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Full Length Article

A comparison of facial contour and patient-reported outcomes following zygomatic implant perforated (ZIP) flaps and fibular osseous flaps for maxillary reconstruction

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Abstract

The zygomatic implant perforated (ZIP) flap is an alternative to the fibular free flap (FFF) for maxillary reconstruction with dental rehabilitation. The aim of this study was to compare facial contour and patient-reported outcomes in matched cases of ZIP flap or FFF maxillary reconstruction. Inclusion criteria were patients who underwent ZIP flap reconstruction between February 2017 and April 2023 with high-resolution preoperative and postoperative computed tomography (CT) imaging, and who had completed the FACE-Q questionnaire, matched with patients who had undergone maxillary FFF reconstruction. Accuracy of facial contour restoration was assessed in CloudCompare® by comparing preoperative and postoperative segmentations of the complete facial mask and midface subsites. Associations with patient-reported outcomes were assessed using linear regression. Twenty patients (10 ZIP, 10 FFF) were included. Mean difference between preoperative and postoperative facial contour did not differ significantly between groups for complete facial mask (1.0 mm ZIP vs 1.1 mm FFF, $p = 0.30$), or subsite analysis (malar eminence $p = 0.49$, nose $p = 0.29$, upper lip $p = 0.31$). Patient-reported outcomes were similar between groups except for saliva function, which was superior in the FFF group ($p = 0.043$). ZIP flaps are a valuable option for maxillary reconstruction in carefully-selected patients.

Keywords: maxilla; zygoma; reconstruction; free tissue flaps

Introduction

Reconstructive options for large neoplastic and traumatic maxillary defects are continually evolving to restore speech, mastication, oral competence, and swallowing function more effectively.[1] First reported in 2017, the zygomatic implant perforated (ZIP) flap comprises a fasciocutaneous free flap perforated by zygomatic dental implants to facilitate timely placement of a dental prosthesis.[2,3] By contrast, the fibular free flap (FFF) is largely regarded as the workhorse option in maxillary reconstruction, and is well-suited to virtual surgical planning (VSP) with primary dental implant placement.[4–6]

To our knowledge, the aesthetic, functional, and health-related quality of life (HRQoL) outcomes following FFF and

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ZIP flap reconstruction have not been compared directly. The aim of this study was to determine if ZIP flap maxillary reconstruction offers similar facial contour and patient-reported outcomes to FFF reconstruction. This study expands upon findings previously reported.[7] Our hypothesis was that FFF reconstruction would provide superior facial contour outcomes and better patient-reported outcomes in aesthetic domains.

Material and methods

Patient selection

Twenty-nine patients who underwent ZIP flap maxillary reconstruction between February 2017 and April 2023 were retrospectively identified from the prospectively maintained Integrated Prosthetics & Reconstruction database at Chris O'Brien Lifehouse. Patients with incomplete HRQoL data or poor resolution imaging were excluded. From 2017, ZIP flap reconstruction was offered to patients where the zygoma was preserved, and preferentially to older patients with comorbidities. Patients who underwent FFF maxillary reconstruction with occlusal-based VSP and dental rehabilitation were matched using the hierarchy: age (within five years), pathology (malignant versus benign), extent of defect (Okay Class II/III versus Class I), postoperative complications, sex, and radiotherapy. Patients with high-resolution (<1 mm thickness) preoperative and postoperative computed tomography (CT) facial imaging and completed FACE-Q questionnaires (see below) that were time-matched to the imaging, were included. Patients were invited to complete the questionnaire via mail, email, or in person at their routine postoperative follow-up appointments. Reminders were sent at two and four weeks following initial contact. Missing data were obtained from medical and surgical records. This study adheres to the STROBE guidelines and was approved by the Institutional Human Research Ethics Committee (Protocol No 2020/ETH02415 and 2021/ETH12271).

HRQoL measures

HRQoL was measured using the validated FACE-Q head and neck cancer module (FACE-Q).[8] FACE-Q contains 14 domains. The function scales include eating, oral competency, salivation, speaking, swallowing, appearance, and smile. The psychosocial scales include eating, drooling, speaking, appearance and smiling distress, and cancer-worry. The experience scale measures satisfaction with information. Cancer-worry and satisfaction with information domains were not relevant in this study and were excluded. Scores were fitted to a Rasch model (0-100) where higher scores indicated better outcomes.

Facial mask segmentation

For each patient, high-resolution preoperative and postoperative CT facial imaging was obtained in a digital imaging and communications in medicine (DICOM) format. The isolated facial contour was generated in 3DSlicer® (version 4.10.2, 2023) (www.slicer.org) using the "Segment Editor" module, manual thresholding, "Islands" and "Erase" tools. A 3 mm thick facial mask was generated using the "Hollow" tool, as this was the minimum thickness that adequately preserved details of the facial contour, and exported in a stereolithographic (STL) format (Fig. 1).

Accuracy of facial contour restoration: complete facial mask analysis

CloudCompare® version 2.9.1, 2023 (www.cloudcompare.org) is a free access point cloud-based software that has previously been used for facial contour analysis.[9] For each patient, preoperative and postoperative facial mask segmentations were superimposed using the manual and automated functions: "Match Bounding-Box Centres", "Align (point pairs picking)", and "Fine Registration (ICP)". The facial masks were aligned superoinferiorly from forehead to mentum and anteroposteriorly from nasal tip to ears. In cases with a significant unilateral deformity, the unaffected side was mirrored. The *difference* in facial contour was defined as the *mean distance* in millimetres between the superimposed preoperative and postoperative facial masks obtained using the "cloud-to-mesh distance" function. A greater difference (mean distance) indicates less accurate restoration of facial contour. A three-dimensional heat map was generated in CloudCompare® for each patient (Fig. 1).

Accuracy of facial contour restoration: subsite analysis

ZIP flaps may be less able to restore contour in certain midface regions. To determine the contribution of each midface subsite to differences in facial contour, a subsite analysis was performed. Separate analyses using the "cloud-to-mesh distance" function were run in CloudCompare® to measure the difference (mean distance) between the superimposed preoperative and postoperative facial masks for each subsite, including the right and left malar eminence, nose, and upper lip (Fig. 2). Only the affected malar eminence was included in the analysis. For bilateral defects, the average was used.

Statistical analysis

Statistical analysis was completed in Stata SE version 14 (StataCorp LP, 2015). The Student's t-test was used to analyse continuous data and the chi squared test to compare categorical data. A linear regression analysis was performed with difference (mean distance), sex, age, type of flap (FFF vs ZIP), and time from reconstructive surgery as covariates to compare HRQoL outcomes. A p value of <0.05 was considered statistically significant.

Results

Patient demographics

Twenty patients who had maxillary reconstruction (10 ZIP and 10 FFF) between February 2017 and April 2023 were

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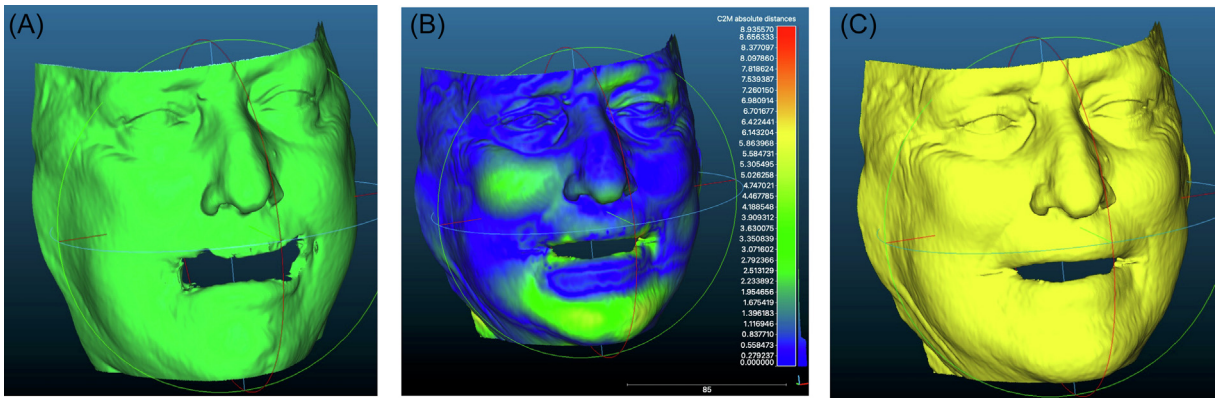

Fig. 1. Three-dimensional heat map (B) measuring the difference (mean distance) between preoperative (A) and postoperative (C) maxillary reconstruction facial mask segmentations using CloudCompare® (www.cloudcompare.org).

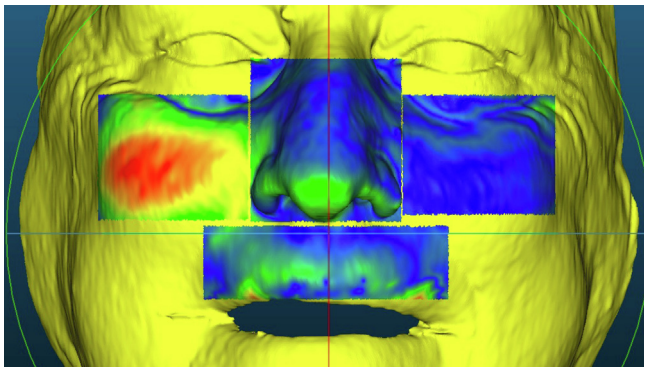

Fig. 2. Three-dimensional heat map illustrating the four subsites analysed using CloudCompare® (www.cloudcompare.org). The heat map measures the difference (mean distance) between preoperative and postoperative maxillary reconstruction facial mask segmentations for the following subsites: right malar eminence, left malar eminence, nose, and upper lip.

included. The median (range) age was 62 (31–91) years, and 11/20 were male. Occlusal-based VSP was used for all FFF cases. One ZIP and two FFF patients had delayed reconstruction, the remaining were primarily reconstructed. The mean follow up was 10.2 months (ZIP) versus 23.6 months (FFF) (p = 0.07) and the mean time to dental rehabilitation was 6.5 weeks (ZIP) versus 2.7 weeks (FFF) (p = 0.43). There were no significant differences between ZIP and FFF groups in sex (p = 0.18), age (p = 0.23), mean time post reconstructive surgery (p = 0.07), pathology (p = 0.33), radiotherapy (p = 0.16), or complications (p = 0.65). The vertical extent of the defect (Brown classification) was similar between groups, mostly Class II. However, more FFF cases were Class IId (3/10 vs 0/10), whereas more ZIP cases were Class IIc (5/10 vs 0/10). Okay Class III defects were more common in FFF (5/10 vs 2/10). Complete clinicopathological characteristics are included in Table 1.

Accuracy of complete facial mask, by reconstruction

Accuracy was measured as the difference (mean distance) between the superimposed preoperative and postoperative facial masks. The greater the difference, the less accurate the restoration of facial contour. No cases of preoperative unilateral facial swelling or deformity required mirroring of the unaffected side for facial contour analysis. The mean difference between the preoperative and postoperative facial masks in the ZIP group was 1.0 mm, which did not differ significantly from that of the FFF group, where the mean difference was 1.1 mm (p = 0.30, 95% CI -0.5 to 0.1 mm) (Table 2). Radiotherapy was associated with a greater difference between the preoperative and postoperative facial masks (p = 0.02, 95% CI 0.05 to 0.6 mm).

Accuracy of subsites, by reconstruction

The mean difference between the preoperative and postoperative subsite facial masks for the ZIP group did not significantly differ from that of the FFF group, including affected malar eminence (p = 0.49, 95% CI −1.2 to 0.6 mm), nose (p = 0.29, 95% CI −0.6 to 0.2 mm), and upper lip (p = 0.31, 95% CI −1.7 to 0.6 mm).

Patient-reported outcomes, by reconstruction

Shown in Fig. 3, FFF reconstruction was associated with better saliva function after adjusting for the effect of age, accuracy, sex, and time since surgery (31.8, p = 0.043, 95% CI 1.2 to 62.4). There were no statistically significant differences in the remaining HRQoL domains according to type of reconstruction.

Secondary outcomes

Female sex was associated with a worse appearance score after adjusting for age, difference in facial mask, choice of reconstruction, and time since surgery (−38.1, p = 0.026, 95% CI −70.9 to −5.3). There were no statistically significant differences in HRQoL outcomes in the remaining domains according to sex. Patient-reported outcomes did not differ significantly with radiotherapy.

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Table 1
Clinicopathological characteristics of the study population (n = 20). Data are number.

	ZIP (n = 10)	FFF (n = 10)	Total (n = 20)	p value
Sex:				
Male	7	4	11	0.18
Female	3	6	9	
Median (range) age (years)	65 (50–91)	61 (31–89)	62 (31–91)	0.23
Mean time post reconstructive surgery (months)	10.2 (median 6.8, range 2.7–26.8)	23.6 (median 19.5, range 3.4–61.9)	16.9 (median 11.4, range 2.7–61.9)	0.07
Timing of reconstruction:				0.53
Immediate	9	8	17	
Delayed	1	2	3	
Maxilla Okay classification:				0.35
I	4	2	6	
II	4	3	7	
III	2	5	7	
Brown classification:				
IIb	4	5	9	
IIc	5	0	5	
IId	0	3	3	
IIIb	0	1	1	
VIc	1	1	2	
Malignancy:				0.33
Yes	8	6	14	
No	2	4	6	
Pathology:				
Ameloblastoma	1	3	4	
Angiosarcoma	1	0	1	
Congenital defect	0	1	1	
Melanoma	1	0	1	
Osteoradionecrosis	1	1	2	
Osteosarcoma	0	1	1	
Squamous cell carcinoma	5	4	9	
Other	1[a]	0	1	
Type of free flap:				<0.001
ALT	6	0	6	
RFFF	4	0	4	
FFF	0	10	10	
Radiotherapy:				0.16
Yes	5	2	7	
No	5	8	13	
Complication:				0.65
Yes	4	5	9	
No	6	5	11	
Clavien Dindo grade:				
I	2	1	3	
II	1	4	5	
IIIa	0	0	0	
IIIb	1	0	1	
IVa	0	0	0	
IVb	0	0	0	
V	0	0	0	
Mean time from reconstructive surgery to dental rehabilitation (weeks[b,c])	6.5 (median 4.3, range 1.7–18.7)	2.7 (median 0, range 0–19.0)	4.7 (median 2.1, range 0–19.0)	0.43

ALT = anterior lateral thigh; FFF = fibular free flap; RFFF = radial forearm free flap; ZIP = zygomatic implant perforated flap
[a] Mucormycosis of palate following invasive fungal sinusitis in the context of immunosuppression (cystic fibrosis and lung transplant)
[b] Outliers excluded
[c] Dental rehabilitation data not available in 2 patients (1 ZIP flap, 1 FFF)

Discussion

To our knowledge, this is the first study to compare facial contour and functional and psychosocial patient-reported outcomes following ZIP and FFF maxillary reconstruction. We found that both ZIP and FFF resulted in acceptable restoration of facial contour, with a mean difference between the preoperative and postoperative facial masks of approxi-

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Table 2
Mean difference (mean distance) between preoperative and postoperative midface subsites and overall facial mask measured in three dimensions following maxillary reconstruction with zygomatic implant perforated (ZIP) flaps compared with fibular free flaps (FFF) (n = 20).

Subsite	Mean difference between preoperative and postoperative facial mask (mm)		Mean (95% CI) difference between ZIP and FFF (mm)	p value
	ZIP	FFF		
Affected malar eminence[a]	1.2	1.5	−0.3 (−1.2 to 0.6)	0.489
Nose	0.9	1.1	−0.2 (−0.6 to 0.2)	0.291
Upper lip	1.6	2.1	−0.5 (−1.7 to 0.6)	0.308
Overall facial mask	1.0	1.1	−0.1 (−0.5 to 0.1)	0.260

[a] Affected malar eminence refers to the laterality (right vs left). For bilateral and midline defects, an average value of left and right malar eminences was taken.

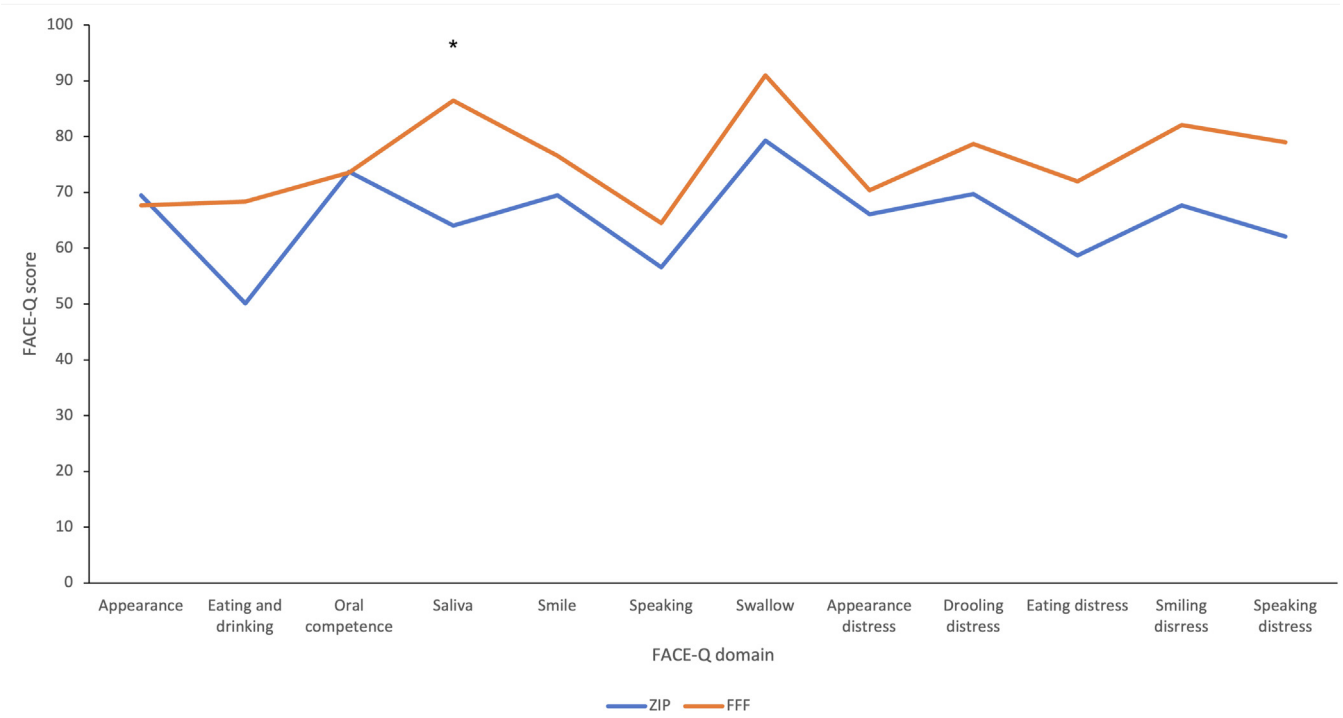

Fig. 3. Comparison of patient-reported outcomes measured using FACE-Q following maxillary reconstruction with zygomatic implant perforated (ZIP) flap compared with fibular free flap (FFF), adjusting for the effect of age, accuracy, sex, and time since surgery (n = 20).

mately 1 mm. There was no significant difference between groups by complete facial mask or subsites, and FACE-Q patient-reported outcomes were mostly similar.

Accuracy of facial contour restoration

Aesthetic outcomes in maxillary reconstruction have typically been assessed subjectively by patients or surgeons, which limits comparison between studies.[10–13] We used a three-dimensional quantitative comparison of preoperative and postoperative facial masks to objectively assess aesthetic outcomes. Similar aesthetic outcomes were demonstrated following ZIP and FFF reconstruction across subsites and overall. The nose and malar regions were the most accurate and the upper lip was the least, likely due to its inherent mobility, and most reconstructions involved only the infrastructure of the maxilla. Contracture following detachment of the upper lip from the maxilla in maxillectomy may account for lip inaccuracy. While quantitative measures of facial contour accuracy are limited, our findings lie within the reported range of bony accuracy (0.44–7.8 mm).[14]

Our method using free-access software including 3DSlicer® and CloudCompare® offers objective, reproducible aesthetic evaluation without specialised training or equipment. Routine high-resolution CT imaging in DICOM format enables assessment, and quantitative output permits direct comparison between patients and centres. This protocol is adaptable to various applications.

Patient-reported outcomes

Improved patient-reported outcomes following maxillary reconstruction have been associated with dentoalveolar rehabilitation with osseointegrated implants, VSP, and less exten-

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sive soft tissue resection.[1,15,16] Conversely, large tumour size, late tumour stage, radiotherapy, and younger age at surgery have been associated with worse patient-reported outcomes.[15,17]

FACE-Q is a validated HRQoL questionnaire with functional and psychosocial measures specific to patients with head and neck cancer.[8] Patient-reported outcomes following maxillary reconstruction were largely similar between ZIP and FFF groups, except for salivation. Better saliva outcomes in the FFF group may represent a type I error due to selection bias, as there was a higher proportion of patients receiving radiotherapy in the ZIP group (5/10 ZIP vs 2/10 FFF), causing salivary hypofunction and xerostomia.[17–19]

Secondary outcomes

Female sex was associated with poorer appearance function compared with males following maxillary reconstruction, regardless of reconstruction type. This may reflect societal pressures or a greater willingness to report appearance-related concerns.[17,20–22] Radiotherapy was associated with lower accuracy; however, this did not affect HRQoL. This is likely due to insufficient statistical power, as radiotherapy is typically associated with worse HRQoL.[17]

Choice of ZIP flap vs FFF reconstruction

For larger defects involving the orbital floor or zygoma, bony reconstruction is often required for structural support, whether for aesthetic or functional reasons. The ZIP technique offers a more accessible option for smaller defects but relies on the presence of the zygoma for implant placement.[23] ZIP flaps combine the benefits of early occlusal loading using zygomatic implants with those of fasciocutaneous flaps, including being easier to raise and inset, a longer pedicle length, and lower morbidity, and being suitable for elderly patients and those with peripheral vascular disease. This is associated with high rates of implant survival and rapid dental rehabilitation using implant-retained dental prostheses.[2] ZIP flaps may be a good option for patients with moderate-sized, low maxillary defects not involving the orbital floor or zygoma, particularly where osseous free flap reconstruction is not possible.[2,24–26]

Our cohort included a high proportion of FFF cases with immediate dental rehabilitation (that is, jaw-in-a-day or prelamination) resulting in a lower mean time to dental rehabilitation of 2.7 weeks, compared with 6.5 weeks in the ZIP group. This is not typical of dental rehabilitation in FFF maxillary reconstruction, which traditionally takes at least 6 to 12 months.[27–30] Two outliers were excluded from the FFF group where the dental prosthesis was placed at 58 and 114 weeks after reconstruction.

Limitations

This analysis is novel due to the stringent inclusion criteria and the recent introduction of the ZIP flap technique. Our study required patients to have high-resolution preoperative and postoperative scans, full dental rehabilitation, and FACE-Q questionnaires at time points that matched imaging. Whilst analyses controlled for sex, age, and time since surgery, the small sample size precludes reliable estimates. The disparity in time since surgery between groups is reflective of ZIP flaps being a newer technique (only introduced in 2017), resulting in fewer cases that had completed routine follow up. Shorter follow up in ZIP patients may exaggerate the effects of postoperative oedema or radiotherapy. Imaging variability (for example, head position or facial expression) may introduce error. We attempted to address this error by incorporating midface subsite analysis where similar mean differences across subsites suggest that complete facial contour results were reliable. This subsite analysis was not intended as a stand-alone measure of accuracy, and larger cohorts are required to validate subsite findings.

Our hypothesis that FFF reconstruction provides better aesthetic outcomes is not supported by these data, but it was impossible to match patients on all criteria and hence the results should be viewed with caution. Our results may be reflective of surgeons' selection bias based on the extent of bony and soft tissue deficiency. Historically, we have used FFF reconstruction in larger defects and only recently introduced the ZIP flap technique as a potential treatment option, but this analysis has given us confidence to expand its use.

Conclusions

This study has shown that the mean difference in preoperative and postoperative contour for ZIP flap and FFF maxillary reconstruction was approximately 1 mm, indicating favourable facial contour outcomes in carefully-selected patients using either approach, with similar patient-reported function and psychosocial outcomes. Whilst these results are promising, further studies with larger sample sizes and longer follow up are required to assess outcomes and define the ideal patient population for ZIP flap reconstruction.

Conflict of interest

We have no conflicts of interest.

Ethics statement/confirmation of patients permission

This study was approved by the institutional Human Research Ethics Committee (Protocol No 2020/ETH02415 and 2021/ETH12271).

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