Versatility of Free Cutaneous Flaps for Upper Extremity Soft Tissue Reconstruction

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J Hand Microsurg 2017;9:58–66.

Abstract

Keywords

- ▶ free cutaneous flaps
- ▶ upper extremity reconstruction
- ▶ anterolateral thigh flap
- ▶ superficial circumflex iliac artery flap
- ▶ deep inferior epigastric perforator flap
- ▶ superficial inferior epigastric artery flap

The goals of upper extremity soft tissue reconstruction should go well beyond providing coverage and restoring function. As the field of reconstructive microsurgery has evolved, free cutaneous flaps (FCFs) are gaining wider application. The advantages of FCF include minimizing donor-site morbidity by preserving the muscle and fascia, improving versatility of flap design, and superior aesthetic results. This review highlights the application of anterolateral thigh, superficial circumflex iliac artery, deep inferior epigastric perforator, superficial inferior epigastric artery, and flow-through flaps for reconstruction of upper extremity defects. These flaps share several qualities in common: well-concealed donor sites, preservation of major arteries responsible of providing inflow to distal extremity, and potential for a two-team approach (donor and recipient sites). While the choice of flaps should be decided based on individual patient and defect characteristics, FCF should be considered as excellent options to achieve the goals of upper extremity reconstruction.

Introduction

Upper extremity defects resulting from trauma or oncologic resection represent unique challenges for reconstruction because of the potential requirements for a large area of coverage, obliteration of dead space, and provision of vascularized and durable tissue through which secondary procedures can be performed.¹ Though some local flap options, such as the radial and ulnar artery pedicle flaps, exist, they often provide insufficient amount of tissue and steal an arterial inflow and a venous outflow from an already injured extremity.² This can potentially lead to arterial and venous insufficiency that could result in claudication, cold intolerance, chronic edema, and even tissue necrosis.^{3,4}

In terms of free tissue transfers, muscle flaps have sometimes been used for large upper extremity defects because of their robust vascularity, long pedicle, and ability to obliterate dead space. However, major limitations of muscle flaps exist, including donor-site morbidity associated with sacrifice of a functional muscle, need for skin graft, and difficulty with flap elevation for future revisions. In breast reconstruction, the evolution of autologous abdominal tissue options has progressed from transverse rectus abdominis muscle (TRAM) flaps to muscle-sparing TRAM to deep inferior epigastric perforator (DIEP) and superficial inferior epigastric artery (SIEA) flaps. Similarly, the next logical advancement in upper extremity reconstruction is free cutaneous flaps (FCFs), which further reduces donor-site morbidity and allows for

received

February 2, 2017

accepted after revision

May 19, 2017

published online

June 27, 2017

© 2017 Society of Indian Hand & Microsurgeons

DOI <https://doi.org/10.1055/s-0037-1603918>

ISSN 0974-3227.

one-staged repair with early mobilization, decreased edema, and improved aesthetic results.

Cutaneous flaps can include any or all suprafascial components and are supplied by perforating vessels from the deep fascia. The advantages of FCF include minimal donor-site morbidity, versatility in design, possible flap thinning at the time of elevation or at a future date, potential for reinnervation of recipient site, superior aesthetic outcomes, and potential availability of cutaneous veins as a venous outlet.⁵ The major disadvantages include the technical demands of performing perforator dissection and the need for anastomosing small-caliber vessels; however, continued improvements in surgical technique and knowledge of vascular anatomy have reduced these barriers.^{6,7} The versatility of FCF makes them important options for management of challenging upper extremity defects.

The purpose of this article is to highlight several important FCF for upper extremity reconstruction, review the evidence for their application, and present representative examples of each type of flap. The flaps included in this review are well-suited for upper extremity reconstruction because of several factors: (1) minimizing donor-site morbidity by preserving muscle and fascia; (2) improving versatility of flap design; (3) achieving a more compatible, better textured, and durable coverage; (4) avoiding using a flap that requires sacrifice of a major vessel providing inflow to the extremity; (5) can be harvested with the patient in the supine position, thus avoiding intraoperative repositioning and facilitating a two-team approach; (6) having potential to create a sensate flap that has particular importance in the hand; (7) well-concealed donor-site scar for optimal aesthetic outcome at both donor and recipient sites.

Anterolateral Thigh Flap

Since its introduction in 1984 by Song et al,⁸ the free anterolateral thigh (ALT) flap has gradually become the workhorse flap for soft tissue reconstruction of head and neck defects and has gained increasing popularity in reconstruction of abdominal, pelvic, and extremity defects.⁹ This popularity derives from its versatility, reliable perforators, and long vascular pedicle. The ALT flap may be harvested as a musculocutaneous, fasciocutaneous or suprafascial flap and may also include other tissue types such as the fascia lata or bone from the iliac crest.¹⁰ This versatility makes the ALT flap an excellent option for reconstruction of both proximal and distal upper extremity defects.

The arterial supply of the ALT flap comes from the perforating vessels arising from the descending branch of the lateral circumflex femoral artery (LCFA), a branch of the profunda femoris. Distally, the descending branch travels between the vastus lateralis and rectus femoris muscles and gives off septo- and musculocutaneous perforators. Most perforators are located within a 3-cm radius of the midpoint from the anterior superior iliac spine (ASIS) to the lateral border of the patella (→Fig. 1A). Flap harvest is performed with the patient in the supine position, and dissection is started from the medial border of the flap proceeding until

Fig. 1 ALT flap harvest. (A) Preoperative flap marking with the patient in the supine position including both the flap dimensions and location of cutaneous perforators. (B) Cutaneous ALT flap with two perforators within a long vascular pedicle and the lateral femoral cutaneous nerve (black arrow).

cutaneous perforators are identified. After one or more perforators have been selected, they can be traced back to the main trunk of the descending branch of the LCFA. The LCFA pedicle length can range from 8 to 12 cm with a vessel diameter of greater than 2 mm.¹¹ The lateral femoral cutaneous nerve can be harvested for sensory reinnervation of the flap (→Fig. 1B). Primary closure of the donor site can usually be achieved with flap width of up to 6 to 9 cm whereas wider flaps may need skin grafting.¹² In some patients, the ALT flap can be bulky (→Fig. 2). Flap thinning may be required and can be performed at the time of elevation or a subsequent stage to improve contour (→Fig. 3).^{13,14} If a thin flap is required, such as in cases of distal upper extremity defects, a suprafascial dissection lends to the harvest of a thin flap.

A high success rate has been reported for free ALT flaps. Wei et al reported a flap survival rate of 97% in 501 cutaneous or fasciocutaneous free ALT flaps performed for a variety of indications.¹² Similarly, Lee et al reported a flap survival rate of 96% in patients with high-energy trauma.¹⁵ In cases of upper extremity reconstruction, results are also highly encouraging with flap survival rates ranging from 90 to 100% as described by several case series.^{16,17} Flap-related complications in upper extremity reconstruction have been reported in 25 to 27% of cases, including skin necrosis, infection, hematoma, and complete flap loss in one case.¹⁶⁻¹⁹

The ALT flap provides a large amount of soft tissue and can be used to reconstruct a wide range of upper extremity injuries. Its size and long vascular pedicle makes it well suited for large defects. Its disadvantage is that it may be bulky or hair bearing in some patients.

Fig. 2 Free ALT flap coverage of dorsal hand defect. (A) Extensive dorsal hand soft tissue defect with metacarpal fracture and exposed extensor tendons. (B) Immediately after coverage with nondebunked free ALT flap.

Fig. 3 ALT flap debulking. (A) ALT flap is elevated, and extensive debulking with remove of subcutaneous fat is performed. (B) Improved contour and appearance after flap debulking in a subsequent stage.

Superficial Circumflex Iliac Artery Flap

The groin flap, based on the superficial circumflex iliac artery (SCIA), was first described as a pedicled flap in 1972 by McGregor and Jackson and holds historical importance as the first successful free tissue transfer described in 1973.^{20,21} The

groin flap did not initially gain widespread application due to its variable arterial anatomy and flap bulk. However, it could provide a thin flap when harvested in the suprafascial plane and has a well-concealed donor site, making it an ideal option for reconstruction of distal upper extremity defects (►Fig. 4).

The SCIA most commonly arise from the femoral artery and vein, divides into superficial and ASIS, and usually runs superficial to the deep fascia of the sartorius muscle. In contrast, the deep branch runs beneath the deep fascia of the sartorius muscle prior to entering the suprafascial layer to give off several perforators. The orientation of the flap should be designed along the course of the SCIA to include the maximum number of perforators. To allow for primary closure of the donor site, the width of the flap should not exceed 8 cm.²² Flap elevation starts at the lateral border. A dominant perforator should be identified and dissected toward the deep fascia. The entire flap can be reliably supplied by the dominant perforator with a short segment of either the superficial or deep branch of the SCIA. A lateral cutaneous branch of the intercostal nerve may be preserved to create a sensate flap.²³

In their original paper, Koshima et al reported 10 cases of SCIA flaps for extremity reconstruction with 100% success rate.²⁴ Similarly, Hsu et al reported 100% success in a series of 12 patients who received SCIA flaps for reconstruction of extremity and head and neck defects.²⁵ Hong et al reported a series of 79 patients who received SCIA flaps for lower extremity reconstruction with the average flap size being 75.7 cm², and the authors achieved a 95% flap survival rate.²² In a follow-up study by the same group, Goh et al reported a success rate of 95.2% in 210 SCIA flap reconstructions for a variety of defects, majority of which were for reconstruction of upper and lower extremity defects.²⁶ In this series, the average flap size was 86.3 cm² and contained an average of 2.3 perforators per flap. For the donor site, the authors could achieve primary closure in all cases with a 1% donor site complication rate. Recently, Kim et al reported 52 cases of SCIA flap for reconstruction of distal upper and lower extremity with 2 cases of total flap loss and an average flap thickness of only 5 mm, demonstrating the potential for harvesting a thin and pliable flap ideal for distal upper extremity reconstruction.²⁷

The SCIA flap provides a thin- and moderate-sized flap that can be used to reconstruct defects of distal upper extremity. The major advantages of SCIA flap include a well-concealed scar and versatile flap thickness. One of the major disadvantages of the SCIA flap is a short pedicle with an average length of approximately 5 cm, which makes it not suited for deep defects.²⁶ Although the groin flap can also be used as a pedicled option, its use requires 2 to 3 weeks of upper extremity to groin attachment, which can lead to patient discomfort, joint stiffness, and delayed rehabilitation.

Deep Inferior Epigastric Artery Perforator Flap

Lower abdominal-based free flaps have been widely used for breast reconstruction. The deep inferior epigastric artery

Fig. 4 SCIA flap for reconstruction of distal forearm defect. (A) Flap design in parallel to the course of SCIA/V. Skin perforators were detected by handheld Doppler and marked. (B) Flap elevated off of the superficial branch of the SCIA. (C) Scar excision, re-creation of the defect, flexor tenolysis, and median nerve internal neurolysis. (D) Flap inset, note the excellent contour achieved without need for debulking due to the thin SCIA flap.

perforator (DIEP) flap, first described by Koshima and Soeda,²⁸ has gained increasing popularity at many institutions because it preserves the rectus abdominis muscle and reduces the risk of abdominal bulges and hernias compared with TRAM flaps.^{29,30} Though commonly used for autologous breast reconstruction, the DIEP flap has not been frequently used for upper extremity reconstruction.^{31–33} The free DIEP flap can provide a large amount of skin and soft tissue with an aesthetic donor-site scar and should be considered in the reconstructive algorithm of large proximal upper extremity defects (► Fig. 5).

Preoperative imaging with computed tomographic angiography (CTA) or magnetic resonance angiography is often performed to determine the perforator anatomy prior to flap dissection. Flap dissection proceeds from lateral to medial. Once the perforators from the medial and lateral rows have been identified, the largest perforator should be selected as the vascular pedicle. Multiple perforators can be included especially if they are along the same axis. Musculocutaneous perforators are the most common type with a majority of them having a short intramuscular course (< 4 cm).³⁴ Dissection of the pedicle then proceeds by making a small incision on the anterior rectus sheath to trace the perforator back to its origin from the DIEA, which usually results in a long pedicle length. The superficial epigastric vein may be preserved to augment venous outflow, if necessary. A sensate

flap can be created by harvesting the anterior cutaneous branches of the intercostal nerves. Additionally, the inguinal lymph nodes can be harvested along with this flap to treat upper extremity lymphedema in select patients.³⁵

Reports on the use of DIEP flaps for upper extremity reconstruction are rare and limited to a few case reports. Tang et al reported a series of 22 pediatric cases of using free DIEP flap for reconstruction of complex soft tissue defects of upper and lower extremities with an overall flap survival rate of 95.5%.³³ Van Landuyt et al reported one case of upper arm defect that was reconstructed with DIEP flap that was successful but did have partial flap necrosis.³² Li et al reported one successful case of free DIEP flap used in combination with free-toe transfer for reconstruction of thumb and first web space defects.³¹

The DIEP flap is a reliable perforator flap that can provide soft tissue coverage for large defects in the proximal upper extremity. Its major advantages include the large size, long pedicle, and aesthetic donor site. The disadvantages of the DIEP flap include the violation of anterior rectus sheath leading to a risk of abdominal bulges, and, most importantly, the thick bulk of the flap may require additional surgical revisions such as liposuction. Furthermore, the memory of the abdominal adipose tissue may mean that significant body weight gain may translate to increased flap bulk on the upper

Fig. 5 DIEP flap for reconstruction of upper arm defect after excision of sarcoma. (A) Flap design over the lower abdominal skin. (B) Elevated flap with long pedicle. (C) Wide local excision with preservation of the posterior radial collateral vessels as the recipient vessels. (D) Follow-up results demonstrating excellent contour and color match.

extremity. The DIEP flap is not commonly selected for upper extremity reconstruction because of these disadvantages; however, it should be included as an option for larger defects.

Superficial Inferior Epigastric Artery Flap

The superficial inferior epigastric artery (SIEA) flap avoids violation of the rectus fascia and has been applied successfully for not only breast reconstruction but also extremity and head and neck defects in properly selected patients.^{36–38} The SIEA is a branch arising from the common femoral artery, and the superficial inferior epigastric vein (SIEV) drains into the great saphenous vein. They travel superiorly through the lateral portion of the femoral triangle, eventually piercing the fascia of Scarpa to lie in the subcutaneous tissue. Like the DIEP flap, the SIEA flap can be designed transversely in an elliptical shape on the lower abdominal wall (► Fig. 6).

Dissection proceeds until the SIEA has been identified. At this point, the vessel diameter must be assessed to determine whether it is of a reasonable caliber for microvascular transfer. If the SIEA is not identified or is deemed too small, the surgeon may proceed to explore the contralateral vessel or pursue an alternative option such as DIEP or SCIA flaps. The pedicle may be traced back toward the femoral vessels, and a mean pedicle length of 7 cm has been reported.³⁹ If a thin flap is required, debulking at the time of elevation may be performed by excision of fat deep to the fascia of Scarpa.

There are few reports of SIEA flaps used for upper extremity reconstruction, and most are small case series.^{38,40,41} Most outcomes data on SIEA flaps are derived from the breast

Fig. 6 SIEA flap. (A) Flap harvest and left in situ based on the left superficial inferior epigastric vessels. Note the pink coloration throughout the entire flap without evidence of flap congestion any of the four zones. (B) Donor-site closure with low transverse scar and excellent contour of the lower abdomen.

reconstruction literature. Studies comparing SIEA with DIEP have found significantly decreased donor-site morbidity with SIEA flaps, including better abdominal function and reduced pain.³⁶ However, several studies have noted that SIEA may have a higher rate of arterial complications, up to 14% in one series, compared with DIEP flaps.^{42,43} The diameter of SIEA may be an important predictor for higher risk of arterial complications, and strict selection based on SIEA diameter of greater than 1.5 mm by one group led to 100% success rate in 27 free SIEA flaps.⁴⁴

These studies demonstrate that the SIEA flap may not be available or ideal in all patients, but in selected patients, it can be used for coverage of large soft tissue defects of the upper extremity with minimal donor site morbidity (►Fig. 7). Because of its unreliability, a backup strategy such as DIEP or SCIA flaps must be considered prior to selecting SIEA flap as the primary reconstructive option. The caliber of the SIEA vessel is an important determinant of the success of the flap. The SIEA flap also shares the same disadvantage of excessive flap bulk as DIEP flaps.

Flow-Through Flaps

When a concomitant vascular injury is present in addition to the soft tissue defect, a flow-through flap (FTF) may be an ideal solution to address both problems simultaneously. Several flap options have been described for this application, including the temporoparietal fascia flap,⁴⁵ ALT flap,^{46,47} radial artery forearm flap,⁴⁸ and arterialized venous flaps.⁴⁹ The choice of flaps will depend on the location and size of the defect, and a variety of anastomosis configurations have been

described including artery-vein-artery, artery-vein-vein, and vein-vein-vein.

For small defects of the digits and the hand, a free venous flap is a versatile option with minimal donor-site morbidity (►Fig. 8). Venous flap was first introduced by Nakayama et al and is defined as a composite flap of the skin, subcutaneous tissue, and veins.⁵⁰ It does not contain an artery, and thus does not require deep dissection or sacrifice of a major vessel to an extremity. Additionally, they are thin and pliable, thus making them ideal for reconstruction over tendons or other areas of the hand where achieving mobility is critical. Common donor areas for venous flaps include the saphenous and volar forearm regions.

Yoshimura et al performed 13 arterialized venous flaps for reconstruction of skin defects of the fingers and achieved a 92.3% survival rate.⁴⁹ In terms of reconstructing both soft tissue and vascular injuries, Nishi et al reported seven cases of arterialized venous flaps for this dual purpose and achieved near-complete survival in all cases.⁵¹ In a large series consisting of 154 arterialized venous flaps for hand reconstruction, Woo et al reported a success rate of 98.1%.⁵² Though many authors have reported success with

Fig. 7 SIEA flap reconstruction of forearm and hand defect. (A) Left upper extremity radial side injury as a result of a rollover motor vehicle accident. (B) SIEA flap inset with 100% viability of the entire flap. (C) Follow-up results demonstrate well-healed defect with excellent contour after flap debulking surgery.

Fig. 8 Flow-through flap. (A) Ischemic right ring finger with volar soft tissue defect, transected radial digital artery (RDA) and exposed flexor tendon. (B) Flap design and elevation based on a central subcutaneous vein. (C) Flap inset onto the defect with afferent anastomosis to the proximal RDA stump and efferent anastomosis to the distal RDA stump to restore arterial inflow. Note initial congestion appearance of the FTF. (D) Appearance of the viable FTF and healed donor site during subsequent follow-up visit.

arterialized venous flaps, a major concern with venous flaps remains a high frequency of venous congestion and inconsistent survival.⁵³ In fact, a period of initial venous congestion can often be expected but will usually resolve over time.⁵⁴ Recent modifications such as using dual venous drainage⁵⁵ and multiple arterial anastomosis⁵⁶ have reduced venous congestion and allowed for successful transfer of larger-sized flaps up to 12 cm × 20 cm. Rozen et al noted venous congestion in 4 out of 6 cases performed with one venous outflow whereas no venous congestion was seen with 11 cases where dual discontinuous efferent veins were included.⁵⁵ Other authors have advocated for shunt restriction as a strategy to decrease venous congestion.^{57,58} In a clinical series of 22 cases, Lam et al reported a venous congestion rate of 27% when using the shunt-restriction technique, all of which resolved without additional intervention.

Though venous and other FTFs are not required for most digital or hand defects, they should be considered in specific situations where concomitant vascular injury is present along with a soft tissue defect. For smaller defects, venous FTFs are especially promising because of the minimal donor-site morbidity, unlimited potential donor sites, and rapid flap harvest. Strategies such as dual efferent veins and shunt restriction can be considered to reduce rates of venous congestion.

Conclusion

The ideal free flap for upper extremity reconstruction should have the following features: similar tissue consistency to the recipient site, minimal donor-site morbidity, and a pedicle size that is slightly smaller in diameter than the recipient vessel, which allows for potential end-to-side anastomosis to prevent interruption of distal inflow to the hand. In reconstruction of hand defects, the flap of choice should be thin and pliable to achieve optimal contour and early rehabilitation. Therefore, muscle flaps are usually not ideal for hand reconstruction because they tend to be bulky, may limit tendon gliding, and yield poor cosmetic results when covered by skin grafts. Furthermore, performing a secondary operation such as tenolysis is more challenging due to additional fibrosis. Therefore, cutaneous or fasciocutaneous flaps are generally a better option for functional reconstruction of the upper extremity.

Lateral, scapular, parascapular, radial, and ulnar forearm fasciocutaneous flaps have all played important roles in upper extremity reconstruction, but all have their significant shortcomings. The primary disadvantages of lateral arm flap are its limited size, unaesthetic donor scar, and short pedicle. Scapular and parascapular flaps cannot be thinned and are harvested in the lateral decubitus position, which hinders a two-team approach. Radial, ulnar, and posterior interosseous flaps require sacrifice of an arterial inflow to the hand, have limited size, and results in unsightly donor-site scars. However, these fasciocutaneous flaps are time-tested because of their reliable anatomy and proven success rates, and will continue to serve as important options for upper extremity reconstruction.

In recent years, the ALT, SCIA, DIEP, and SIEA flaps have also been used for upper extremity reconstruction. These flap options share several traits in common: adequate pedicle diameter permitting microvascular anastomosis, not requiring sacrifice of a major vessel to an extremity, easily concealed donor-site scars, and having possibility of simultaneous recipient and donor team approach to reduce operative time. Our preference is to use thin SCIA flaps for distal upper extremity defects such as the dorsum of the hand and volar wrist areas. DIEP and SIEA flaps are reserved for upper arm or very large soft tissue defects. The authors find the ALT flap to be most versatile and can be used for large defects or even distal defects if a thin flap is harvested. In complex injuries resulting in both a soft tissue defect and a vascular injury, FTF should be considered as a one-step solution. With advancements in microsurgical technique, reconstructive surgeons should place more emphasis on minimizing donor-site morbidity and improving functional and aesthetic outcomes. FCFs address these goals and should play an increasingly larger role in upper extremity reconstruction.

Funding

None.

Conflict of Interest

None.

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