (Mean difference 21%, 95% CI 6–35, p = 0.007).

Table 1
Patient, Tumor, and Flap Characteristics.

Perioperative Characteristic	VSP Group		Non-VSP Group	
	n	% of Cohort	n	% of Cohort
All Patients	9	39	14	61
Female Patients	3	33	7	50
Malignant Pathology	7	77	14	100
Brown Defect Classification				
I	0	0	0	0
II	2	22	2	14
III	2	22	4	29
IV	1	11	2	14
V	4	44	6	43
VI	0	0	0	0
Cordeiro Defect Classification				
1	0	0	0	0
2	2	22	2	14
3a	2	22	4	29
3b	3	33	3	21
4	2	22	5	36
Scapula Components				
Scapular Tip	5	55	5	36
Lateral Border	1	11	7	50
Scapular Tip + Lateral Border	3	33	2	14

Anatomic position of bone

A comparable number of separate bone segments were used in the reconstruction of both the VSP and non-VSP groups (mean of 1.8 segments vs 1.4 segments, p = 0.23). However, more of the segments were determined to be in anatomic position in the VSP group compared to the non-VSP group (mean 1.8 segments vs 1.0 segments, mean difference 0.78, 95% CI 0.18–1.38, p = 0.013). Similarly, a larger percentage of segments were placed in anatomic position in the VSP group (100% vs 71%. mean difference 28%, 95% CI 2–55, p = 0.035).

Bone segment apposition

The overall number of appositions between free flap bone segments and native bone was comparable between the VSP and non-VSP groups (mean 3.1 vs 2.6 appositions, p = 0.30). The number of appositions in which the bone segments achieved contact was higher in the VSP group compared to the non-VSP group (mean 2.2 vs 1.4 appositions, mean difference 0.8, 95% CI 0.0–1.6, p = 0.05). The overall percentage of bone segments did not show a significant difference (mean 67% for VSP, 55% for non-VSP, p = 0.35).

Postoperative projection symmetry

Postoperative bony AP, lateral and vertical projection was compared to preoperative bony position in the VSP patients, as shown by example in Fig. 1. Seventeen measurements were taken in six patients. The mean absolute value of the difference from expected position was found to be 7.2 mm. A majority of the measurements (82%) showed postoperative deviation of less than 1 cm compared to the preoperative ‘ideal’ position of the bone.

Table 2
The impact of VSP on measures of reconstructive complexity and success. Significant P values bolded.

Metric	VSP Group	Non-VSP	95% CI of Mean Difference	P - Value
Number of Subunits Resected	6.0	5.7	−1.5 to 2.0	0.74
Number of Subunits Reconstructed	5.9	4.1	0.31–3.04	**0.018**
Total Number of Segments Implanted	1.8	1.4	−0.23 to 0.93	0.23
Number of Segments in Anatomic Position	1.8	1.0	0.18–1.4	**0.013**
Percent of Segments in Anatomic Position	100%	71%	2–55	**0.035**
Total Number of Appositions	3.1	2.6	−0.51 to 1.6	0.30
Number of Appositions with Bony Contact	2.2	1.4	0.0–1.6	**0.05**
Percent of Appositions with Bony Contact	70%	60%	−21 to 42	0.49

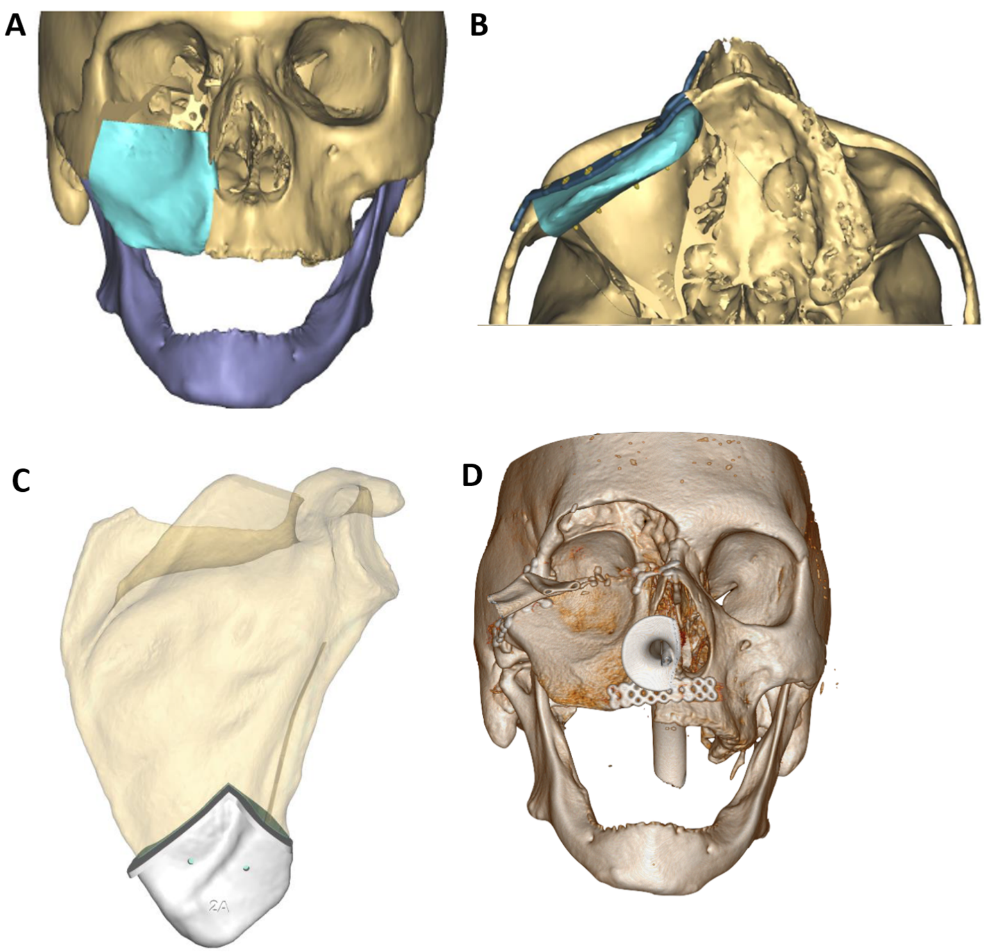

Fig. 2. Right scapula to maxilla in a 67-year-old male with maxillary sinus squamous cell carcinoma. Surgical plan in panels A and B calls for use of scapular tip for reconstruction of the alveolus and anterior wall of the maxilla. In panel C, an earlier 'positive cutting guide' design. Fixation of cutting guide to scapula is difficult without disturbing the muscular attachments over the bone to be harvested. Ex vivo the scapula tip was flipped such that the subscapularis surface (anterior side of scapula) became the anterior face of the maxilla (D).

Notable similarities

Other variables were compared and found to not significantly differ between the VSP and non-VSP groups. This included overall operative time (12.3 h vs 12.6 h, p = 0.70) and ischemia time (2.5 h vs 2.4 h, p = 0.66). Shoulder dysfunction as measured by the DASH score was comparable (Total score 14.4 for VSP vs 17.1 for non-VSP, p = 0.24), with a similar amount of scapular bone harvested in both groups (harvested surface area 24.3 cm^2 for VSP vs 21.9 cm^2 for non-VSP, p = 0.56). Quality of life as measured by the FHNSI-10 survey was comparable between groups (Total score 16.6 for VSP vs 14.9 for non-VSP, p = 0.59). There were no flap failures in either group during the follow-up period.

Discussion

The midface is a complex anatomic area, making ideal reconstruction challenging. Suboptimal reconstruction may result in poor orbital and oral function as well as cosmetic deformity and risks fistula or hardware infection. The subscapular system is well-suited for midface reconstruction, as numerous separate components can be harvested and tailored for different purposes. Despite these advantages, midface reconstruction remains extremely challenging.

VSP has been used in the head and neck, most commonly in the setting of fibula free flap reconstruction of mandibular defects. This study reports one of the first series of the use of VSP in scapular free flap reconstruction in the midface and is the only series to compare patients with and without VSP in this setting. Despite equal distribution of

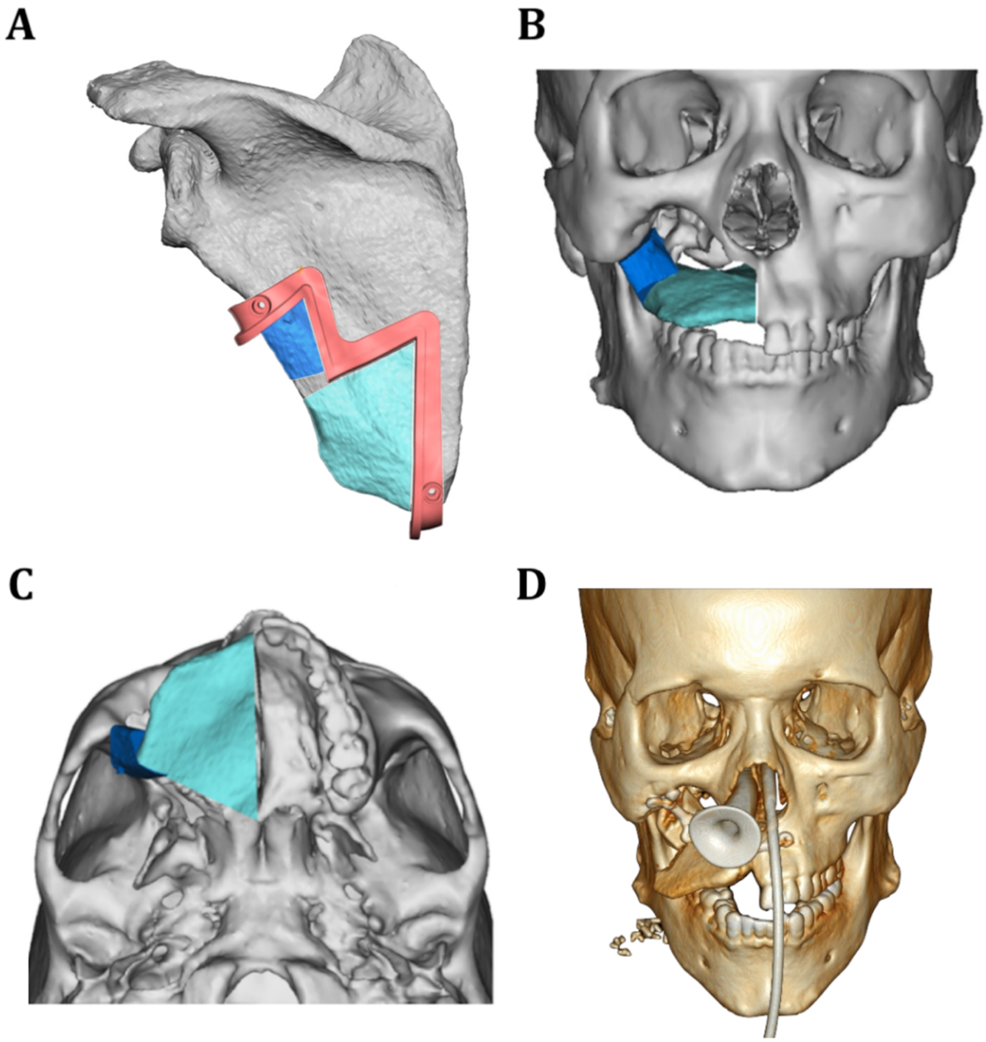

Fig. 3. Left scapula to right hard palate for adenoid cystic carcinoma. A negative cutting guide was used and fixated to the scapular tip (panel A). With this modification the teres major and infraspinatus muscle can be elevated off the scapula bone that will ***not*** be harvested with the flap. Preoperative planning for horizontal inset of scapula tip for right hard palatal defect (B and C). Postoperative 3D reconstruction of horizontal inset of scapula tip show in panel D.

defects based on Brown and Cordeiro classification schemes [12,13], the use of VSP was associated with reconstruction of both a higher overall number and a higher percentage of subunits. By visualizing the defect and rotating it in three dimensions preoperatively, the surgeon may plan more complex reconstructions, incorporating different portions of the subscapular system in the form of a chimeric flap.

VSP was also associated with a higher proportion of bone segment contact at the appositions. The scapula is covered in soft tissue, and the underlying bone has varying shape and thickness, making it difficult to judge where to make the optimal cuts. The cuts suggested by VSP resulted in bone contact in a high percentage of cases. Whether this increase in bony contact is clinically significant or results in higher rates of complete union could not be evaluated in this study as most of the scans were performed in the immediate perioperative period; nevertheless prior studies have shown that close bony apposition correlates with higher rates of bony union [17]. Further this allows for preplanned cuts on the scapula to design a wide array of accurate fitting bony fragments.

We report a novel mechanism to assess success of free flap reconstruction, by measuring the AP, lateral and vertical distance between the reconstructed bone from the position of the bone on the preoperative scan, or a mirror image of the preoperative scan for secondary reconstructions. VSP was associated with less than 1 cm deviation in 82% of measurements. Exactly how much deviation from normal bony anatomy is cosmetically acceptable has not been determined, and this does not account for the overlying soft tissue. However, such a small deviation seems remarkable given the complex nature of the area and the reconstructive goals.

We would also like to comment on some reconstructive problems we encountered that have VSP-based solutions, including the design of VSP cutting guides, hard palate reconstruction, dental rehabilitation and secondary reconstruction.

Technical aspects of cutting guides

The standard cutting guide used in fibula free flap reconstruction is a 'positive cutting guide' that is shaped like the bone to be harvested, is secured to the fibula bone, and provides spaces for the introduction of a saw to divide the bone at the appropriate angle. This model was initially used and is shown in Fig. 2. The scapular bone has many muscle attachments, which are important for bone viability, complicating fixation of the cutting guides. The development of a 'negative cutting guide' allowed for fixation to the portion of the scapula that will not be harvested. An example of this is shown in Fig. 3. The muscles can be elevated back to allow for placement of the guides with preservation of portions of infraspinatus and teres major when desired. If the muscles are divided, the remnants can be resuspended. Guide design can follow the amount of bone needed for the flap and smaller guides can allow for

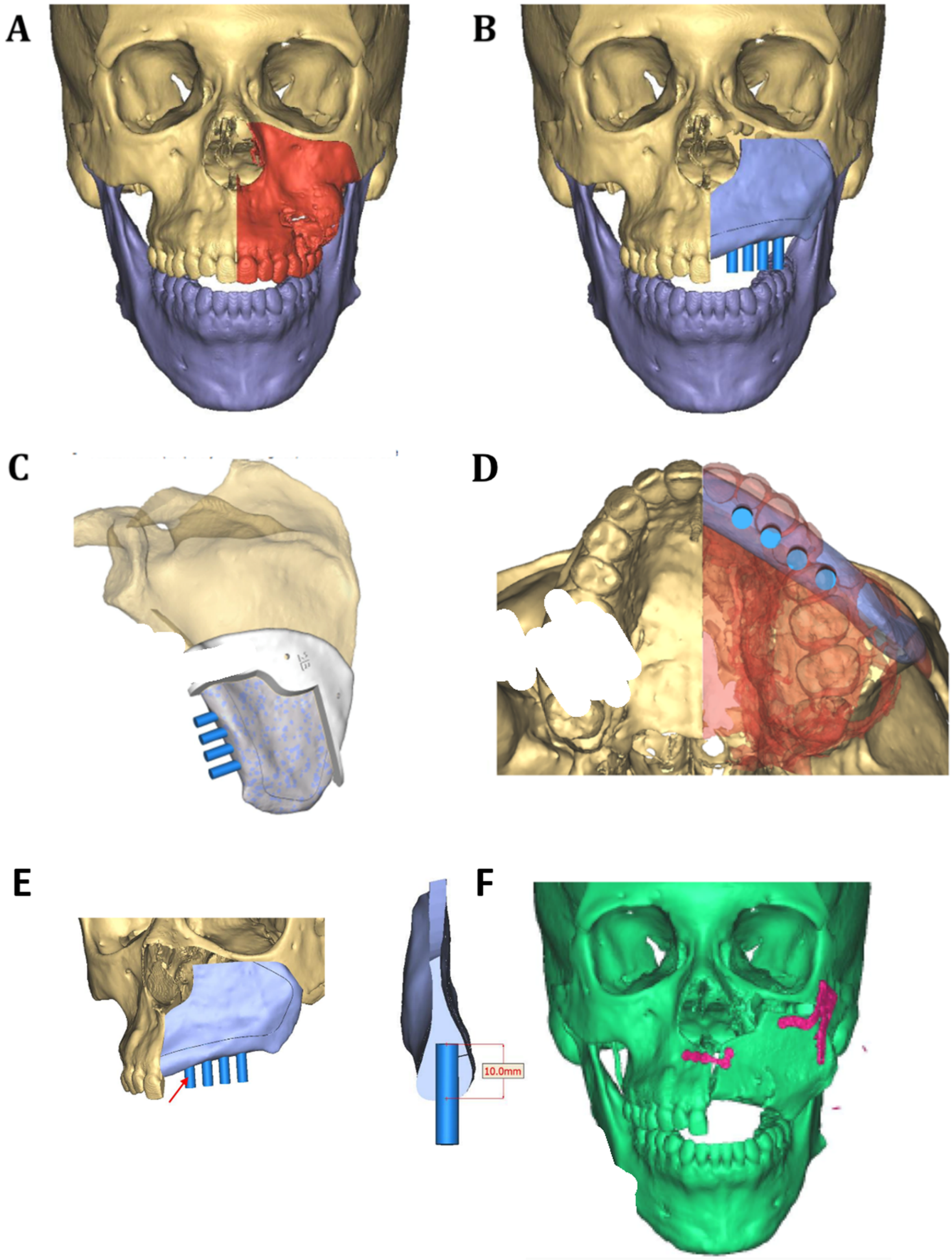

Fig. 4. Left scapula to left maxilla for ameloblastoma in 35-year-old woman. Expected bone defect shown in panel A. The surgical plan called for using scapula tip for reconstruction of alveolus and anterior wall of maxilla (B). Negative cutting guide was used to fixate to the scapula tip (C). D and E show orientation of planned dental implants, which were placed in the scapula during the harvest. Postoperative result shown in F.

less disruption. We have also modified our approach in some cases to preserve the entire latissimus muscle with intact innervation by approaching scapula dissection from both the medial and lateral of the muscle in an effort to improve shoulder function. In general, DASH scores tend to normalize approximately 6 months postoperatively. Additionally, when making pilot holes while using positive cutting guides, it is difficult to locate drilled holes with a screw as a result of pilot hole visualization being obstructed by the soft tissue. Self-drilling/self-tapping screws can help avert this problem, however they are generally not manufactured long enough to pass through the thick muscle over the scapula. A 3–5 mm “offset” between the cutting guide and the bone was utilized and incorporated into scapula cutting guide designs to approximate the bulk of muscle [18]. Use of the negative cutting guide and elevating the muscle out of the way also allows for the use of the shorter self-drilling/self-tapping screws.

Palate reconstruction

The scapular tip is similar in size and shape to the hard palate and anterior wall of the maxilla [19–21]. Therefore, the scapula tip can be oriented in either a horizontal position to recreate the hard palate, or a vertical position to recreate the anterior maxilla and alveolar ridge. When placing the scapula in a vertical position, the oronasal/oroantral fistula can still be closed by obliteration of the maxillary sinus using the soft tissues of the flap. For extensive defects involving the orbital rim and/or zygoma, “mega-flaps” with various different bone and muscle components can accomplish the reconstructive goals, and the vertical orientation is superior (Figs. 2 and 4) [4]. The vertical orientation is

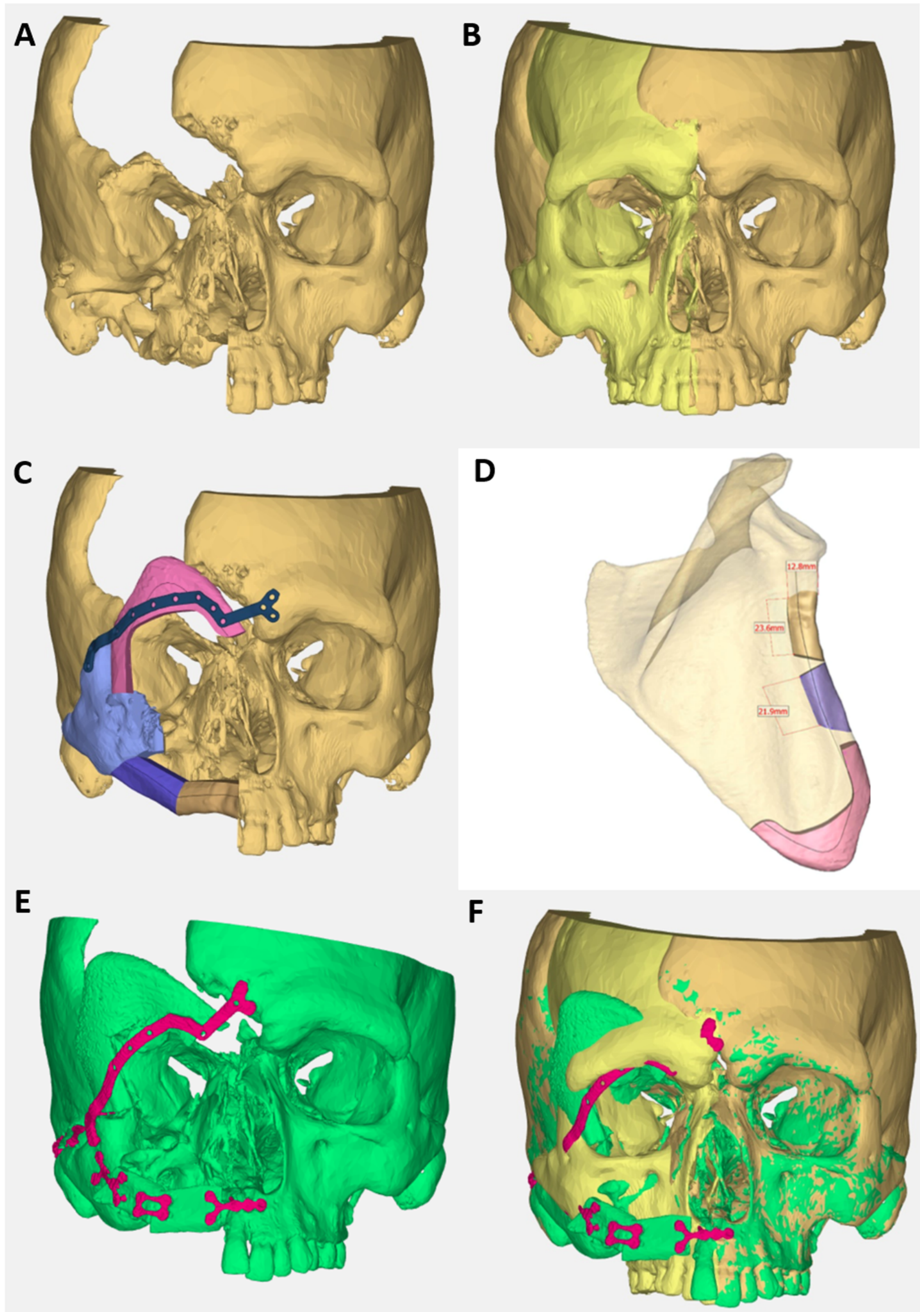

Fig. 5. Right scapula to right face for reconstruction after self-inflicted gunshot wound. Preoperative defect is shown in panel A. A mirror image of the more normal left side was used to plan the reconstruction (B). Surgical plan (C) showing reconstruction of orbital rim and zygomatic arch. Subscapular system components included lateral border of scapula (circumflex scapular) and scapular tip (angular) in addition to latissimus muscle (thoracodorsal) as chimeric flap all harvested on the subscapular artery and vein (D). Postoperative result shown in E, with excellent fidelity to preoperative mirror image scan in F.

also superior for dental implantation [22]. For infrastructure maxillectomy defects, the horizontal orientation is preferred (Fig. 3). However, plating across the premaxilla only will cause inferior displacement of the scapula posteriorly near the soft palate. This can be prevented with an additional plate to the oral surface of the posterior hard palate, which will mucosalize over time.

Dental rehabilitation

Dental implantation and rehabilitation increases the quality of life of head and neck cancer patients [23]. Over the past two decades there have been increasing trends to reconstruct midface defects with free flaps rather than to use obturators [24]. Dental implantation into scapula free flaps is well-documented, with reports of success rates as high as 97.6%, which is comparable to its success in fibula free flaps [25,26]. Historically, dental implantations into scapula free flaps has been done as a secondary procedure, due to concerns over pedicle position and soft tissue manipulation [22]. There are several advantages to immediate placement of dental implants, including ease of placement outside the confines of the oral cavity and no need for stripping of the periosteum. In addition, survival of dental implants decreases if placed after radiation therapy [3]. In Fig. 4 we show a case of a patient with a benign ameloblastoma, where VSP was used to plan a scapular tip flap with primary dental implants. Three 4.3x10 mm Nobel (Danaher Corporation, Washington, D.C.) conical connection implants were placed while the flap was still vascularized in the back. To our knowledge, this

is the first case of immediate placement of dental implants into a scapula tip flap.

VSP for secondary reconstruction

In some cases, whether due to prior resection or trauma, there will be an absence of normal bony anatomy on the defect side available for plating. Obtaining acceptable projection in these situations can be challenging. VSP becomes extremely helpful for these reconstructions, as mirror images of the normal side can be used as a template upon which to base cutting decisions and the design of a custom plate to reach adjacent bone. As seen in Fig. 5, VSP allowed the surgeon to reconstruct the orbital rim and premaxilla in a patient who was missing both due to a prior gunshot injury. When compared to the contralateral normal bony anatomy, this reconstruction produced deviations of 3 mm of underprojection in the AP dimension at the anterior superior orbital rim, 3.3 mm of overprojection at the lateral rim, and 6 mm of underprojection at the superior rim.

Some surgeons hesitate that should the ablative surgery deviate from the original plan, the VSP loses value and represents wasted resources. We have still found the VSP and cutting guides to be extremely useful in this setting, as the cutting guide provides a general size and shape estimate that offers a frame of reference upon which modifications can be made. Making bony measurements “on the fly” on the scapula is more challenging than on the fibula because of the thick soft tissue covering, and thus is more prone to error.

There are some inherent limitations to this study. These procedures were performed by high-volume free flap surgeons at a tertiary care institution, and thus the conclusions may not be applicable in other settings. The determination of subsite resection, anatomic position and bone segment apposition are based on agreement between three of the authors, and while every effort was made to be consistent, there is some inherent bias in this process. Future studies could compile data across institutions to answer questions not addressed by this study, including the influence of VSP on overall hospitalization and operative costs, and long-term clinical outcomes.

Conclusions

This is the largest series of VSP for maxillary reconstruction using SF to date. This study suggests that VSP provides benefit for midface reconstruction with the SF as it correlates with improved bony apposition and successful reconstruction of more subunits. These outcomes translated to the more complex reconstructions as well, demonstrating the versatility of VSP.

Declaration of Competing Interest

None declared for all authors

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