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Septocutaneous perforator mapping and clinical applications of the medial arm flap

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Summary *Background:* The medial arm flap has a long history but remains underused despite providing multiple advantages. We reviewed our experience with using the medial arm flap to clarify the distribution of septocutaneous perforators and its relationship with pedicled flap design.
Patients and methods: This retrospective study included 36 consecutive patients who underwent reconstructive surgery with a medial arm flap (42 arms). Septocutaneous perforator mapping was conducted using a refined coordinate system originating at the medial epicondyle, with the *y*-axis running to the axillary apex.
Results: At least three perforators were identified along the medial intermuscular septum of the arm, located densely at 88 ± 8%, 49 ± 9%, and 20 ± 6% of the distance between the medial epicondyle and axillary apex (i.e., arm length), with a prevalence of 95.2%, 100%, and 85.7%, respectively. All arms had at least one medium- or large-sized perforator, and 90.5% of arms had at least two such perforators. Twenty-nine flaps were transferred as pedicled distant flaps for head and neck reconstruction or hand reconstruction, while the remaining 13 were transferred as perforator-based propeller flaps for axillary, elbow, or chest wall reconstruction. Thirty-six flaps underwent pre-transfer expansion. The average flap size was 157.9 ± 64.5 cm^2 (range: 40-330 cm^2). All flaps were successful, except for one perforator-based flap, which was replaced due to partial loss. Donor site morbidity was minimal.
Conclusions: Given its rich septocutaneous perforator distribution, the medial arm flap can be harvested reliably with versatile design and minimal donor site morbidity, thus deserving more attention in reconstructive surgery.

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Introduction

The medial arm flap has been used in soft tissue reconstruction for hundreds of years, since Tagliacozzi first described it in his treatise on plastic surgery in 1597.[1] This flap offers multiple advantages including thinness, pliability, fine color, hairless surface, and well-concealed donor site scar. Ensuring adequate blood supply represents an important issue when using the medial arm flap. The superior ulnar collateral artery (SUCA) is generally considered the dominant blood supply to the medial arm,[2-6] and the medial arm flap can be transferred as a free flap based on the SUCA. In fact, the direct cutaneous branches of the brachial artery, namely, the septocutaneous perforators, provide significant blood supply to the medial arm skin.[7] Although many authors[8-10] have corroborated the significance of the septocutaneous perforators in the medial arm flap, this flap remains underappreciated because of the anatomical variations of such perforators.

Several constant perforators of the medial arm have been identified using cadaveric dissections.[11-13] However, perforator mapping based on absolute distances does not account for discrepancies in arm length, which leads to reduced accuracy and reproducibility of the measurements. Furthermore, while the constant perforators identified near the middle portion of the arm are helpful for designing free flaps, they generally cannot provide sufficient supply for pedicled perforator flaps, especially with a propeller design.

In this study, we reviewed our experience with the medial arm flap to clarify the distribution of septocutaneous perforators and its relationship with pedicled flap design. For this purpose, we devised a modified methodology to map the perforators based on relative rather than absolute distances in a coordinate system, as originally proposed by Tinhofer et al.[13] We hope that our findings will promote the clinical applications of the medial arm flap.

Patients and methods

Patients and study design

This retrospective study was conducted with approval from the institutional ethics committee, in conformance with the Helsinki Declaration, and in strict adherence to the STROBE guidelines. Between March 2014 and January 2018, reconstructive surgery with medial arm flaps was performed in 36 patients, and all were included in this study (42 arms). The number, size, and location of the septocutaneous perforators were explored and recorded intraoperatively. There were 24 male patients and 12 female patients, with an average age of 23.6 years (age range: 5–66 years) and body mass index of $18.7 \pm 3.5\,kg/m^2$. The etiologies included post-burn scar ($n = 27$), sarcoma ($n = 5$), and congenital melanocytic nevus ($n = 4$). After lesion resection or scar contracture release, there were 42 resultant defects requiring flap reconstruction in the head and neck ($n = 26$), axilla ($n = 7$), elbow ($n = 4$), hand ($n = 3$), and chest wall ($n = 2$) (see Table, Supplementary Digital Content 1, which summarizes the demographics and indications of patients undergoing medial arm flap surgery).

Mapping the perforator distribution

Considering the patient positioned supine with the arm abducted at 90° and supinated to expose the medial side, we established a coordinate system for perforator mapping, as described elsewhere[12,13] (Figure 1). The coordinate system originated at the medial epicondyle, with the *y*-axis running from the medial epicondyle to the apex of the axilla, defined at the midpoint between the anterior and posterior axillary lines. The *y*-axis thus corresponded to the surface marking of the medial intermuscular septum. The arm length was defined as the distance between the medial epicondyle and axillary apex. The borders of each third of the *y*-axis were marked on the skin. The axis of the flap was centered along the *y*-axis, and the maximum flap territory extended from the anterior to the posterior midline of the arm, along the full length of the arm.

Operative details

One or both arms were chosen, according to the location and size of the defect. The patient was positioned supine, with the arm abducted at 90° and supinated to expose the medial side. Staged operations were performed for flaps that required pre-transfer expansion, and perforator mapping of the medial arm was thus also conducted in two stages. In the first stage, an incision was made along the anterior edge of the designed area. Suprafascial dissection proceeded until the medial intermuscular septum. Several septocutaneous perforators emerging from the septum could be visualized, and their number was recorded (Figure 2A). The locations of the perforators emerging from the septum were marked on the skin surface with methylene blue. For each perforator, the distance from the medial epicondyle was measured and recorded. The size of the perforators at the fascial level was categorized as large (>1 mm), medium (0.5–1 mm), or small (<0.5 mm), as described elsewhere.[14] Based on our prior experience with cadaveric dissection, the dissection in this first stage stopped at 3 cm distal to the axillary apex or 5 cm proximal to the medial epicondyle, where the perforators presented densely. After ligating the perforators separately from the designed pedicle, the dissection continued posteriorly until an adequate pocket was achieved for the placement of an expander with proper size. In the second stage, a proximally or distally based pedicled flap was elevated, and the proximal or distal septocutaneous perforators were further explored (Figure 2B, C). All perforators recorded in both stages were analyzed. To account for discrepancies in arm length, perforator positions were expressed relative to the arm length, considering the medial epicondyle as the origin and the axillary apex at 100% of the arm length along the *y*-axis of the defined coordinate system.

Flap design and clinical applications

When used for head and neck reconstruction or hand reconstruction, the medial arm flap was elevated as a proximally or distally based pedicled distant flap with the dominant perforator preserved in the pedicle. The distal portion of

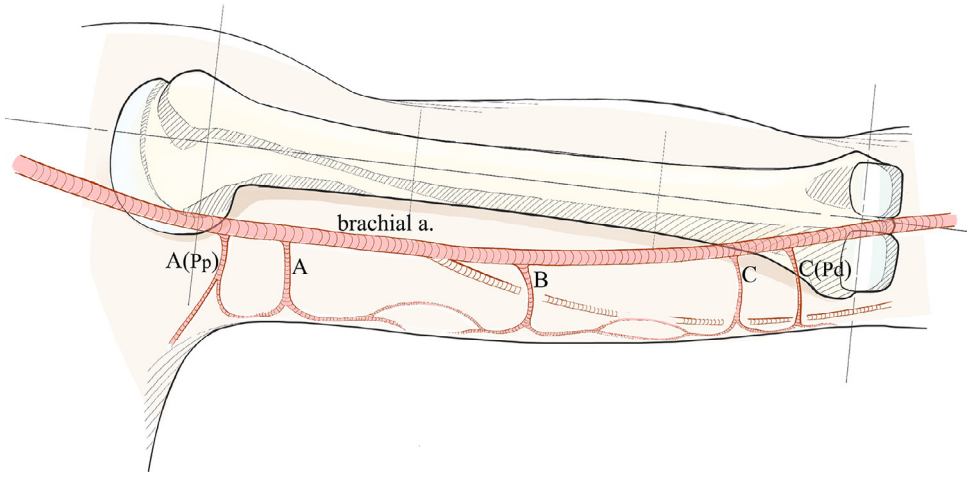

Figure 1 Schematic drawing of septocutaneous perforators originating from each third along the medial intermuscular septum of the arm. The perforators in the proximal, middle, and distal third of the arm length (distance between the medial epicondyle and axillary apex) were designated as A, B, and C, respectively. Brachial a.: brachial artery, A(P_p): first perforator in the proximal third, C(P_d): last perforator in the distal third.

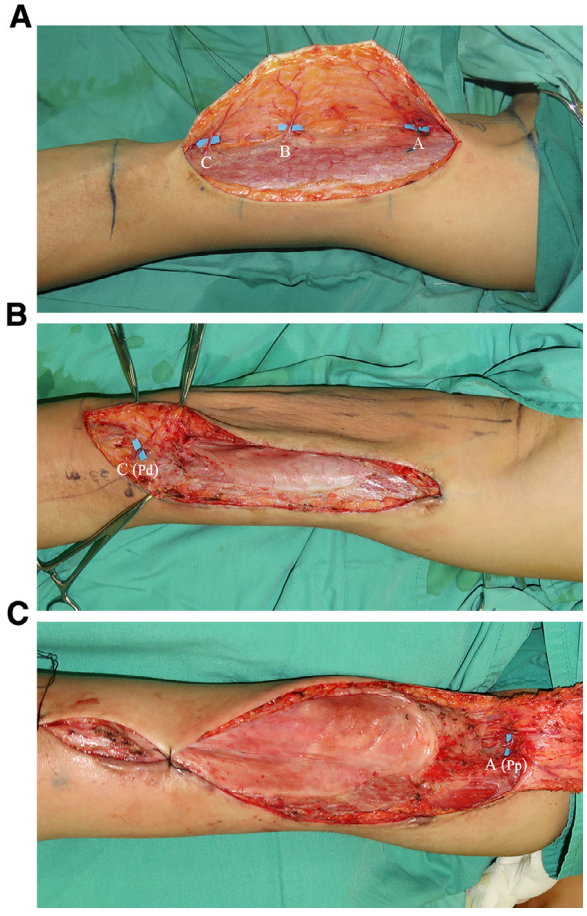

Figure 2 Two-stage mapping of septocutaneous perforators. A. During the first stage, which involved expander placement, three septocutaneous perforators were identified, with each located in a different third of the arm. B, C. In the second stage, the septocutaneous perforators were further explored distally and proximally.

the flap was transferred to reconstruct the defect by the Tagliacozzi method (for head and neck reconstruction) or in a cross-arm fashion (for hand reconstruction). The proximal portion was either sutured as a skin tube or overlapped with the residual lesion flap (see Figure, Supplementary Digital Content 2, which illustrates the technique for transferring the medial arm flap as a pedicled distant flap). Pedicle division was performed at 3 weeks after surgery. The residual lesion was excised and resurfaced with the remaining flap.

Perforator-based propeller flaps were used for axillary, elbow, or chest wall reconstruction (Figures 3 and 4). Retrograde dissection was performed to achieve adequate pedicle length. Then, the flap was rotated at specific angles to cover the defect. Care was taken to avoid any kinking, twisting, or tensioning of the pedicle. The donor site was closed either primarily or using a flap or skin graft. Indocyanine green angiography using the SPY imaging system (Novadaq Technologies Inc., Richmond, BC, Canada) was performed to evaluate flap perfusion intraoperatively (see Video, Supplementary Digital Contents 3 and 4, demonstrating intraoperative SPY imaging of flap perfusion). SPY-Q Analysis Toolkit software (Novadaq Technologies Inc.) was used to quantify perfusion depending on the fluorescence of the area of interest relative to the fluorescence noted in other areas within the field of view (Figure 5) (see also Figure, Supplementary Digital Content 5, which demonstrates the excellent flap perfusion of a proximally based pedicled medial arm flap).

Results

Patients and flaps

A total of 42 medial arm flaps were used in 36 patients, with 6 patients undergoing bilateral flap transfers. Of these, 36 flaps (in 30 patients) were pre-expanded using a rectangular expander, to a volume of 80–400 mL (Shanghai Winner

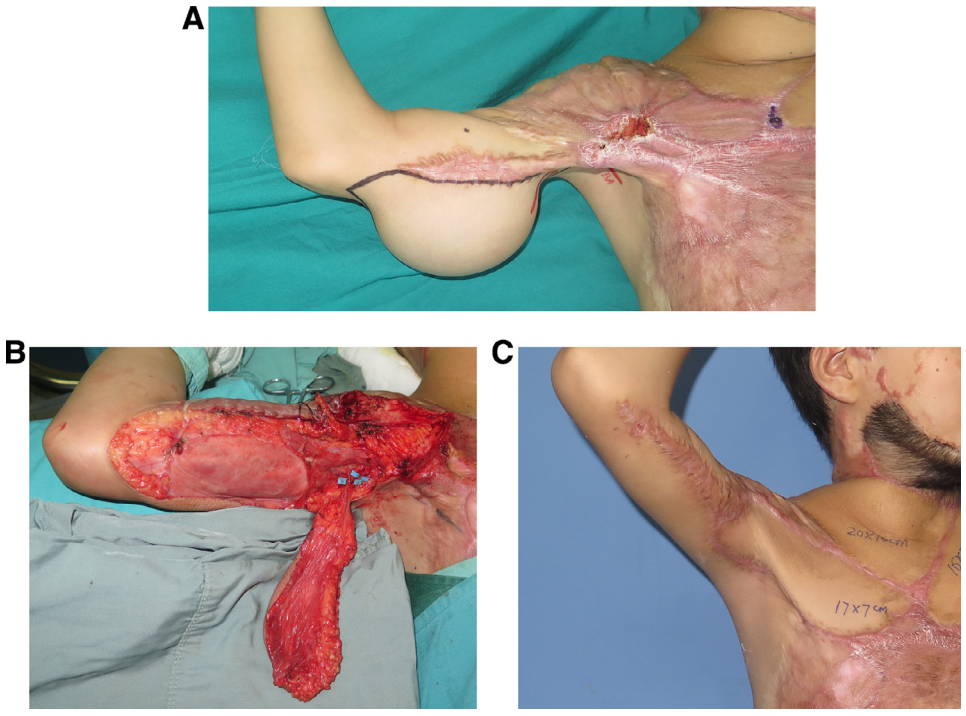

Figure 3 Axillary reconstruction using the perforator-based propeller flap. A. Preoperative view showing scar contracture of the right anterior axilla, with the medial arm skin pre-expanded. B. Intraoperative photograph of an elevated perforator-based medial arm flap measuring 119 cm^2 (17×7 cm^2), with a 3.5-cm long pedicle, based on a large-sized septocutaneous perforator located proximally. C. Postoperative view showing improved axillary range of motion with esthetic appearance.

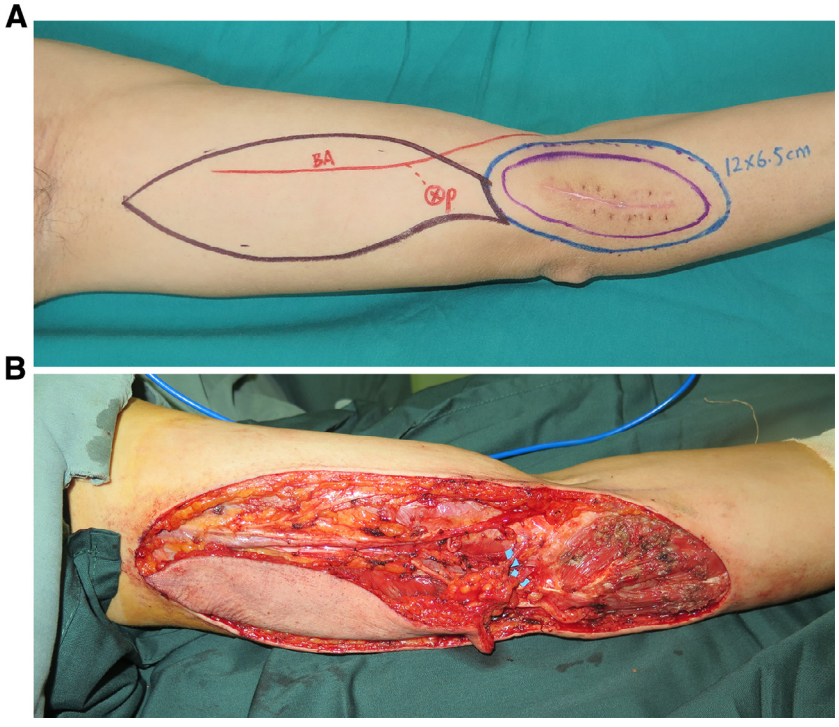

Figure 4 Elbow reconstruction using the perforator-based propeller flap. A. Design of a distally based flap. B. Intraoperative photograph of the elevated perforator-based medial arm flap measuring 82.5 cm^2 (15×5.5 cm^2), with a 3.0-cm long pedicle.

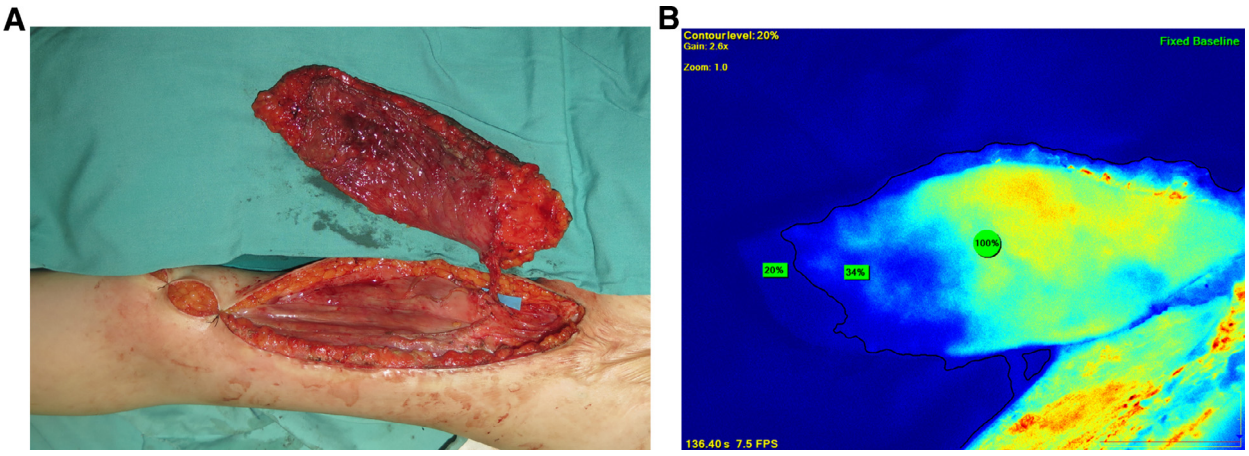

Figure 5 Perfusion of flaps for axillary reconstruction. A. Intraoperative photograph of a perforator-based medial arm flap measuring 220 cm^2 (22 × 10 cm^2), based on a large-sized perforator located proximally. B. Intraoperative fluorescence imaging revealing relatively good flap perfusion.

Table 1 Characteristics and outcomes of 42 medial arm flaps.

Characteristic	Pedicled distant flap	Perforator-based propeller flap
Patients receiving the flap	25 (69.4)	11 (30.6)
Flaps used	29 (69.0)	13 (31.0)
Proximally based	18 (62.1)	9 (69.2)
Distally based	11 (37.9)	4 (30.8)
Pre-expansion	29 (100)	7 (53.8)
Flap size, cm^2	10 × 4 to 22 × 15	14 × 5 to 22 × 10
Pedicle length, cm	N/A	2.5–4.5
Complications		
Partial flap loss	0	1 (7.7)[a]
Hematoma	1 (3.4)[b]	0
Venous congestion	0	2 (15.4)[c]

Data are given as frequency (percentage), frequency, or range, as appropriate.
[a]Healed after surgical debridement and a second flap transfer.
[b]Recovered after surgical removal of hematoma.
[c]Resolved after removal of compression on the pedicle and bloodletting by the needle prick technique.

Plastic Surgery Products Co., Ltd., Shanghai, China). Expansion was achieved over the course of 24.2 ± 5.9 weeks, and all expansions were completed successfully. An average of 2.6 ± 0.9 surgical procedures (range: 1–4 procedures) were performed per patient. Among the 42 flaps in this study, 29 were used as pedicled distant flaps (in 25 patients) and 13 as perforator-based propeller flaps (in 11 patients). The average flap size was 157.9 ± 64.5 cm^2 (range: 10 × 4 to 22 × 15 cm^2), with a perforator pedicle length of 3.2 ± 0.6 cm (range: 2.5–4.5 cm). All patients tolerated the surgery well, and all but four flaps healed uneventfully. One pedicled distant flap developed hematoma after pedicle division but recovered with re-exploration and hematoma removal. One perforator-based flap had partial loss of the distal third due to arterial insufficiency, requiring surgical debridement followed by a second flap transfer. Finally, two perforator-based flaps had venous congestion but survived completely with conservative therapy (Table 1).

Table 2 Characteristics of septocutaneous perforators in the medial arm.

Characteristic	Perforator		
	A (proximal)	B (middle)	C (distal)
Prevalence, %	95.2	100	85.7
Relative position on *y*-axis[a]	0.88±0.08	0.49±0.09	0.20±0.06
Size, %			
Large	47	6	10
Medium	31	48	37
Small	22	45	53

The perforators in the proximal, middle, and distal third of the arm were designated as A, B, and C, respectively.
[a]Perforator locations are given as relative values obtained as the distance from the medial epicondyle to the perforator divided by the total arm length (distance between the medial epicondyle and axillary apex).

Perforator distribution

On average, 4.5 ± 1.4 (range: 3–8) septocutaneous perforators from the medial arm were identified, with a total of 190 perforators in 42 arms. The average arm length was 20.5 ± 2.8 cm (range: 15–25 cm). There were at least three perforators in all arms, including at least one medium- or large-sized perforator in 100% of arms and at least two such perforators in 90.5% of arms. The proximal, middle, and distal thirds of the arm were found to have 1.5 ± 0.1 (range: 0–3), 1.6 ± 0.1 (range: 1–4), and 1.4 ± 0.2 (range: 0–3) perforators, respectively. Because all perforators were identified to lie within 1 cm above or below the *y*-axis, we did not analyze *x*-axis data any further. The perforators in the proximal, middle, and distal third of the arm were designated as A, B, and C, respectively. The first perforator in the proximal third and the last perforator in the distal third were designated as P_p and P_d, respectively (Figure 1). The distribution of perforators was mapped on the *y*-axis (Figure 6). The characteristics of the identified perforators are summarized in Tables 2 and 3.

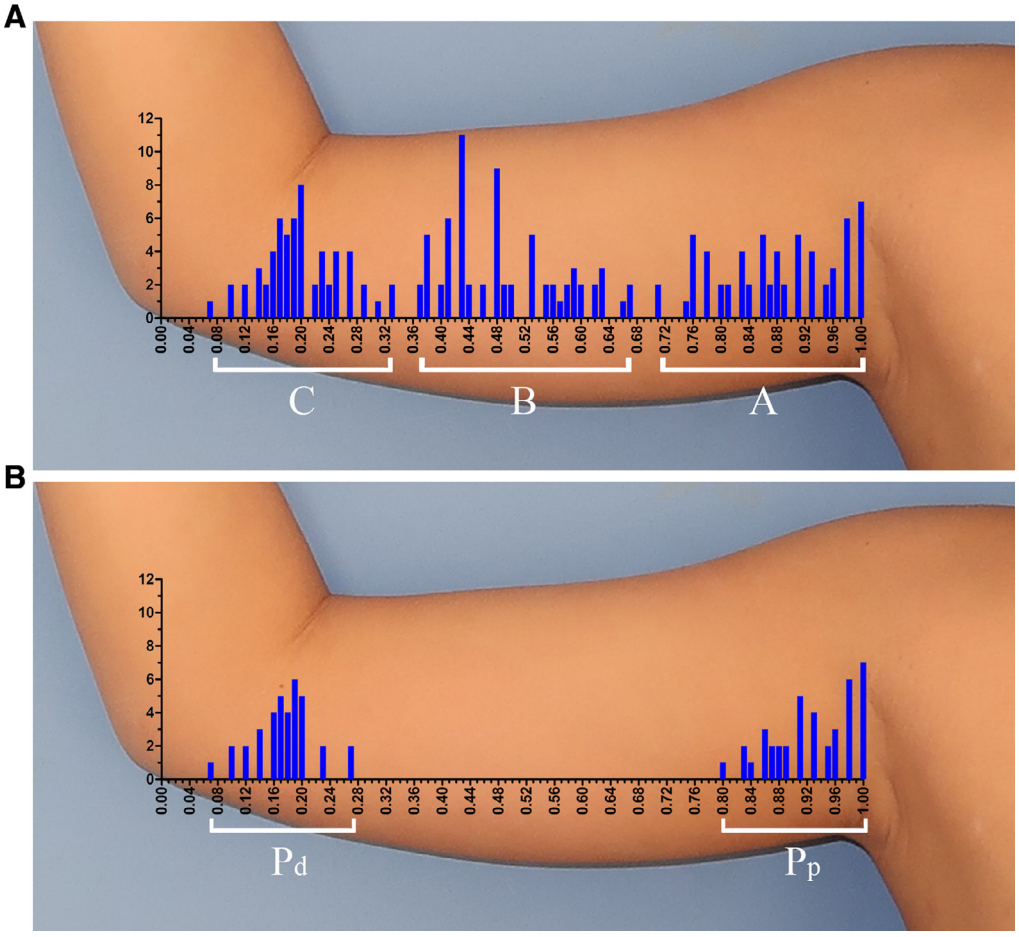

Figure 6 Septocutaneous perforator mapping in the medial arm. The locations are given as relative values obtained as the distance from the medial epicondyle to the perforator divided by the total arm length (distance between the medial epicondyle and axillary apex). A. The perforators in the proximal, middle, and distal third of the arm were designated as A, B, and C, respectively. B. P_p: first perforator in the proximal third, P_d: last perforator in the distal third.

Table 3 Characteristics of the outermost perforators P_p and P_d.

Characteristic	Perforator	
	P_p	P_d
Prevalence, %	95.2	85.7
Relative position on *y*-axis[a]	0.93 ± 0.06	0.17 ± 0.04
Size, %		
Large	65	11
Medium	25	44
Small	10	44

P_p and P_d were defined as the first perforator in the proximal third and the last perforator in the distal third of the arm, respectively.
[a]Perforator locations are given as relative values obtained as the distance from the medial epicondyle to the perforator divided by the total arm length (distance between the medial epicondyle and axillary apex).

Donor site management

All but four donor sites were closed directly. At three donor sites, where the flap had required elevation with extreme pre-expansion (width: 11–12 cm) for total cheek defect reconstruction, the defect was closed using another flap from the dorsal region. The remaining donor site, where no pre-expansion had been conducted before chest wall reconstruction, was closed with a split-thickness skin graft. Donor-site morbidity was minor. No patients reported shoulder stiffness or required intervention after pedicle division. One patient had numbness and decreased strength involving the whole donor upper extremity after pedicle division, which resolved spontaneously within 4 weeks. A slightly widened scar without itching or pain commonly developed at the donor site, but no patients reported dissatisfaction with the appearance.

Discussion

With the development of the angiosome concept and perforasome theory,[15] perforator flaps have become increasingly used in reconstructive surgery. Adequate perforator mapping ensures optimal flap design.[14,16] In the medial arm flap territory, the major blood supply is provided by the septocutaneous perforators, which arise from the brachial

artery, SUCA, inferior ulnar collateral artery, or superficial brachial artery, if present.[7-13,17,18] Only three anatomical studies have focused on perforator mapping for this flap, reporting inconsistent results.[11-13] Hwang et al.[11] found that a constant perforator could be found within a circle of diameter 2.89 cm, centered 8.9 cm above and 1.2 cm medial to the medial epicondyle. Perignon et al.[12] reported the same but for a circle of radius 2.4 cm, centered at 7.5 cm above and 0.5 cm medial to the medial epicondyle. Finally, Tinhofer et al.[13] reported the same but for a circle of radius 3 cm, centered at 8 cm above and 1 cm medial to the medial epicondyle. The discrepancies probably arise from reporting absolute distances while using different coordinate systems, which originated from the medial epicondyle but had the *y*-axis running either to the acromion[11] or to the axillary apex.[12,13] Second, the information provided by these anatomical studies can indeed help guide the harvesting of free perforator flaps but not that of pedicled perforator flaps, which tend to be harvested more proximal to the midpoint of the arm, or of perforator-based propeller flaps, which must be harvested from near the defect.[19] Third, the musculocutaneous perforator, which is the nondominant vessel in the medial arm, was not excluded explicitly.[12,13] Finally, anatomical studies do not reflect clinical experience because cadavers have altered vascular patency and lack blood flow.[13]

To account for discrepancies in arm length, we expressed perforator positions relative to arm length and mapped them in a coordinate system as described by Tinhofer et al.[13] However, we further refined the coordinate system by trisecting the *y*-axis and analyzing the perforators of each third separately. Moreover, while Tinhofer et al. reported absolute numbers of the constant perforators for a mean arm length of 25 cm, we aimed to improve reproducibility and thus reported such results in relative values. All perforators could be identified around the surface marking of the medial intermuscular septum (*y*-axis). Finally, we found constant perforators of each third located densely at 88%, 49%, and 20% of the arm length, with the most proximal and the most distal septocutaneous perforators located at 93% and 17% of the arm length, respectively. Given the arm length, the absolute location of such perforators can be readily obtained. This can serve as a valuable guide for both pedicled and free perforator flaps, which represents a distinct advantage of the present study. When a proximally or distally pedicled perforator flap is indicated, one of the outermost constant perforators with a large caliber could be chosen as the pedicle. In our study, all nine proximally pedicled perforator flaps were elevated based on perforator P_p (which was medium or large), while the four distally pedicled perforator flaps were based on perforator P_d or another C perforator of sufficient size (if P_d was small). When a free flap is needed, any large-sized perforator can be considered.

We found an average of 4.5 perforators along the medial intermuscular septum of the arm, which is consistent with previous observations.[9,11-13,20] According to the angiosome theory, elevating a medial arm flap with full length should be based on at least 1.5 perforator angiosomes connected by true anastomoses,[21] as medial arm flaps based on a single perforator have less favorable survival.[22-24] A recent three-dimensional reconstruction of the arm based on angiography in cadavers revealed intricate vascular anatomy and chain-linking of vessels without a change in caliber.[25] Intraoperative imaging with indocyanine green and SPY technology is useful for evaluating real-time perfusion but may overestimate flap viability.[26] Based on our experience, relatively good perfusion of the perforator-based flaps with full arm length generally reflects the establishment of true anastomoses. Additionally, the safe size of the perforator-based medial arm flap was 109.5 ± 41.3 cm^2, which is consistent with the average angiosome size reported in cadavers.[13]

Regarding clinical applications, the medial arm flap is used as a pedicled flap[3,10,27-29] or a free flap,[2,4-6,8,17,18] both in fasciocutaneous[10,27,28] and in perforator flap surgery.[22-25] We typically transferred the medial arm flap as a pedicled distant flap or a perforator-based propeller flap, reflecting the versatility of this medial arm flap in various reconstructions. Tissue expansion was used in most flaps to increase flap vascularity and size, as well as to allow primary closure of the donor site with reduced morbidity.[30] When elevating a pedicled distant flap, which is not a random-pattern flap but a perforator-plus flap,[31] the key technical point is to preserve the proximal or distal perforators within the flap pedicle. Robust blood supply guarantees reliable transfer of large pre-expanded pedicled distant flaps measuring up to 330 cm^2 (22×15 cm^2). Similarly, a large-sized perforator with good venae comitantes can adequately supply full-length perforator-based medial arm flaps. In our study, flaps with a maximum safe size of 220 cm^2 (22×10 cm^2) were elevated after pre-expansion. Major disadvantages of the pedicled distant flap include the need for a multiple-staged procedure (generally, three for a single pre-expanded flap) and donor arm immobilization. However, all patients in our study tolerated the surgery well and completed the therapy. Moreover, the learning curve is short, and there is no need for sophisticated microsurgical vascular anastomosis. Furthermore, even larger flaps are viable and provide excellent skin quality, making them especially suitable for massive facial defect reconstruction.[29] To our knowledge, no report has described the transfer of a larger medial arm flap, either pedicled or free.

Perforator-based propeller flaps of the upper limb provide multiple advantages including adequate tissue match, ample rotation, and reliable transfer.[19] In our series, we used perforator-based medial arm flaps with propeller flap design for axillary and elbow reconstruction. In all cases, joint function improved substantially. Additional advantages of perforator-based propeller flaps include easy flap harvest due to the septocutaneous perforator; esthetic appearance, without residual dog-ear at the base of the flap[27]; possibility to use proximal perforator-based propeller flaps to manage both anterior and posterior axillary contracture; ability to elevate the flap based on the distal perforator without disturbing the ulnar nerve, which is not possible when using the reverse medial arm flap.[28] In our study, venous compromise (albeit minor) occurred in two of the four distal perforator-based flaps, probably because there were fewer medium- and large-sized perforators in the distal than in the proximal third of the arm (Table 2).

Perforator length, though a significant determinant of vessel patency in propeller flaps,[32] was not measured in all patients who underwent pedicled distant flap transfer because extensive perforator dissection was unnecessary.

We could measure the perforator length in propeller flaps and found an average of 3.2 cm, in agreement with previous observations.[17,18] Our findings suggest that perforators may be absent from the proximal and the distal thirds of the arm in 4.7% and 14.3% of cases, respectively, precluding the elevation of a perforator-based flap. Handheld Doppler ultrasound, although used widely, may play a limited role in planning perforator-based medial arm flap surgery preoperatively because the subcutaneous tissue of the medial arm is relatively thin and the brachial artery is wholly superficial, making it difficult to differentiate between Doppler signals from the main vessel versus the perforators.[19] To guarantee flap surgery success, it is recommended to make an exploratory incision[13] and establish an alternative plan, such as delayed procedures.

Conclusions

The medial arm is expected to contain at least three septocutaneous perforators, densely located at 88%, 49%, and 20% of the arm length (relative to the medial epicondyle). Thus, the medial arm flap can be reliably harvested with great freedom, versatility, and limited donor site morbidity, deserving much attention in reconstructive surgery.

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

Conflict of interest

None.

Supplementary material

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.bjps.2019.01.025.

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