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Reconstructive

Anatomical Landmark-guided Strategy for Computer-assisted Reconstruction of Infrastructure Maxillary Defects Using Free Fibula Flap

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Background: Computer-assisted surgery in head and neck reconstruction yields predictable and favorable clinical outcomes. However, there is a lack in the optimal arrangement of the fibula bone segments to re-establish the function and aesthetics of the maxilla.
Methods: This study proposed a novel anatomical landmark-guided strategy for the virtual surgical planning (VSP) of infrastructure maxilla reconstruction using a free fibula flap. The optimal positioning of fibula segments was validated with a retrospective clinical study. Patients who underwent computer-assisted infrastructure maxillectomy and reconstruction with a free fibula flap from May 2017 to April 2024 were reviewed. Reproducibility of the landmarks and associated clinical parameters was assessed in VSP compared with the preoperative maxilla. Additionally, a structured quantitative approach was adopted for postoperative surgical outcome analysis by comparison of the postoperative maxilla and the VSP.
Results: Twenty patients fulfilled the criteria of this study. In 11 cases, we conformed to the proposed reconstruction strategy (group A). In 9 cases, we adopted a modified approach (group B) with deviations in the count of fibula segments and positioning strategy. In group A, the pooled median landmark error was 2.19 mm (interquartile range, 1.63–2.91 mm) in the VSP compared with the preoperative maxilla; in group B, the error was 4.54 mm (interquartile range, 2.05–6.15 mm). The clinical parameters demonstrated satisfactory recapture of the alveolar arch and maxillary width.
Conclusions: This anatomical landmark-guided strategy was validated with satisfactory reproducibility of the quantitative metrics in the VSP. The anatomical landmarks and associated clinical parameters provided a structured quantitative approach for postoperative analysis of computer-assisted maxillary reconstruction using FFFs. *(Plast Reconstr Surg Glob Open 2025;13:e6626; doi: 10.1097/GOX.0000000000006626; Published online 24 March 2025.)*

INTRODUCTION

The maxilla serves important functions in speech, mastication, swallowing, and aesthetics of the midface area. Previous literature classified maxilla defects based on distinct regions.[1–3] Infrastructure maxillary defects are the most common type of maxillary defect secondary to oncologic resection of oral cancers and are defined as defects inferior to the infraorbital foramen, primarily involving the alveolar arch and plate, with possible involvement of the nasal cavity, maxillary sinus, and zygomaticomaxillary buttress.[3,4]

The primary goals of reconstructing infrastructure maxillary defects include restoring the alveolar arch for proper occlusion function, recovering the oronasal and oroantral seals for swallowing and speech functions, and rebuilding the maxillary framework for aesthetic

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purposes. Common repair options include the use of prosthetic obturators, local and regional flaps, soft-tissue free flaps, and vascularized bone flaps.[5–13] Among the various choices of bone flaps, the free fibula flap (FFF) offers exceptional versatility in folding and positioning multiple osteotomized segments and abundance of osteomyocutaneous tissue, and allows for bicortical engagement of osseointegrated dental implants, making it a viable composite free flap in infrastructure maxillary defects, especially in cases with extensive palatomaxillary component.[1,14–18]

In FFF reconstruction, computer-assisted surgery (CAS) has demonstrated greater predictability and precision compared with freehand surgery.[19,20] CAS refers to the incorporation of computers in the preoperative, intraoperative, and/or postoperative phases of surgery. In the preoperative phase, virtual surgery planning (VSP) determines the arrangement of multiple bone segments that are designed to yield desirable functional and aesthetic outcomes.[21] However, the current VSP strategy relies predominantly on the surgeon's experience and preferences in incorporating multiple factors, including the original contour of the jawbones, the volume of tissue loss, the position of the dental arch, and so on. To reduce clinical workload and streamline the VSP workflow, a novel landmark-guided strategy for computer-assisted reconstruction of infrastructure maxillary defects using the FFF was proposed and validated with a retrospective study.

> **Takeaways**
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> **Question:** Can the proposed anatomical landmark-guided strategy guide the virtual surgical planning (VSP) of infrastructure maxilla reconstruction using free fibula flaps?
>
> **Findings:** The anatomical landmark-guided strategy developed was validated with high reproducibility of the quantitative metrics in VSP. The anatomical landmarks and associated clinical parameters also constituted a structured quantitative approach for postoperative analysis of computer-assisted maxillary reconstruction using free fibula flaps.
>
> **Meaning:** The strategy proposed incorporates multidisciplinary considerations and provides valuable references to the positioning of fibula bony segments in computer-assisted maxillary reconstruction. It also carries the potential to be used for the development of automated VSP functions in software in the future.

MATERIALS AND METHODS

Subjects

Patients who underwent computer-assisted maxillary reconstruction in the Department of Oral and Maxillofacial Surgery in Queen Mary Hospital from May 2017 to April 2024 were selected based on the following criteria. The inclusion criteria were (1) age older than 18 years; (2) signed and dated informed consent; (3) diagnosis of benign or malignant tumor in the maxilla inferior to the infraorbital foramen, primarily involving the alveolar arch and plate; (4) having undergone computer-assisted infrastructure maxillectomy and reconstruction using an FFF; (5) surgery conducted with patient-specific surgical template of either transfer guide or patient-specific surgical plate (PSSP); and (6) complete follow-up information, including postoperative computed tomography (CT) scans. The exclusion criteria were (1) patients with surgical resection involving the infraorbital rim, (2) maxillary reconstruction utilizing other flaps, and (3) patients lost to follow-up. This study has been approved by the institutional review board of the University of Hong Kong/Hospital Authority Hong Kong West Cluster with a reference number of UW 16-315. The study protocol has been registered in ClinicalTrials.gov (NCT03057223).

Virtual Surgical Planning

Virtual skull and fibula models were segmented from CT scans using Materialise ProPlan CMF 3.0 (Materialise, Leuven, Belgium) for interactive VSP. The preoperative maxilla was used as a reference to guide the optimal folding and placement of the fibular segments. In cases where the tumor growth substantially deformed the maxilla, virtual dental wax-up and mirroring of the contralateral maxilla were conducted in Materialise 3-matic 13.0 (Materialise). (**See figure, Supplemental Digital Content 1**, which displays reconstruction of a new preoperative maxilla to guide the fibula reconstruction by virtual dental wax-up combined with the mirroring of the contralateral maxilla, **http://links.lww.com/PRSGO/D917**.) The extent of partial maxillectomy was determined based on clinical and imaging information, including CT or magnetic resonance imaging.[22] Subsequently, the fibula was virtually osteotomized and positioned by a trained junior surgeon under the supervision of the chief surgeon as well as the prosthodontist in charge, who fine-tuned and finalized the VSP. The detailed workflow of VSP was described in the study by Yang et al.[23]

Three-dimensionally Printed Patient-specific Surgical Templates

The final VSP was exported to Materialise 3-matic 13.0 for designing patient-specific surgical templates. Digital prototypes of the surgical cutting guides were 3-dimensionally printed using either ULTEM 1010 MED610 resin (Stratasys Ltd, Eden Prairie, MN) or pure grade 2 titanium powder. The PSSPs were printed with pure grade 2 titanium powder, and the transfer guides were printed with ULTEM 1010 MED610 resin. For cases using transfer guides, the fibula segments were positioned with the transfer guides and fixed with intraoperatively bent titanium miniplates and screws (MatrixMIDFACE Plate and Screw System, DePuy Synthes). The use of transfer guide or PSSP was randomly assigned. In either situation, surgery was performed strictly according to the VSP. The longest available follow-up CT scan of each case was used for postoperative analysis in this study, ranging from 2 months to 2 years postoperatively.

Anatomical Landmarks and Clinical Parameters

Based on the principle of functional rehabilitation, 3 anatomical landmarks were defined on the upper alveolar arch: (1) incisor point (I), (2) canine point (C), and (3) molar point (M). The I point defined the anterior position of the upper alveolar arch and provided reference for lip and nasal support; The C point represented the greatest curvature between the upper anterior teeth and posterior teeth, which typically guided the osteotomy plane between the fibular bone segments.[24] The M point was determined according to the position of the first molar or the second premolar in a shortened dental arch design.[25] These points were also referred to as horizontal landmarks, which marked the anatomical curvature of the upper alveolus and guided the placement of fibular segments to provide bony structures for dental implant placement at the appropriate superior-inferior and buccolingual levels.

Two additional anatomical landmarks were defined as vertical landmarks located at the zygomaticomaxillary buttress: (4) jugale point (J)[26] and (5) zygoma point (Z). The J point dictated the need for the posterior vertical fibular segment to connect the horizontal segments to the remnant zygoma, whereas the Z point guided the positioning of the posterior vertical fibular segment. Overall, the defined anatomical landmarks aimed to guide the optimal alignment of fibular segments in restoring infrastructure maxillary defects (Table 1; Fig. 1).

Based on the anatomical landmarks, 4 clinical parameters were established, emphasizing the essential functional and aesthetic aspects of infrastructure maxillary reconstruction: (1) anterior arch width, (2) posterior arch width, (3) ipsilateral arch angle, and (4) maxillary width. These clinical parameters were used to evaluate the clinical feasibility of VSP and served as quantitative metrics to assess reconstruction outcomes (Table 2; Fig. 1).

The Anatomical Landmark-guided Strategy

Single- or multisegment FFF design was utilized for the reconstruction of infrastructure maxillary defects depending on the extent of the maxillary defect. The number of fibular segments was determined with reference to the number of anatomical landmarks included in the defect. Specifically, the involvement of 1 or 2 landmarks necessitated a single-segment design (Fig. 2), the involvement of 3 landmarks necessitated a 2-segment design (Fig. 3), and the involvement of 4 landmarks necessitated a 3-segment design (Fig. 4).

In this retrospective validation study, clinical cases were categorized into 2 groups based on whether the VSP conformed to this proposed landmark-guided strategy. If the number and positioning of the fibula segment(s) aligned with the proposed landmark-based strategy, a case was categorized as group A (standard strategy). If there was a mismatch of the number between the fibula segment with gross deviations from the proposed strategy (eg, if 3 landmarks including the I, C, and M points were involved in the resection and only 1 long fibula segment was used for reconstruction), a case was categorized as group B (modified strategy).

Strategy Validation and Accuracy Assessment

To assess the feasibility of the proposed landmark-based strategy, corresponding reconstructed landmarks were defined in the reconstructed maxilla (Table 1; Fig. 1). The associated clinical parameters were also defined correspondingly in the reconstructed model (Table 2; Fig. 1). The preoperative maxilla, VSP, and postoperative maxilla models were aligned via N-point registrations followed by global registration functions based on the trimmed unoperated part of the upper skull in Materialise 3-matic 13.0. Two stages of measurements were conducted for strategy validation and postoperative accuracy assessment, respectively. First, the VSP was compared with the preoperative maxilla to validate the feasibility of the landmark-based strategy via the deviations of (1) anatomical landmarks and (2) clinical parameters, as defined in respective models. Second, the postoperative maxilla was compared with the VSP to assess the accuracy of the surgical outcomes via 3 sets of quantitative metrics: (1) the point deviation of the anatomical landmarks, (2) the absolute difference of clinical parameter measurements, and (3) the deviation of individual fibular segments.[27]

Oral Rehabilitation

Occlusal rehabilitation of patients who had undergone jaw reconstruction was performed by the prosthodontic team at the Faculty of Dentistry, the University of Hong Kong with

Table 1. Definitions of Anatomical Landmarks in Preoperative Maxilla and Reconstructed Models

Anatomical Landmarks	
I	The inferior midpoint of the anterior septal alveolus bone between bilateral upper central incisors
rI	The most inferior point of the reconstructed maxilla at the mid-sagittal plane of the skull
C	The center point of the alveolar socket of canines at the level of the alveolar bone crest
rC	The most inferior point of the reconstructed maxilla at the same coronal plane as the contralateral canine
M	The center point of the alveolar socket of the first molar at the level of the alveolar bone crest; or the center point of the second premolar in a shortened dental arch design
rM	The most inferior point of the reconstructed maxilla at the same coronal plane as the contralateral first molar; or the second premolar in a shortened dental arch design
J	The intersection of the lateral contour of the maxillary alveolar process and the lower contour of the zygomaticomaxillary process of the maxilla
rJ	The most lateral intersection of the reconstructed maxilla at the same coronal plane as the contralateral jugale point
Z	The most anterolateral point at the inferior cutting plane of the remnant zygoma
rZ	The most anterolateral point at the superior plane of the vertical posterior fibula segment along the zygomaticomaxillary process

rC, reconstructed canine point; rM, reconstructed molar point; rJ, new jugale point in the reconstructed maxilla; rZ, reconstructed zygoma point.

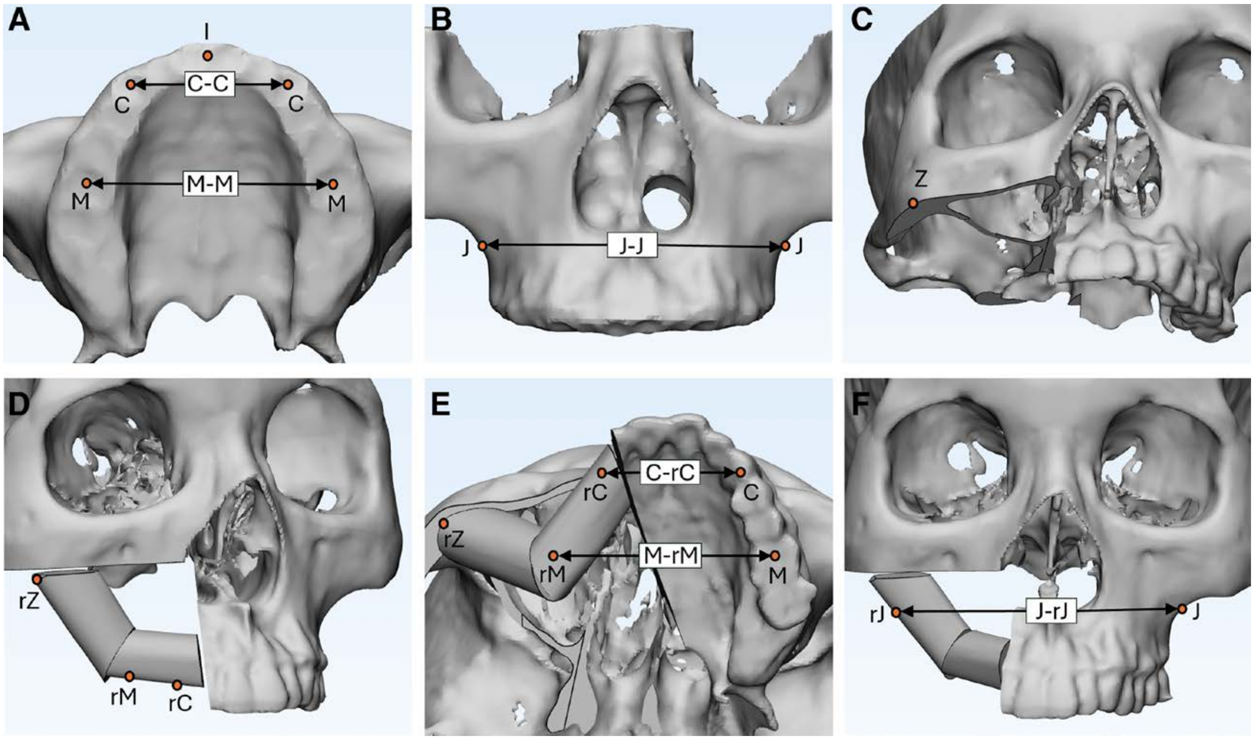

Fig. 1. Key anatomical landmarks and clinical parameters in the preoperative maxilla and VSP. A, Occlusal view of the preoperative maxilla. B, Frontal view of the preoperative maxilla. C, Inferior view of the resected maxilla. D, Lateral view of the VSP of the maxilla. E, Occlusal view of the VSP of the maxilla. F, Frontal view of the VSP of the maxilla. C-C, anterior arch width; C-rC, reconstructed anterior arch width; J-J, maxillary width; J-rJ, reconstructed maxillary width; M-M posterior arch width; M-rM, reconstructed posterior arch width; rC, reconstructed canine point; rM, reconstructed molar point; rJ, new jugale point in the reconstructed maxilla; rZ, reconstructed zygoma point.

Table 2. Definitions of Clinical Parameters in the Preoperative Maxilla and Reconstructed Models

Clinical Parameters	
C-C	The distance between the center points of the alveolar socket at the level of the alveolar crest of bilateral canines in the preoperative maxilla, measured between bilateral C points
C-rC	The distance between the center point of the alveolar socket at the level of the alveolar crest of the canine and the most inferior point of the reconstructed maxilla at the same coronal plane, measured from C point to contralateral rC point
M-M	The distance between the center points of the alveolar socket at the level of alveolar crest of bilateral first molars (or second premolars) in the preoperative maxilla, measured between bilateral M points
M-rM	The distance between the center point of the alveolar socket at the level of the alveolar crest of the first molar or second premolar and the most inferior point of the reconstructed maxilla at the same coronal plane, measured from M point to contralateral rM point
I-C-M	The curvature of the preoperative maxillary dental arch, formed by ipsilateral I, C, and M points
rI-C-M	The curvature of the reconstructed maxillary dental arch, formed by ipsilateral (r)I, (r)C, and (r)M points
J-J	The distance between bilateral intersections of the lateral contour of the maxillary alveolar process and the lower contour of the jugal process, measured between bilateral J points
J-rJ	The distance between the unoperated jugale point and the most lateral point of the reconstructed maxilla at the same transverse plane, measured from J to contralateral rJ point

C-C, anterior arch width; C-rC, reconstructed anterior arch width; I-C-M, ipsilateral arch angle; J-J, maxillary width; J-rJ, reconstructed maxillary width; M-M posterior arch width; M-rM, reconstructed posterior arch width; rC, reconstructed canine point; rI-C-M, reconstructed ipsilateral arch angle.

dental implant-supported prostheses. In cases where dental implants were placed simultaneously at the stage of maxillary reconstruction, the operation was assisted using the "three-in-one" patient-specific surgical guides.[7]

Statistical Analysis

All statistical analyses were performed using IBM SPSS Statistic version 29. Descriptive statistics were calculated for the quantitative metrics for reconstruction verification and accuracy evaluation. Data in this study did not follow normal distributions as indicated by Shapiro–Wilk test ($P < 0.05$). P value tests were analysis of Kruskal–Wallis test and the Mann-Whitney test for nonnormal continuous outcomes. Statistical significance was defined as a P value less than or equal to 0.05.

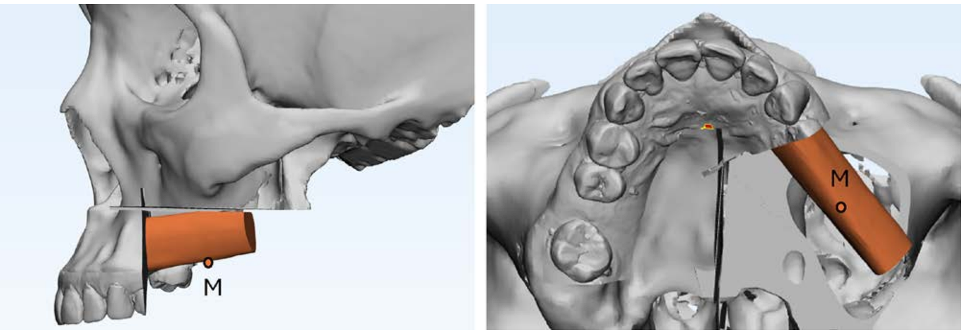

Fig. 2. Single-segment FFF reconstruction. The single-segment fibula flap was used for infrastructure maxillectomy involving no more than 2 landmarks. When the M point was involved in the maxillary resection as shown, a single-segment fibula VSP was indicated to re-establish the landmark and to repair the defect. The inferior border of the fibula segment was guided by the position of the M point in the preoperative maxilla and the distal resection plane of the maxilla at the level of the alveolar crest.

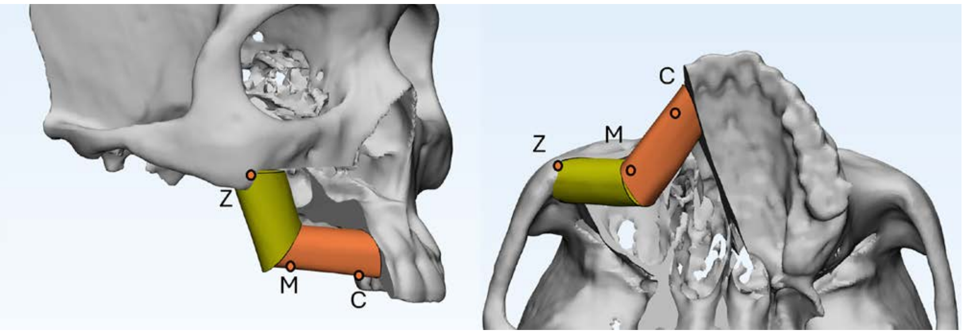

Fig. 3. Two-segment FFF reconstruction. The 2-segment design was used when 3 anatomical landmarks were involved in tumor resection in the following 2 scenarios. In scenario 1, when the I, C, and M points were involved, 2 horizontal segments were positioned along the curvature of the dental arch guided by the landmarks involved in the preoperative maxilla. In scenario 2, when the C, M, and J points were involved, one horizontal segment was positioned along the dental arch guided by the C and M points, whereas 1 vertical segment was guided by the Z point on the superior cutting plane, adjoining the remnant zygoma and the horizontal segment along the posterior maxillary buttress as shown.

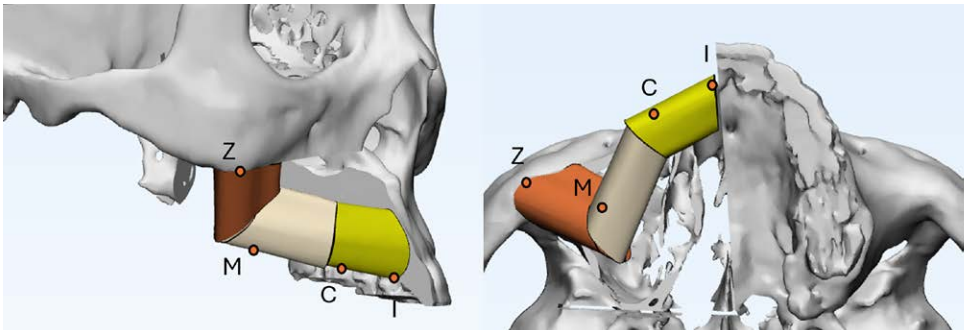

Fig. 4. Three-segment FFF reconstruction. The 3-segment design was used where tumor resection involved all 4 landmarks (I, C, M, J points) as shown. Two horizontal segments were positioned along the dental arch, guided by the I, C, and M points. The superior end of the vertical segment was guided by the Z point. Note that the J point was not intentionally reproduced in the FFF construction but used as a landmark to dictate the number of fibular segments required.

RESULTS

Demographic Data

A total of 20 patients were included in this study (Table 3). The mean age of patients was 56.6 ± 14.4 years, ranging from 32 to 80 years. The study cohort comprised 10 (50.0%) women and 10 men (50.0%), and 18 cases of malignancy and 2 cases of benign tumors. In 14 patients, simultaneous dental implants were placed during maxillary reconstruction, and 1 patient (case 18) underwent

Table 3. Patient Demographics

Characteristics	Frequency	Percentage (%)
Sex		
Male	10	50
Female	10	50
Age, y		
30–49	6	30
50–69	11	55
70 or above	3	15
Diagnosis		
Malignant tumor	18	90
Squamous cell carcinoma	12	
Mucoepidermoid carcinoma	1	
Verrucous carcinoma	1	
Sclerosing microcystic adenocarcinoma	1	
Carcinoma ex pleomorphic adenoma	1	
Epithelioid hemangioendothelioma	1	
Benign tumor	2	10
Ameloblastoma	1	
Odontogenic myxoma	1	

second-stage dental implantation. (**See table, Supplemental Digital Content 2**, which displays clinical information of 20 cases, **http://links.lww.com/PRSGO/D918**.) Until June 2024, implant-supported fixed dental prostheses were provided in 4 patients, whereas 9 patients were waiting for the final dental prosthesis.

Validation of Landmark-guided Strategy

The positioning of fibula segments in all cases was largely in line with the proposed anatomical landmarks, exhibiting acceptable errors (Table 4). In 11 cases, we followed the landmark-guided strategy (group A), with a median pooled landmark error of 2.19 mm (interquartile range [IQR], 1.63–2.91 mm) between the VSP and preoperative maxilla. In 9 cases, we adopted a modified strategy (group B), with a median pooled landmark error of 4.54 mm (IQR, 2.05–6.15 mm). A statistically significant difference was observed between the deviation of the I, C, and M points of the 2 groups ($P < 0.05$).

For the clinical parameters (Table 5), both groups demonstrated excellent reproducibility of the anterior arch width (1.12 mm [IQR, 0.55–1.67 mm] in group A; 1.69 mm [IQR 0.44–3.93 mm] in Group B), with no statistically significant difference ($P = 0.40$). However, group A showed significantly higher reproducibility of the posterior arch width (0.49 mm [IQR, 0.14–1.00 mm]), as well as the ipsilateral arch angle (4.95 degrees [IQR, 22.03–9.25 degrees]) compared with group B ($P < 0.01$). The means and SDs of corresponding measurements were listed in Supplemental Digital Content 3 and 4. (**See table, Supplemental Digital Content 3**, which displays mean and SD of preoperative versus VSP anatomical landmark linear variation [mm], **http://links.lww.com/PRSGO/D919**.) (**See table, Supplemental Digital Content 4**, which displays the mean and SD of preoperative versus VSP clinical parameters measurements variation, **http://links.lww.com/PRSGO/D920**.)

Postoperative Accuracy Assessment

All 20 cases in this study cohort were assessed collectively through the comparison of postoperative and the VSP maxilla models. The median deviation of the anatomical landmarks was 2.42 mm (IQR, 1.50–4.68 mm), with no statistically significant difference between point deviations of I, C, M, and Z points ($P = 0.50$). The median difference of the width measurements was 1.02 mm (IQR, 0.40–2.06 mm), with no statistically significant difference between anterior arch width, posterior arch width, and maxillary width ($P = 0.77$). The median absolute angular difference of the ipsilateral arch angle was 6.62 degrees (IQR, 1.88–12.23 degrees). The results of other measurements were shown in Table 6. The means and SDs of corresponding measurements are listed in Supplemental Digital Content 5. (**See table, Supplemental Digital Content 5**, which displays the mean and SD of postoperative versus VSP reconstruction accuracy assessment by anatomical landmarks, clinical parameters, and fibula segment measurements, **http://links.lww.com/PRSGO/D921**.)

CASE ILLUSTRATION

A 33-year-old man presented with epithelioid hemangioendothelioma at the left maxilla involving the I, C, M, and J points (Fig. 5). This case used a transfer guide for the positioning of the fibula segments. A comparison of the preoperative maxilla and VPS showed a mean linear error of 2.28 mm of the 4 anatomical landmarks. The anterior arch width and posterior arch width showed a minimal deviation of 1.12 and 0.09 mm, respectively. The patient demonstrated satisfactory functional and aesthetic clinical outcomes at the follow-up 3 years postoperatively.

DISCUSSION

The challenge of FFF reconstruction of the maxilla is that the operator must incorporate multiple factors including the size of the maxillary defect, the anatomy of the zygomaticomaxillary complex, soft-tissue condition, postoperative adjuvant therapy, dental arch forms, prosthodontic rehabilitation plan, and so on in the surgical plan.[2,8,11,28,29] Although it has been shown that VSP flattens the learning curve of FFF,[30] a surgeon with limited experience may still find it challenging to determine the exact number, length, and position of the fibular segments for maxillary reconstruction. This study integrated these factors and proposed a simple and practical strategy for the VSP of infrastructure maxilla defect reconstruction utilizing FFF.

The feasibility of the landmark-based strategy was validated by the high reproducibility of the quantitative metrics. Ideally, the standard surgical algorithm was adopted, yielding higher reproducibility of the anatomical landmarks as in group A with a mean error of less than 2.5 mm in the VSP compared with the preoperative maxilla. Correspondingly, the anatomy of the dental alveolar arch was more accurately recaptured with an error of less than 1.5 mm in both the anterior and posterior arch widths and

Table 4. Anatomical Landmark Deviation Between VSP and Preoperative Maxilla (mm)

	Group A (N = 11), Median (IQR)	Group B (N = 9), Median (IQR)	*P*
I	2.21 (1.87–2.67)	5.12 (4.73–5.91)	0.036*
C	2.40 (1.42–2.90)	5.58 (4.25–6.28)	<0.001*
M	1.91 (1.49–2.95)	4.57 (2.85–6.54)	0.005*
Z	1.81 (1.60–4.65)	2.45 (1.51–5.49)	0.867
Combined†	2.19 (1.63–2.91)	4.54 (2.05–6.15)	<0.001*

*$P \leq 0.05$ (Mann-Whitney test).
†No significant intragroup difference is observed between I, C, M, and Z points. Group A: $P = 0.957 > 0.05$; group B: $P = 0.216 > 0.05$ (Kruskal–Wallis test).

Table 5. Clinical Parameter Measurement Deviation Between VSP and Preoperative Maxilla

	Group A (N = 11), Median (IQR)			Group B (N = 9), Median (IQR)			
	Preoperative	VSP	Difference	Preoperative	VSP	Difference	*P*
Anterior arch width (mm)	31.77 (28.04–32.9)	30.79 (27.45–31.47)	1.12 (0.55–1.67)	32.02 (30.51–34.71)	30.79 (28.23–31.65)	1.69 (0.44–3.93)	0.399
Posterior arch width (mm)	47.75 (45.76–51.08)	47.75 (46.38–51.44)	0.49 (0.14–1.00)	46.06 (44.07–51.44)	48.81 (46.65–52.00)	2.65 (0.845–3.19)	0.006*
Ipsilateral arch angle (degrees)	137.43 (134.06–143.60)	141.54 (132.12–146.33)	4.95 (2.03–9.25)	136.85 (132.32–141.50)	168.14 (149.03–171.35)	29.41 (14.39–34.75)	0.004*
Maxillary width (mm)†	70.26 (63.84–72.58)	77.52 (74.92–79.75)	7.17 (6.06–11.08)	66.695 (64.29–69.11)	75.49 (73.14–80.94)	8.725 (6.89–10.33)	0.955

*$P \leq 0.05$ (Mann-Whitney test).
†Maxillary width variation is significantly higher compared with both anterior arch width and posterior arch width in both groups ($P < 0.05$, Kruskal–Wallis test). Anterior arch width and posterior arch width variation show no significant difference in both groups. Group A: $P = 0.108 > 0.05$; group B: $P = 0.931 > 0.05$ (Mann-Whitney test).

Table 6. Postoperative Surgical Accuracy Assessment by Comparison Between Postoperative Maxilla and VSP

Anatomical Landmarks (mm)	Median (IQR)	Clinical Parameters	Median (IQR)	Fibular Segments	Median (IQR)
I (n = 9)	1.56 (1.18–4.95)	Anterior arch width (mm) (n = 16)	1.03 (0.37–1.82)	Axis angle deviation (degrees) (n = 36)	7.625 (4.77–10.4)
C (n = 18)	2.155 (1.56–4.39)	Posterior arch width (mm) (n = 18)	0.77 (0.41–2.57)	Center point deviation (mm) (n = 36)	3.05 (1.83–4.87)
M (n = 19)	2.77 (1.31–4.81)	Maxillary width (mm) (n = 14)	1.67 (0.34–3.26)	Cutting plane angle deviation (degrees) (n = 72)	10.75 (5.90–15.88)
Z (n = 15)	4.21 (1.78–5.04)	Width combined (mm) (n = 48)*	1.02 (0.40–2.06)		
Combined (n = 61)†	2.42 (1.50–4.68)	Ipsilateral arch angle (degrees) (n = 18)	6.62 (1.88–12.23)		

*The anterior arch width, posterior arch width, and maxillary width show no significant difference, $P = 0.774 > 0.05$ (Kruskal–Wallis test).
†The linear deviation of I, C, M, and Z points show no significant difference, $P = 0.495 > 0.05$ (Kruskal–Wallis test).

an error of less than 7 degrees in the ipsilateral arch angle. On the contrary, if there was a mismatch of the number of fibular segments and gross deviation from the dental arch as in group B, a statistically significant increase in deviation of the anatomical landmarks, as well as clinical parameters, was observed. Nevertheless, given the limited sample size of this study, the statistical difference between the 2 groups must be interpreted cautiously. A larger number of cases, preferably from multiple centers, are required to substantiate the clinical difference between the standard and modified reconstruction approaches.

Multiple factors could contribute to the modification of VSP as in group B. First, the length of vascularized fibula segments is 1 major concern. In 2018, van Gemert et al.[31] recommended a minimal FFF length of 2 cm in the study of complications in FFF reconstruction of the mandible which was based on the cadaver study done by Bähr,[32] reporting a minimal length of 2 cm for the fibula segment to be revascularized. Based on this prerequisite, in patients with smaller dental arches, 1 long fibular segment is sometimes used instead of 2 shorter segments connecting the I, C, and M points as indicated. This would result in increased error of the anatomical landmarks and drastically increased ipsilateral arch angle as reflected in the measurements of group B. Based on the same principle, the fibular segments are sometimes placed more laterally to the original dental arch and the zygomatico-maxillary buttress outline to ensure sufficient length of each segment. Another commonly encountered issue was the variance of the cross-sectional dimension of the fibula in relation to the dental occlusal clearance. For instance, a patient with a very deep dental bite and large fibula bone may require the fibular segments to be positioned more superiorly than indicated in the surgical algorithm. Other factors include considerations for postoperative adjuvant radiotherapy and subsequent tissue fibrosis, facial soft-tissue condition, and optimization of bony contact between the fibula flap and remnant maxilla.[28] Although a review of the cases in group B showed that the deviation of the fibular segments could potentially be offset

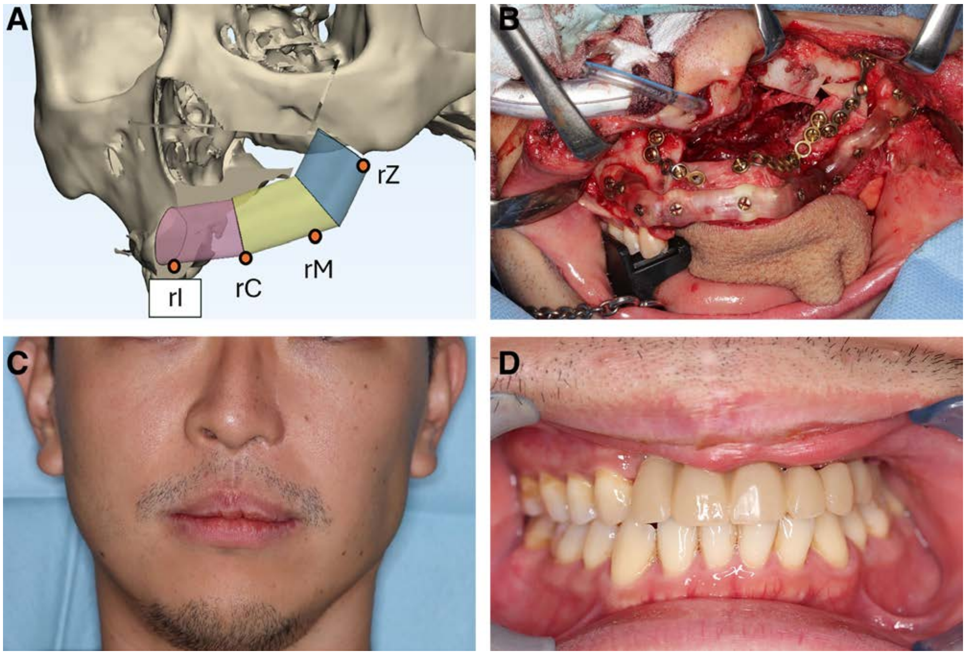

Fig. 5. A 33-year-old man presented with epithelioid hemangioendothelioma at the left maxilla. A, A 3-segment FFF design was used to reconstruct the maxilla, adhering to the reconstruction strategy of reconstructing the I, C, M, and Z points involved in the tumor resection. This case was categorized as group A accordingly. Four simultaneous dental implants were planned in the fibula segment, replacing the bilateral central incisors and first and second premolars. B, Fibular segments were guided by a patient-specific transfer guide and fixed by intraoperatively bent titanium miniplates and screws before the removal of the guide. C, An implant-supported dental prosthesis was placed. D, Frontal postoperative clinical photograph showed satisfactory facial symmetry and adequate soft-tissue support in the midface area.

by the adjustment of dental implant position and the use of angulated abutments up to 30 degrees, factors such as axial loading, emergence profile, and soft-tissue management still favor straight access of dental implant in the VSP, which requires accurate recapture of the dental arch form by an FFF.[33] On the other hand, it is our clinical experience that the hard tissue discrepancy can sometimes be camouflaged by the soft tissues, resulting in clinically acceptable aesthetic outcomes. However, the exact amount of offset tolerated is to be investigated.

Although the proposed landmark-based strategy offers practical references, the VSP must be considered case by case and is subject to variation in different clinical centers. It must be acknowledged that there remain other surgical designs that were not illustrated in this strategy, such as a double-barrel fibula flap, though it is more commonly used in more extensive defects involving the orbital rim.[29,34] Further study is required to verify the feasibility of the panel of anatomical landmarks in more extensive maxillary defects.

Given the heterogeneity in the published data on CAS of the maxillary reconstruction, there has been a lack of high-quality quantitative studies, making it challenging to compare the surgical accuracy.[19,35] In the present study, the center point linear deviation of the 36 fibula segments in 20 cases was 3.37 ± 1.81 mm, in keeping with the systematic review by van Baar et al,[19] which ranged from 0.44 to 7.8 mm. The angular deviation of the fibular segments was 8.30 ± 4.68 degrees, which slightly exceeded the reported range between 2.90 and 6.96 degrees from 2 single-centered studies based on 6 cases by Zheng et al[36] and 11 cases by Schepers et al.[37] Overall, the surgical precision was satisfactory in this retrospective study cohort.

Apart from surgical accuracy, it is also imperative to assess the effectiveness of the functional and aesthetic maxillary reconstruction with objective parameters. However, no available quantitative data specifically addressed the functional reconstruction of the maxilla. This study adopted a structured approach based on quantitative metrics of the functional and aesthetic outcomes of the maxilla using a series of clinical parameters. The anterior and posterior arch widths, and the ipsilateral arch angle quantified how accurately the curvature of the maxillary dental arch had been re-established, which reflected the effectiveness of functional reconstruction. The widths of the maxillary dental arch and maxillary width indicated the sufficiency of soft-tissue support, which reflected the aesthetic outcomes of the midface. Further study is required to substantiate the validity of the quantitative metrics in postoperative aesthetic assessment.

Admittedly, there has been a lack of discussion on bilateral inferior maxillary defect reconstruction in this study due to the scarcity of clinical cases. Several additional factors must be considered, including possible insufficiency of the length of fibula bone, twisting and kinking of the pedicle, lack of oronasal support, and the dilemma between soft tissue support and dental implant placement.[38] The landmark-based surgical algorithm proposed in this study requires further clinical validation on the applicability to the reconstruction of bilateral maxillary defects utilizing the FFF.

CONCLUSIONS

This study developed a practical anatomical landmark-based strategy for FFF reconstruction of infrastructure maxillary defects based on the I, C, M, J, and Z points. The use of the landmarks as well as the associated clinical parameters including anterior arch width, posterior arch width, ipsilateral arch angle, and maxillary width constituted a structured quantitative approach for postoperative analysis of CAS of maxillary reconstruction. These landmarks carry the potential to be used to develop automated VSP functions in software platforms, which will save manpower and cost, and reduce VSP time for computer-assisted maxilla reconstruction.

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