

The Role of Supermicrosurgery and Arborization Capture in Improving Free-styled Propeller Flap Survival

Ankur Khajuria, BSc (Hons),
MBBS (Dist.), FHEA, FRSPH,
MRCS, MAcadMEd, MSc, PhD*†
Isao Koshima, MD, PhD‡
Ruben Y. Kannan, FRCS, PhD†

Background: Propeller flaps have a higher-than-normal incidence of partial flap necrosis. Although venous supercharging has been shown to reduce this risk, its application is limited outside the scope of lower limb propeller flaps. In this article, we look at the ability of arborization capture and supermicrosurgery to allow propeller flaps to capture adjacent perforasomes and significantly improve flap survival.

Methods: In a retrospective case series across two institutions, the outcomes of two groups of patients who had propeller flaps were compared. Group A patients were those who had conventional free-styled propeller flaps (n = 25), whereas Group B (n = 19) patients had propeller flaps algorithmically selected for either (1) arborization capture or (2) venous supercharging, or both. Two-way ANOVA analysis was performed to evaluate inter-group differences.

Results: Conventional propeller flaps had a 64% complete survival rate (32% partial necrosis rate and a 4% total necrosis rate) compared with a 94% complete survival rate in modified propeller flaps. Of the 12 cases of arborization capture (perforator complex diameters of 1–2 mm), only one flap sustained partial flap loss, whereas all seven supercharged propeller flaps (selected for perforator diameter <1 mm, with venous supercharging, in addition to arborization capture) survived completely.

Conclusions: The arborization technique should be the mainstay technique for all propeller flaps with perforator complex diameters of less than 2 mm while supercharging further enhances its survival, particularly in perforator complex diameters of less than 1 mm. (*Plast Reconstr Surg Glob Open* 2021;9:e3974; doi: 10.1097/GOX.0000000000003974; Published online 10 December 2021.)

INTRODUCTION

After Milton's experiments disproved the random flap concept¹ and put forward the existence of vertically oriented blood vessels perforating through into superficial tissue, the perforator flap concept was born. It was Asko-Selvajarala, who in 1984 first coined the term "free-styled" perforator flap,² a concept subsequently popularized as both pedicled and free flap types.³ The principle here was that when any perforating vessel was found, a flap could be raised on this vessel for reconstructive purposes.

Bravo et al more recently identified three different types of perforator flaps, viz. peninsular, islanded, and propeller flaps.⁴ The latter group has been documented as having a significantly higher rate of distal flap necrosis, more so in the case of free-styled propeller flaps and in instances where the perforator diameter is less than 1 mm. It is important to note that we refer to the perforator complex here; a combination of artery, venae comitantes, and an accompanying nerve⁵ with the understanding that the perforator complex diameter is directly proportional to the size of the venae comitantes⁶ and inversely related to venous congestion.

One of the major drawbacks with perforator flaps and in particular, propeller flaps in the past has been the risk of partial flap necrosis due to the inability to capture adjacent perforasomes and a lack of understanding of direct and indirect linking vessels. It was the introduction of the propeller flap concept⁷ that crystallized the thought processes around this subject and led to better-defined methods of flap raising. This and the increased emphasis of pedicle dissection and selection has helped increase the probability

From the *Kellogg College, University of Oxford, Oxford, UK; †Department of Plastic Surgery, Queen Victoria Hospital, East Grinstead, UK; ‡International Centre of Lymphoedema (ICL), Hiroshima University, Hiroshima, Japan.

Received for publication June 25, 2021; accepted October 12, 2021.

Copyright © 2021 The Authors. Published by Wolters Kluwer Health, Inc. on behalf of The American Society of Plastic Surgeons. This is an open-access article distributed under the terms of the [Creative Commons Attribution-Non Commercial-No Derivatives License 4.0 \(CCBY-NC-ND\)](https://creativecommons.org/licenses/by-nc-nd/4.0/), where it is permissible to download and share the work provided it is properly cited. The work cannot be changed in any way or used commercially without permission from the journal.

DOI: 10.1097/GOX.0000000000003974

Disclosure: The authors have no financial interest in relation to the content of this article.

of success in propeller flaps, particularly with reference to larger diameter and well-recognized perforator complexes.⁸

However, when pushing the boundaries of this philosophy to free-styled perforator flaps to any part of the body as has been the case in one of the author's (RYK) early practice, the inherent limitations of free-styled propeller flaps when compared with a larger more well-defined perforator such as the posterior tibial artery re-emerge. In this article, we look at the evolution of an algorithmic approach to propeller flap harvesting and inset, based on the learning curve of a single surgeon's (RYK) practice.

PATIENTS AND METHODS

In a retrospective case series over a 5-year period (2013–2017), the outcomes of 44 successive patients were analyzed before and after the introduction of technical modifications in free-styled propeller flaps, irrespective of body site. Twenty-five propeller flaps were raised conventionally (Group A), compared with 19 propeller flaps in Group B, based on the surgical algorithm depicted in Figure 1. The study was approved and registered with the audit department at Queen Victoria Hospital.

The demographics across both groups were similar with mean ages of 60 years in Group A and 50 years in Group B with 1:1 male-to-female ratios. There were three co-morbidities in the former group, viz the use of vasopressor in two patients and an autoimmune disorder in one, while one patient in Group B had diabetes and the

other had severe dementia. The mean perforator diameters were similar at 1.25 mm in Group A and 1.1 mm in Group B, whereas mean defect sizes were 186 cm² (Group A) versus 241 cm² (Group B).

Surgical Technique

When performing propeller flaps, it is crucial to dissect the vascular pedicle as far down to the source vessel as necessary to prevent flap congestion on pivoting the flap in. Most of these rules pertain to larger perforator complexes of greater than 2 mm diameter, but there remain certain limitations with perforator dissection, viz (1) small perforators of less than 2 mm diameter and (2) perforator complexes that arborize in a deeper plane than the conventionally perceived supra-fascial plane. A classic example of this is the 1–2 mm diameter lateral nasal artery perforators (LNAP), which arborize within the levator labii superioris alaeque nasi (Fig. 5). Here, it is advisable to take a cuff of the underlying muscle as an inverted cone of tissue from the base of the perforator to the source vessel. This captures the tiny arterioles and venules which branch out from the main perforator, deep to the fascial layer (Fig. 2), thereby increasing both inflow and reducing resistance to outflow on pivoting the propeller flap, without risking inadvertent damage to tiny vessels. This is particularly true in the face as the inflow and outflow channels of perforators do not necessarily travel within a single complex like the deep inferior epigastric system. It is to be noted that there is no arbitrary extent for arborizing vessels, but in general, these are within a 1-cm radius of the main perforator.

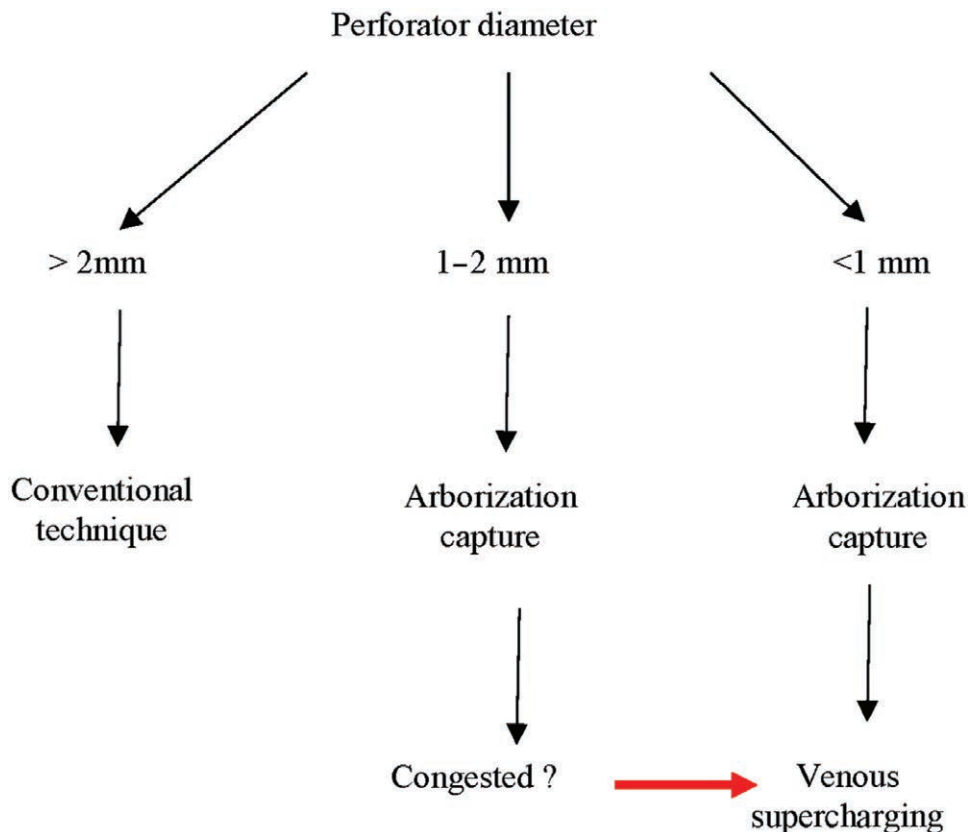


Fig. 1. Algorithmic approach to selecting technical modifications to the propeller flap.

Perforator arborization

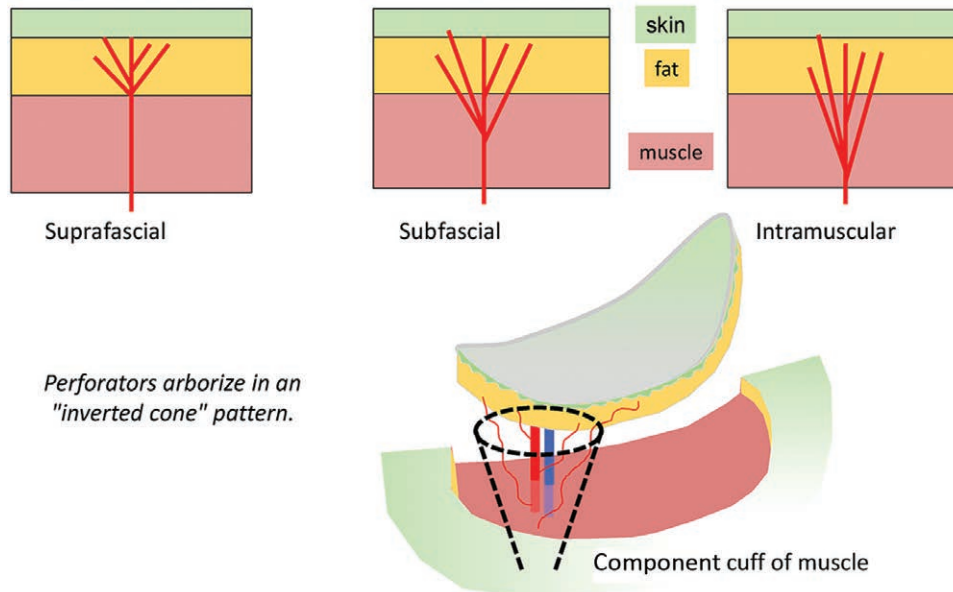


Fig. 2. An illustration of the harvesting of an inverted cone of muscle cuff around different perforators, allowing the capture of arborizing vessels at varying tissue planes for maximal inflow and outflow.

With this modification, we have observed in our clinical practice that the viable length of flap can be increased by 30% as it improves overall flap perfusion while reducing distal venous congestion and, hence, partial flap failure. Once the flap has been inset, give it approximately 15 minutes before reassessing the flap for features of venous congestion. As a congested flap precedes flap failure, the options then are (1) pivot the flap in the opposite direction, in case of 180 degree turns, (2) replace the flap back into its original position and “delay” it for 2–3 weeks, or (3) perform venous supercharging of a distal vein within the flap to an adjacent subcutaneous vein.⁹

In this study, the third option was selected in two situations, viz (1) flaps with perforator complex diameters of less than 1 mm and (2) any propeller flap with venous congestion. In the case of free-styled propeller flaps, these veins are usually less than 0.8 mm in diameter and hence, a super-microsurgical skillset is required in many instances.¹⁰ This is done in a manner that ensures ante-grade flow, thereby allowing greater outflow from the propeller flap. Such a situation is illustrated as follows. It is to be noted that no flaps that required arborization capture necessitated venous supercharging.

Case Illustration

A 43-year-old man presented with a large basal cell carcinoma over the left shoulder area, leaving a 10 × 6 cm defect down to fascia, following tumor extirpation. Using a hand-held Doppler probe (Huntleigh Ltd, UK), a nearby perforator based on the thoracoacromial artery was identified. This perforator was 1 mm in diameter and was pivoted through 180 degrees, and as per our algorithm, a

0.5 mm diameter supra-fascial perforating vein was identified and anastomosed end-to-side to the upturned cephalic vein using 10/0 Ethilon interrupted sutures, as shown in Figure 3. The flap survived completely with wound healing achieved within 10 days while normal shoulder movements were possible immediately following surgery.

Statistical Analysis

The parameter analyzed in this study was whether the technical modifications, viz. arborization capture/venous supercharging made a significant difference in

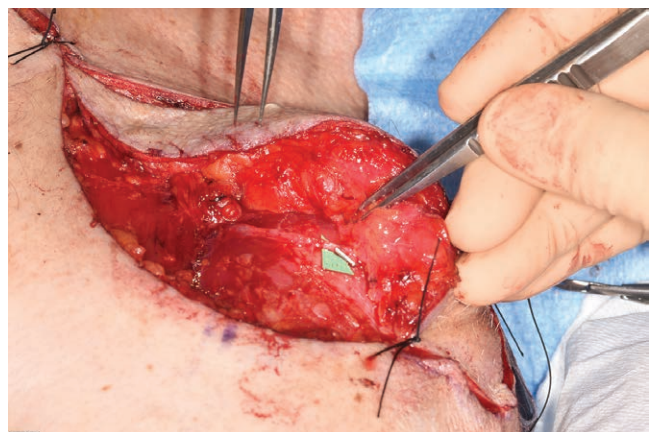


Fig. 3. A thoracoacromial artery perforator propeller flap based on a 1 mm perforator pivoted through 180 degrees to reconstruct a shoulder defect, postoncological reconstruction. The tiny 0.5 mm flap perforator vein shown here, following anastomosis to the cephalic vein (end-to-side) allowed for a reduction in intrinsic flap resistance and augmented venous outflow.

terms of overall flap survival. These data were statistically analyzed using two-way ANOVA (GraphPad Prism v6, USA).

RESULTS

In Group A wherein propeller flaps were conventionally raised by tracing them down to the source vessel,⁸ a 64% complete survival rate was noted (32% partial necrosis rate and a 4% total necrosis rate) compared with those in Group B with a 94% complete survival rate in the algorithmically selected propeller flaps. The mean torsion angle in Group A was 118 degrees, whereas it was slightly higher (154 degrees) in Group B. No leeches were used in either group, with all cases of partial necrosis in both groups being managed conservatively.

In Group B (modified group), there were 12 cases chosen to have only the arborization capture performed (n = 12). These were propeller flaps with perforator complex diameters of between 1 and 2 mm. Within this subset, only one flap sustained partial flap loss wherein the perforating vessel sustained inadvertent excessive diathermy damage, compromising inflow. None of these flaps

developed venous compromise, which requires venous supercharging, as per our algorithm.

In those where arborization capture alone was insufficient or where perforator complex diameters were less than 1 mm, venous supercharging of a subcutaneous/perforator vein (diameters: 0.5–2 mm) was necessary. All seven supercharged propeller flaps (n = 7) showed complete survival (as depicted in Table 1). There was one instance of a donor site dehiscence of a posterior thigh wound, but this was managed conservatively with topical negative pressure dressing. This was secondary to poor wound healing conditions in a diabetic patient.

From a statistical standpoint, a two-way ANOVA analysis between Groups A and B showed a significant difference in terms of flap survival, following the technical modifications discussed. One-way ANOVA analysis showed no statistically significant difference between the two groups in terms of defect size: Group A had a mean ± SD of 185.5 ± 173 cm² versus Group B, which had a mean ± SD of 241 ± 185 cm² (P = 0.35). This translated into faster and uneventful healing in patients from Group B. This is graphically illustrated in Figure 4.

Table 1. Cohort of Patients with Venous Supercharged Flaps for Free-styled Propeller Flaps

Perforator	Site	Diameter	Supercharged vein	Defect	Outcome
Peroneal artery	Lateral leg	1 mm	0.8 mm	12 × 8 cm	100% viable
Sixth intercostal artery	Chest	<1 mm	0.5 mm	15 × 12 cm	100% viable
Thoracoacromial artery	Shoulder	1 mm	0.5 mm	10 × 6 cm	100% viable
Dorsal intercostal artery perforator	Back	1 mm	0.6 mm	12 × 8 cm	100% viable
Reverse-flow angular artery perforator	Nose	<1 mm	0.5 mm	3 × 2 cm	100% viable
Sixth intercostal artery	Chest	1 mm	0.8 mm	10 × 6 cm	100% viable
Posterior thigh	Thigh	1 mm	2 mm	15 × 10 cm	100% viable

Note the supermicrosurgery-range sub-800 μm diameter of the outflow vein used for supercharging in six of the seven free-styled propeller flaps.

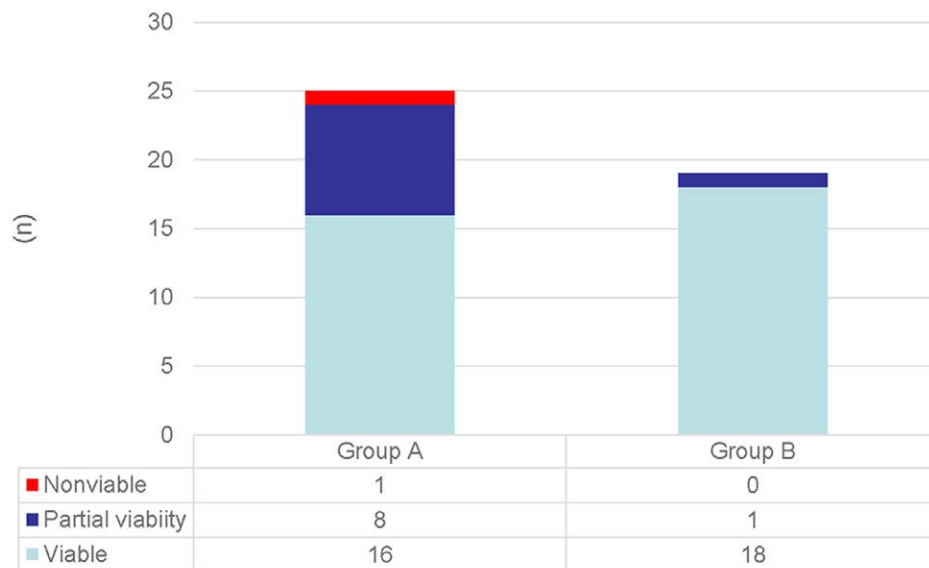


Fig. 4. Bar chart representation of the comparison between Groups A and B, illustrating the statistically significant improvement to overall flap survival with the utilization of arborization capture and venous supercharging, where appropriate.

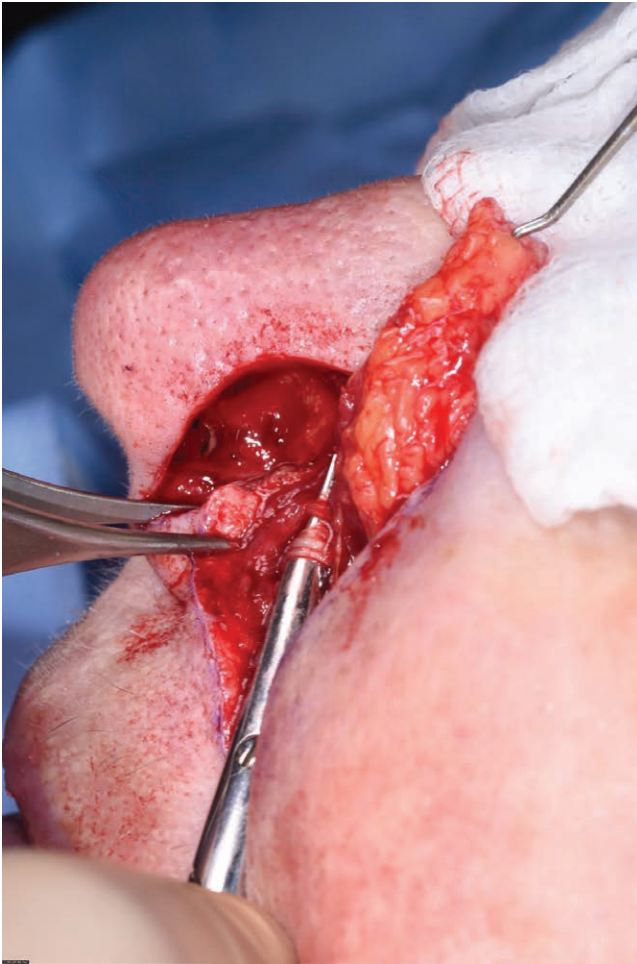


Fig. 5. A clinical image of the arborization capture technique with respect to the LNAP flap, showing the multiple perforating vessels coming through the underlying muscles.

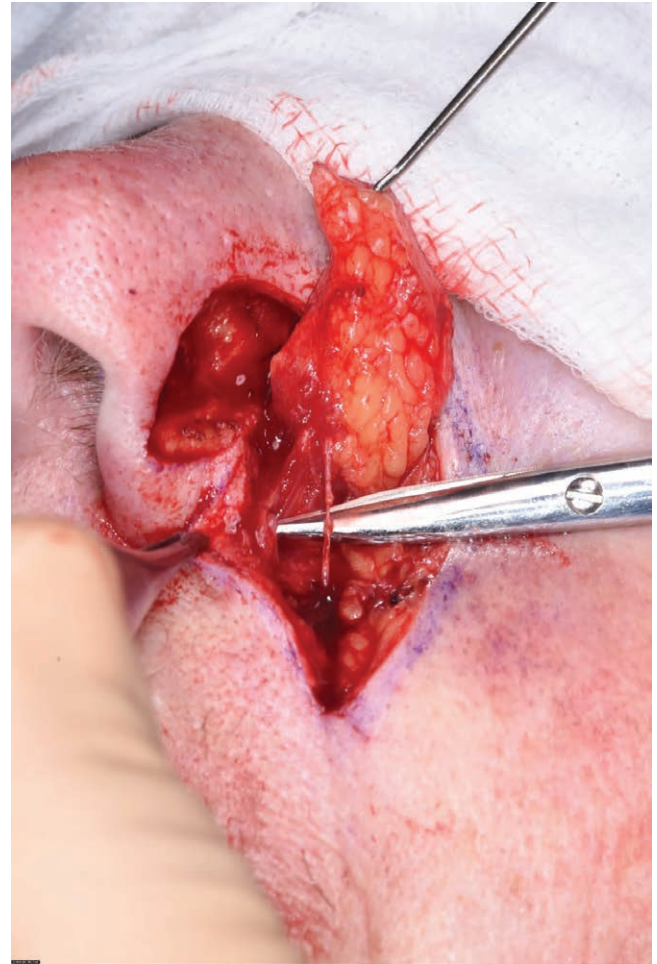


Fig. 6. A clinical image of the arborization capture technique with respect to the LNAP flap, showing the multiple perforating vessels coming through the underlying muscles.

DISCUSSION

The central philosophy with perforator flaps is that tissue vasculature is three-dimensional. When flaps were first designed in the early to mid-20th century, they were conceptualized as two-dimensional when in effect, each flap was being perfused by perforating vessels at the base of the flap or nearby. Therefore, increasing flap perfusion requires finding ways to augment inflow and outflow as well as reducing intrinsic flap resistance, which can be transposed to Ohm's law in a vascular setting.

$$F_t = \frac{\delta P}{\int R} \quad (1)$$

where F is the flow at a given time "t"; δP is the pressure gradient between inflow (artery) and outflow (vein); and $\int R$ is the finite vascular resistance value at the given time "t."

The determining factors for flap survival are (1) the pressure gradient between blood inflow and outflow and (2) the intrinsic vascular resistance of the flap. Widening the pressure gradient requires either increasing blood

inflow into a flap or its venous outflow, or a combination of both. This requires the selection of the largest possible perforator within a flap and, where necessary, dissecting it to the source vessel to find the largest diameter of the perforator complex.

Vascular inflow and outflow may be augmented by including a cuff of tissue (eg, muscle from the source vessel toward the entry point of the perforator into the flap). This allows the capture of all afferent arborizing elements of the perforators and their minor channels. This can increase the length of these flaps as exemplified with the lateral nasal artery perforator (LNAP) flaps in this series (Figs. 5-6). This is especially true in the facial artery angiosome, as the arterial and venous components of the perforator complex are often separate. These perforating vessels typically arborize into three to five mini-perforators from the underlying lateral nasal artery, with each less than 0.5mm in diameter. During the initial experience with the first three LNAP flaps, the overlying skin could not survive beyond the mid-alae point, but the inclusion of a cuff of the levator labii superioris alaeque nasi, the muscle overlying the lateral nasal artery, has allowed all subsequent LNAP flaps to completely reconstruct the nasal alae

subunit without any flap necrosis or postoperative congestion. This stresses the need to preserve peri-perforator tissue and, by extension, zone of the perforator complex so as to improve flap survival.

The second element to consider with the propeller flap following its inset is its propensity to cause venous congestion due to the kinking of its thin-walled veins/venules on pivoting the flap. This risk rises with increasing torsion angles as it slows down venous return, hence allowing for greater thrombogenicity within the flap vasculature. In this setting, it is essential to have a draining port for the outflow (eg, venous supercharging).⁶

A recent study of venous supercharging lower limb propeller and free flaps conclusively showed that venous supercharging reduces venous congestion and speeds up wound healing.^{11,12} However, when expanding this to all regions of the body on a free-style basis, a super-microsurgical skillset is called for because it substantially increases the probability of performing an optimal venous anastomosis. This equally requires increased meticulousness when raising these flaps, as every possible vein up to 0.3 mm in diameter, whether subcutaneous¹⁰ or perforator,¹³ will have to be preserved. This additional care is certainly worthwhile in terms of flap survival, as demonstrated in this study.

A recent study detailing a mathematical model for perforator flaps in general has shown that intrinsic vascular resistance within these flaps rise exponentially, the further away from its vascular pedicle that one goes. This is due to a compound additive effect of perforasomal vascular resistance in-series. Distal venous supercharging does, however, reduce flap vascular resistance mathematically, by means of introducing a flowthrough-like effect.¹⁴

Taking a step back, however, it becomes evident that this level of detailed dissection is not necessary in all cases. When the source perforator diameter is greater than 2 mm, we find that this approach is not necessary (eg, in the originally described propeller flaps of the lower limbs based on the perforators of the posterior tibial artery).⁸ Therefore, an algorithmic approach to propeller flap dissection as described above is important in selecting only those flaps that require additional modifications.

CONCLUSIONS

To summarize, propeller flaps are a useful reconstructive option, but to ensure optimal results, careful preoperative planning and the surgical agility to make intraoperative decisions based on very detailed dissections are crucial for the best outcomes. With the benefit of our experiences, we propose this algorithmic approach

to propeller flap dissection based on an understanding of perforator arborization before entry into the flap, and a super-microsurgical skillset for the supercharging of sub 1-mm veins ad hoc.

Ankur Khajuria, MRCS, PhD

Kellogg College

University of Oxford

Oxford, UK

E-mail: ankur.khajuria09@imperial.ac.uk

REFERENCES

1. Milton SH. Pedicled skin flaps: the fallacy of the length:width ratio. *Br J Plast Surg*. 1969;56:381.
2. Asko-Seljavaara S. Free style free flap. Paper presented at: Seventh Congress of the International Society of Reconstructive Microsurgery; June 19–30, 1983; New York, N.Y.
3. Wallace CG, Kao HK, Jeng SF, et al. Free-style flaps: a further step forward for perforator flap surgery. *Plast Reconstr Surg*. 2009;124(Suppl 6):e419–e426.
4. Bravo FG, Schwarze HP. Free-style local perforator flaps: concept and classification system. *J Plast Reconstr Aesthet Surg*. 2009;62:602–8; discussion 609.
5. Gravvanis A, Tsoutsos D, Papanikolaou G, et al. Refining perforator selection for deep inferior epigastric perforator flap: the impact of the dominant venous perforator. *Microsurgery*. 2014;34:169–176.
6. Figus A, Wade RG, Gorton L, et al. Venous perforators in DIEAP flaps: an observational anatomical study using duplex ultrasonography. *J Plast Reconstr Aesthet Surg*. 2012;65:1051–1059.
7. Teo TC. The propeller flap concept. *Clin Plast Surg*. 2010;37:615–26, vi.
8. Saint-Cyr M, Wong C, Schaverien M, et al. The perforasome theory: vascular anatomy and clinical implications. *Plast Reconstr Surg*. 2009;124:1529–1544.
9. D'Arpa S, Cordova A, Pignatti M, et al. Freestyle pedicled perforator flaps: safety, prevention of complications, and management based on 85 consecutive cases. *Plast Reconstr Surg*. 2011;128:892–906.
10. Vijayan R, Al-Aswad F, Kannan RY. Supermicrosurgery-assisted venous supercharging of a reverse-flow angular artery perforator flap for nasal reconstruction. *J Plast Reconstr Aesthet Surg*. 2017;70:281–283.
11. Chaput B, Bertheuil N, Grolleau JL, et al. Comparison of propeller perforator flap and venous supercharged propeller perforator flap in reconstruction of lower limb soft tissue defect: a prospective study. *Microsurgery*. 2018;38:177–184.
12. Kim CY, Kim YH. Supermicrosurgical reconstruction of large defects on ischemic extremities using supercharging techniques on latissimus dorsi perforator flaps. *Plast Reconstr Surg*. 2012;130:135–144.
13. Ono S, Ogawa R, Eura S, et al. Perforator-supercharged perforator-based propeller flaps. *Plast Reconstr Surg*. 2012;129:875e–877e.
14. Tao Y, Ding M, Wang A, et al. Basic perforator flap hemodynamic mathematical model. *Plast Reconstr Surg Glob Open*. 2016;4:e714.