The Reconstruction of the Mutilated Hand

**Michael Neumeister, M.D., F.R.C.S.C., F.A.C.S.,¹ Thersa Hegge, M.D.,¹
Ashley Amalfi, M.D.,¹ and Michael Sauerbier, M.D.²**

ABSTRACT

The challenging reconstructive treatment of defects in the upper extremity requires a sound working knowledge of a variety of flaps. As the hand surgeon weighs the pros and cons of each possible flap to obtain definitive closure, he or she must also integrate the priorities of function, contour, and stability as well as the anticipation of further reconstructive surgery in choosing the flap of choice. This review describes the various flaps available for closure of soft tissue defects of the upper extremity. The principles of management of wounds of the upper extremity is described to guide hand surgeons in the early treatment of massive wounds that will eventually need free tissue coverage. Currently used flaps include fasciocutaneous, fascial, musculocutaneous, muscle, and osteocutaneous flaps. Flap selection is based on the characteristics of the defect including size, shape, and location, the availability of donor sites, and the goals of reconstruction. Improved techniques of microsurgery and an ever increasing repertoire of flaps provide the framework for hand surgeons to offer the most appropriate flap based on donor site, thickness, amount of tissue needed, and composition. A discussion of the selection of ideal flaps for any given defect should enable the reconstructive hand surgeon to provide the most appropriate coverage of wounds to the hand and upper extremity.

KEYWORDS: Mutilated hand, hand reconstruction, free flaps, soft tissue

The many specialized structures of the hand and upper extremity work in intimate synchrony to provide a harmonious interplay of precision motor biomechanics with fine tactile senses. Our hands are subject to many common occupational and domestic injuries, including fingertip trauma, tendon lacerations, neurovascular compromise, fractures, and soft tissue loss. We are all aware that even minor trauma to a joint or tendon can result in significant stiffness and loss of function of the finger. The greater the extent of the injury, the greater the risk

of compromise to the function of the hand. This is no more evident than in mutilating hand injuries. The management of these injuries requires a sound knowledge of anatomy, biomechanics, reconstructive principles, and an expertise in the technical nuances of microsurgery.

Most surgeons dealing with mutilated hand injuries embark upon these principles with a set number of goals in mind (Fig. 1). The first goal is to preserve the patient's life. Many of these devastating injuries to the

¹Division of Plastic Surgery, SIU School of Medicine, Springfield, Illinois; ²Department of Plastic Surgery, Hand, and Reconstructive Surgery, Academic Hospital University of Frankfurt am Main, Frankfurt am Main, Germany.

Address for correspondence and reprint requests: Michael Neumeister, M.D., F.R.C.S.C., F.A.C.S., Professor and Chairman, SIU School of Medicine, Division of Plastic Surgery, P.O. Box 19653, Springfield, IL 62794-9653 (e-mail: mneumeister@siumed.edu).

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Figure 1 (A) The surgical goal of the management of mutilating hand injuries is to restore function through reconstruction. (B, C) Toe-to-hand transfers provide pinch and sensation.

limb may be associated with some internal visceral damage such as spleen, liver, or lung. Patients may be pulled into machinery, thrown away from objects, or involved in explosions during industrial, occupational, or domestic accidents. Consequently, these patients, who also have mutilating upper-extremity injuries, need to be treated as trauma victims. A primary and secondary survey and complete trauma workup is often warranted.

The second goal in treating mutilating hand injuries is to preserve the limb if possible. This is followed by a goal to preserve function. Indeed, a limb without function may not only be useless but also could be more of a hindrance to the patient. The final goal for the hand surgeon is to restore lost function. Unlike the lower extremity where prostheses are tolerated extremely well after amputations, upper-extremity amputations are often best served with some form of reconstruction that restores mobility and sensation such as toe-to-hand procedures. Although each finger has an inherent role in the overall function of the hand, not all digits are required to have patients return to gainful employment. Indeed, various guides to the evaluation of permanent impairment, such as the American Medical Association guide, have allocated a value to the loss of the digit and hand (Table 1). As the thumb is considered the most

important functional aspect of the hand, every effort is attempted to preserve the thumb even if it can act only as a sensate stable post.

RECONSTRUCTIVE PRINCIPLES

The principles of wound management in the mangled or traumatized upper extremity include irrigation, debridement, restoration of vascularity, stable bone fixation, repair of specialized tissue such as nerve and tendon, followed by definitive soft tissue coverage.¹ All areas of contamination and nonviable tissue should be removed not only to avoid infection but also to allow the surgeon to realize and appreciate the exact extent of how much tissue is required for reconstruction. Second- or third-look surgeries are often required at 24 to 72 hours to remove contaminants and to allow compromised tissue to declare itself as either viable or nonviable.¹⁻³ The wounds are often treated as "pseudotumors" with aggressive debridement and irrigation ensuring viability of the remaining tissue (Fig. 2).

The initial physical examination should assess the vascularity to the hand or limb. Amputations and tissue rendered ischemic is evaluated for the appropriateness of replantation or revascularization. Vein grafts may be

Table 1 Guides to the Evaluation of Permanent Impairment (American Medical Association)

Amputation	Percentage Impairment (%)		
	Hand	Upper Extremity	Whole Body
Index or long finger	20	18	11
Ring or little finger	10	09	05
Thumb	40-50	36-45	22-27
Hand	—	90	54
Upper extremity	—	—	60

Figure 2 (A) The mangled upper extremity before debridement. (B) The bones are stabilized and the wound treated as a "pseudotumor" with aggressive debridement and irrigation.

required to bridge gaps in the vessels or to get beyond the zone of injury. It is preferable to obtain stable bone fixation first as this will act as a solid scaffold for the subsequent reconstruction or repair of the injured tissues. There are a variety of methods used to provide adequate osteosynthesis each of which has their own set of pros and cons (Table 2). The specific technique of osteosynthesis should be guided by the surgeon's preference and level of expertise; however, plates, screws, and tension bands offer rigid fixation relative to K-wire fixation.

Injury to nerves and tendons should be repaired primarily if possible. Occasionally, however, there is a loss of a segment of tendon or nerve that requires a different means of reconstruction as primary repair is not possible. Nerve gaps are restored with nerve grafts. The grafts can be obtained from a variety of sources depending on the nerve needing reconstruction. Digital nerves are best reconstructed with the distal posterior interosseous nerve at the dorsal wrist or the medial antebrachial nerve in the forearm. Nerve gaps in the digits are easily bridged with nerve conduits without the need to harvest

nerve grafts. Little evidence supports the use of conduits for gaps greater than 2 to 3 cm, however. Larger nerves in the palm or forearm that cannot be repaired primarily require sural nerve grafts.

Replacing segmental loss of tendons is achieved with either tendon grafts or tendon transfers. If the muscle bellies of the musculotendinous units are intact and there are segments of proximal and distal tendon remaining, tendon grafts are more appropriate (Fig. 3). However, if the muscle belly or remaining tendon is inadequate, tendon transfers are recommended. Side-to-side tendon transfers are appropriate for isolated extrinsic tendon loss. For instance, loss of a portion of the extensor digiti communis (EDC) to the long finger can be reconstructed with side-to-side suturing to the adjacent EDC tendon. Occasionally, tendon transfers are not available because of the severity of the injury necessitating the need for functioning muscle transfers. The gracilis muscle is ideal for restoration of extrinsic flexor or extensor function. The ideal timing for the tendon or nerve reconstruction remains controversial to some extent. The benefits of reconstructing these speci-

Table 2 The Mangled Upper Extremity before Debridement

Fixation	Advantage	Disadvantage
K-wire and interosseous wire	Fast, easy Less foreign body load	Not rigid fixation Requires prolonged immobilization to obtain bone healing External K-wire may serve as a portal to bacteria
Tendon band	Strong Fast	Restriction of motion Irritation from wire ends
Plates	Strong, able to contour to bone shape Can start range of motion early Stable, rigid fixation Permits primary healing	Periosteal stripping may devascularize bone fragments Larger foreign body load Restrictive in digits
Lag screws	Compressive and strong Allow early range of motion Permits stable rigid fixation Permits primary healing	Not all fractures amenable to screws (i.e., transverse) Requires greater technical expertise
External fixation	Stable fixation Bridges boney gaps Keeps digit out to length	Limits range of motion Bulky Pin-track infection

alized tissues at the time of flap coverage include limited scarring, early rehabilitation, and fewer surgeries. The concern about performing nerve or tendon grafts at the early reconstructive setting is that if the wound bed were to become infected, the grafts could be lost. This would mean that a second donor site would be required and the recipient bed would likely have a greater degree of scarring potentially hindering return of function.

Soft tissue coverage can ensue once the wound is thoroughly debrided, bone fixation is complete, and the vital structures are repaired or reconstructed. Some areas of the traumatized limb may be closed primarily. Other areas may follow the reconstructive ladder of secondary

intention, split-thickness skin grafts, full-thickness skin grafts, local flaps, regional flaps, distant flaps, and finally free tissue transfer.⁴ It is not necessary, however, nor is it always appropriate, to explicitly follow the rungs of the reconstructive ladder in a step-by-step fashion. Indeed, to obtain or fulfill the goals of soft tissue reconstruction, free tissue transfer may be a better choice to optimize results over other means of closure.^{5,6} Skin grafts may be a suitable choice for coverage when a vascular recipient bed is present. This is particularly true for exposed muscle bellies. There are times, however, when a flap, of any sort, may be a better choice over a skin graft, particularly if the surgeon is attempting to prevent

Figure 3 (A) A dorsal hand wound with injury to the extensor tendons in a 26-year-old man. (B) The wound is debrided and the tendons repaired or reconstructed with grafts prior to early flap coverage. (C, D) Free scapular flap designed and harvested to provide thin, pliable coverage to the hand. (E) Six-month follow-up before debulking of the scapular flap.

secondary contracture in a web space or over a joint. A logical, well thought out operative plan should be executed to provide the most optimal coverage for the hand or upper extremity to preserve or restore limb function while limiting donor-site morbidity.

It is important to understand the complexity of the hand and upper extremity before embarking on the reconstructive efforts so that the most appropriate flap can be chosen for coverage. The functional characteristics of the hands' missing integument mandates respect of its specialized skin and sensory organs. As a part of our reconstructive goal, therefore, attempts at repairing "like with like" tissue should be foremost in the surgeon's mind while contemplating or undertaking reconstruction of soft tissue defects in the upper extremity. The palmar aspect of the hand is covered with glabrous skin notable for its limited sheer, high friction coefficient, and characteristic "fingerprint" papillary ridges. Numerous fibrous septae compartmentalize the subcutaneous tissue of the palm with fibers from the underlying dermis to the musculoskeletal structures below. The density of specialized sensory receptors is greater in the hand.

The skin of the extensor surface of the hand is quite different from its volar, glabrous counterpart. The midaxial line of each digit is formed by connecting the lateral volar finger creases at the distal interphalangeal, proximal interphalangeal, and metacarpal phalangeal joints. It is at this line that the transition from glabrous to nonglabrous skin of the hand occurs. The dorsal skin is relatively soft, pliable, and thin. It is also devoid of the fibrous septae observed in the volar skin. The volar and dorsal skin of the forearm and arm are similar to that of the dorsal skin of the hand, however the relative quantity of subcutaneous fat is usually greater at the more proximal sites.

FLAP SELECTION

Today, a multitude of flaps permit optimal outcomes for the recipient site, as well as the donor site.⁷⁻⁹ Each flap has its own inherent advantage and disadvantage. As such, the hand surgeon tallies the pros and cons of each donor site and flap given any one soft tissue defect. Ultimately, the selection of flap is dependent upon several variables including the size, shape, and location of the defect, as well as the characteristics of the tissue that was lost. In today's age of refined microsurgery and an increased repertoire of flaps that are available of various thicknesses and composite tissue makeup, it behooves us as hand surgeons to select the most ideal flap for any given defect to restore as many of the native skin characteristics that were present prior to the loss of tissue. That is to say, we replace thin skin with thin flaps, neurosensory flaps for areas that demand sensibility, composite tissue loss with composite flaps, and areas

that demand tendon excursion with flaps that permit gliding.¹⁰ Our goal is to restore function and contour approximating the native anatomy as close as possible. Currently used flaps include fasciocutaneous, muscle, musculocutaneous, fascial, and osteocutaneous flaps. A technical derivative of each of these flaps elevates the tissues on perforating vessels. These flaps are known as perforator flaps. The advent of perforator flaps has greatly expanded the number of flaps in our armamentarium that can be used for soft tissue coverage of the upper extremity.¹¹⁻¹³

Keeping in mind all of the characteristics of a flap that are desired for soft tissue coverage, the surgeon must also be aware of other limitations the patient's body habitus offers. For instance, an anterolateral thigh may be the optimal donor site for wound coverage of the back of the hand in a thin patient, whereas the same flap may not be the first choice in the severely obese patient because of excessive bulk. A temporal parietal fascial flap leaves a rather inconspicuous scar on the scalp of a young woman, but the same donor site may be unacceptable in a bald man.

Table 3 Types of Pedicle flaps used in Upper Extremity Soft Tissue Coverage

Fingertip	Advancement
	V-Y (Atasoy-Klinert)
	(Kutler)
	Moberg (thumb)
	Cross finger
	Thenar crease
	Homodigital
	Antegrade
	Retrograde
	Perforator
	Neurovascular island (Littler)
	First dorsal metacarpal
	artery (Foucher, Kite)
	Visor
Finger	Cross finger
	Reverse cross finger
	Foucher
	Reverse dorsal metacarpal artery
	Flag
	Homodigital
	C-ring
	Z-plasty
Hand	Jumping man
	Groin
	Posterior interosseous
	Anterior interosseous
	Reverse radial forearm
	Thoracoepigastric
	Dorsal-ulnar forearm (Becker)

The thin skin of the hand and fingers mandates the similar appraisal of donor characteristics.^{14,15} Small defects may be best treated with small fasciocutaneous flaps such as a free first dorsal metacarpal artery from the opposite hand^{16,17} or a medial plantar flap from the foot.^{18,19} These small flaps were designed with the intent of replacing like with like tissue.^{20–23} Larger fasciocutaneous and muscle flaps are often used for reconstruction of forearm and upper-arm defects for the obvious reason that more volume is required.

Types of Flaps

As noted above, there are many different types of flaps that can be used to optimize soft tissue coverage in the upper extremity.^{24,25} Each type of flap has various advantages and disadvantages. Pedicle flaps offered a

distinct advantage of being somewhat less technically demanding than free tissue transfer. Indeed, there are many times when a pedicled flap is the most appropriate choice for reconstruction. Local, regional, and distant flaps had been used for defects in the fingertips, fingers, hand, forearm, and elbow providing stable and adequate coverage of various defects (Table 3). Pedicled flaps are commonly used for treating small, isolated defects in the upper extremity. Typically, the areas amenable to reconstruction with pedicled flaps include the elbow, dorsum of the hand, and, potentially, the palmar aspect of the hand. The latissimus dorsi muscle can reach to within 6 inches beyond the elbow while still preserving its insertion to the upper humerus. The flap can be tunneled or inset along an upper-arm incision. The pedicled latissimus muscle can also be transferred as a functioning muscle to restore biceps or triceps function while at the

Figure 4 (A) Open wound on the dorsum of the ulnar two digits in a 24-year-old man. (B, C) A distally based radial forearm flap is elevated and transferred into place, tunneling under intact dorsal hand skin. (D) The donor site requires a split-thickness skin graft for closure.

Figure 5 (A, B) A 32-year-old man with a gunshot wound to the left forearm. (C) The wound is debrided prior to definitive closure. (D, E) A pedicled groin flap with bone and skin is designed and elevated. (F) The groin flap is inset to provide stable soft tissue coverage and bone for fixation. (G) The final result with good stability and coverage at 1-year follow-up.

same time providing soft tissue coverage of the upper-arm defects.

The radial forearm flap and the flexor carpi ulnaris muscle are two other examples of tissue that can be based proximally and used for coverage of the

elbow. The radial forearm flap has a distal skin paddle and is based on the radial artery. The flexor carpi ulnaris muscle is released distally and folded back upon itself based on perforators from the ulnar artery.

Pedicled flaps for the dorsum of the hand include the reverse radial forearm, the posterior interosseous flap, and the ulnar artery (Becker) flap. The Becker flap is based on the distal, dorsal perforator from the ulnar artery. The flap has rather small dimensions and usually requires revision of the dog ear as the flap is transposed. The posterior interosseous flap is based on the watershed communications between the volar anterior interosseous artery and the dorsal posterior interosseous artery at the level of the wrist. The anterior interosseous artery sends perforators through the interosseous membrane to anastomose with the posterior interosseous artery. The skin paddle is based over the junction of the proximal one third and distal two thirds

Table 4 Advantages of Free Tissue Transfer for Soft Tissue Coverage of the Upper Extremity

Ample donor tissue
Decreased donor morbidity
Multiple donor sites
Improved contouring at recipient site
May replace like with like tissue
Can be used as a "flow through" flap
Can incorporate composite tissue
Neurosensory potential
Permits limb elevation
Permits early motion

of the dorsal forearm, an area where a proximal anterior perforator exits behind the supinator muscle. This perforator merges into the posterior interosseous artery. The pedicle of the flap is elevated in a plane between

the extensor digiti quinti and the extensor carpi ulnaris muscles.

The reverse radial forearm flap is based on the radial artery distally. The skin paddle is designed on

Table 5 Common Free Flaps used for Soft Tissue Coverage of the Upper Extremity

Flap	Pedicle	Size	Artery Diameter	Neurosensory
Fasciocutaneous flaps				
Anterolateral thigh	Descending branch of lateral femoral circumflex	20 × 40 cm	2–3 mm	Lateral femoral cutaneous nerve
Scapular	Scapular cutaneous branch of the scapular circumflex	12 × 20 cm	2.5–3.5 mm	
Parascapular	Parascapular cutaneous branch of the Scapular circumflex	15 × 30 cm	2.5–3.5	
Lateral arm	Posterior radial collateral	6 × 12 cm	1.5–2.0 mm	Lower lateral cutaneous and posterior antebrachial cutaneous nerves
Radial forearm	Radial artery	15 × 30 cm	2.5–3.5 mm	Lateral and medial antebrachial nerve
Ulnar forearm	Ulnar artery	8 × 10 cm	2–3 mm	Medial antebrachial nerve
Medial arm	Superior ulnar collateral artery or direct branches from the brachial artery	6 × 12 cm	0.8–2.5 mm	Medial brachial cutaneous nerve
Deltoid	Posterior humeral circumflex artery	10–15 cm	2–4 mm	Lateral brachial cutaneous nerve
Groin	Superficial circumflex iliac artery	10 × 25 cm	0.8–1.8 mm	
Medial plantar flap	Branch of medial plantar artery			
Posterior interosseous	Posterior interosseous artery	5 × 12 cm	1.0–2.0 mm	
First dorsal metacarpal	First dorsal metacarpal artery	3 × 3 cm	0.8–1.5 mm	Superficial radial nerve
Toe pulp Web space	First dorsal metacarpal artery of the dorsalis pedis	3.5 × 3.5 cm	1–3 mm	Branch of superficial peroneal nerve
Perforator flaps				
Deep inferior epigastric artery	Deep inferior epigastric artery	15 × 30 cm	1–5 mm	Anterior cutaneous branches of T7–T12
Anterolateral thigh	Descending branch of the lateral femoral circumflex artery	20–40 cm	2–3 mm	Lateral femoral cutaneous nerve
Muscle flaps				
Latissimus dorsi	Thoracodorsal artery	22 × 33 cm	2.5–3.0 mm	
Serratus anterior	Branch of thoracodorsal	10 × 12 cm	2.5–3.0 mm	
Rectus abdominis	Deep inferior epigastric artery	6 × 26 cm	2–5 mm	
Gracilis	Terminal branch of medial femoral circumflex	5 × 30 cm	1.2–1.8 mm	
Extensor digitorum brevis	Branches of lateral tarsal artery and branch of the dorsalis pedis	5 × 5 cm	0.5–2.0 mm	
Fascial flaps				
Temporal parietal fascia	Superficial temporal artery	12 × 14 cm	1.8–2.7 mm	
Scapular fascia	Circumflex scapular artery	12–20 cm	2.5–3.5 mm	
Anterolateral thigh fascia	Descending branch of the lateral femoral circumflex artery	20–40 cm	2–3 mm	
Radial forearm fascia	Radial artery	15 × 30 cm	2.5–3.5 mm	
Lateral arm fascia	Posterior radial collateral artery	6 × 12 cm	1.5–2.0 mm	
Miscellaneous flaps				
Venous flaps	Superficial volar forearm veins	3 × 3 cm	0.5–1.5 mm	
Omentum	Left or right gastroepiploic arteries	24 × 35 cm	2.0–3.5 mm	

the proximal volar third of the forearm. The radial artery is ligated proximally and the flap elevated and transposed to the dorsum of the hand (Fig. 4). The donor site requires skin graft closure. Occasionally, venous congestion can be seen as the venous drainage is retrograde through the venae comitantes veins. The congestion is easily corrected by anastomosing a superficial vein on the skin paddle or the ligated venae comitantes to dorsal hand or forearm veins at the recipient site.

Today, the groin flap has been replaced by several other flaps used in upper-extremity reconstruction. There is, however, still a place in the reconstructive surgeon's armamentarium for the groin flap. The groin flap was one of the first axial pattern flaps used on humans and remains a reliable and versatile option for hand reconstruction. The flap is usually used for dorsal hand coverage but can be used to cover the palmar aspect of the hand as well. It is a common surgical practice in hand reconstruction to use the groin flap for initial coverage of distal hand coverage before free toe-to-hand surgery is performed. This provides an abundant amount of tissue to the hand without violating recipient pedicles needed for future

toe vessel anastomosis. The groin flap is supplied by the superficial circumflex iliac artery (SCIA), which travels 2.5 cm inferior and parallel to the inguinal ligament. The skin paddle becomes a random pattern flap lateral to the anterior superior iliac spine (ASIS) (Fig. 5). If designed to extend more than a flap width past this point, a delay procedure should be considered. The flap is dissected from lateral to medial. The fascia of the sartorius muscle should be elevated with the flaps because the SCIA divides into a superficial and deep branch at the medial border of the sartorius muscle. Dissection in this plane allows the superficial branch to be taken with the flap, while the deep branch is ligated. At this location, care must also be taken to avoid the lateral femoral cutaneous nerve. Once the flap is elevated, the donor site is closed primarily and the base of the flap tubed prior to inset. The traumatized hand is then moved into the groin, and the flap is inset to cover the defect location. The flap is divided 2 to 3 weeks after elevation, and the remainder of the flap is inset.

For many defects in the hand and upper extremity, however, free tissue transfer offers distinct advantages over pedicle flaps (Table 4). The vast variety of free

Figure 6 (A, B) A 23-year-old woman with a mangled upper extremity before and after debridement and stabilization. (C) A rectus abdominus muscle flap is harvested to close the defect in the upper extremity. (D) The final result after 1-year follow-up.

flaps available for transfer have different anatomic characteristics of size and pedicle diameter and length that may help the hand surgeon decide on which type of flap to choose (Table 5). Table 4 illustrates some of the more common and other less common free flaps that have been used to obtain soft tissue coverage of the hand or upper extremity. The list is not exhaustive, however, for there are many muscle and fascia flaps that could also be harvested, and indeed have been described, yet have not met with wide use.^{26,27}

Muscle Flaps

Several different muscles can be easily transferred on their dominant pedicle.^{28–32} A few of these muscles appear recurrently in the literature because of the ease of the dissection and reliability. Each of these muscles can be taken with the cutaneous paddle as well. The latissimus dorsi and the rectus abdominis muscles offer stable vascular coverage for rather large defects of the upper extremity, whereas the serratus anterior, gracilis, and extensor digitorum brevis are often used for the

smaller defects of the hand^{33–35} (Fig. 6). Muscle flaps have the advantage of being extremely pliable, of variable size, and have the ability to obliterate dead space in the large wounds. Muscle flaps have traditionally been used for contaminated wounds or wounds that have a history of osteomyelitis, due to the enhanced vascular supply and antibiotic delivery of muscle. Recently, however, fasciocutaneous flaps have proven just as useful for osteomyelitis. The often bulky nature and the potential difficulty in secondary elevation during future surgeries for underlying ligament, tendon, or nerve reconstruction of these muscle flaps make cutaneous flaps a better choice for soft tissue reconstruction of the hand and upper cavity most of the time.

Fasciocutaneous Flaps

Fasciocutaneous flaps are often used for reconstruction of soft tissue defect because of the similar properties the skin has to that of the lost tissue. The skin is usually soft and pliable and is easily elevated if secondary procedures are required such as ligament reconstruction or tendon,

Figure 7 (A) A first web space contracture is release with a resultant defect. (B) A lateral arm fasciocutaneous flap is harvested and inset for soft tissue coverage of the first web space. (C) The final result at 12-month follow-up illustrating good function and contour.

nerve, or bone grafting. The skin flaps can be contoured and sculpted to fit the defect. These flaps oftentimes have improved color and contour match and can be taken as perforator flaps to decrease bulk and reduce donor-site morbidity.^{17,36-41} There is a limit, however, of how much tissue can be harvested from a cutaneous donor site and still obtain primary closure. For instance, the width of a lateral arm flap usually has a limit of 6 cm in diameter (Fig. 7). Beyond this distance, the donor site will not be able to be closed primarily, and a skin graft will be required. This would leave an unacceptable donor site in a highly exposed area on the lateral arm. On the other hand, an enormous amount of tissue can be harvested from the anterolateral thigh donor site (Fig. 8). Flaps up to 10 to 15 cm in diameter may be closed primarily. Ideally, the surgeon should always try to choose a flap that would permit primary closure of the donor site. In the obese patient, fasciocutaneous flaps may be

extremely thick, resulting in a poor contour at the recipient site. There are many reports of harvesting thin or ultrathin flaps by removing much of the fat away from the main pedicle as it enters the flap.^{12,42-46} During the thinning of the flap, care must be taken not to injure the arborization of the vessels as they leave the main pedicle into the subcutaneous tissue of the flap. As an alternative to acute debulking of the flap, the tissue can be debulked safely 2 or 3 months later using direct excision or with liposuction. Definitive tailoring of the flap may require two or three of these debulking procedures to ultimately leave a contoured, aesthetically appropriate soft tissue coverage of the hand or upper extremity (Fig. 9). Unlike the lower extremity, fasciocutaneous flaps to the upper extremity seldom result in a lymphedematous, biscuit-like appearance on the limb. The deep inferior epigastric perforator (DIEP) flap offers abundant tissue and a minimal donor-site scar making this an excellent choice for flap closure of upper-extremity defects (Fig. 9). The anterolateral thigh flap, lateral arm flap, radial forearm flap, scapular flap, parascapular, and deep inferior epigastric artery flap perforator flap are commonly employed free flaps used today for soft tissue reconstruction of upper-extremity defects⁴⁷⁻⁵⁹ (Fig. 10A-C and Fig. 3).

Figure 8 (A) A mutilating upper-extremity defect in a 27-year-old woman. (B) Soft tissue coverage is obtained with an anterolateral fasciocutaneous thigh flap.

Fascial Flaps

Fascial flaps have a distinct advantage over other flaps because they are very thin and pliable.⁶⁰⁻⁶⁵ Numerous reports document the superiority of fascial flaps when placed over exposed tendons because of the enhanced ability of the flap to permit tendon glide without adhesions. Tendons can be sandwiched between folded fascia to permit glide yet avoid the bulk of other flaps. For these reasons, fascial flaps have become ideal coverage for soft tissue defects for both the extensor and flexor surfaces of the hand. A split-thickness skin graft or full-thickness skin graft is required to cover the fascia for definitive closure. This necessitates the second donor site. The donor site from where the fascia flap was harvested is closed primarily without tension. This limited donor-site morbidity also makes fascial flaps rather appealing.

Technically, any fasciocutaneous flap could be subdivided into its fascial and cutaneous components. This means the number of fascial flaps would be at least that of their fasciocutaneous counterparts. The temporal parietal flap is widely used for soft tissue coverage of the hand and forearm.^{66,67} This flap has an easily identifiable superficial temporal vascular pedicle in the preauricular area and can be harvested up to the size of 12 cm × 10 cm. Additionally, the temporal parietal fascial flap can be harvested with a deeper branch of the superficial temporal vessels, the middle temporal

Figure 9 (A) An 18-year-old woman sustained a mutilating left upper-extremity injury in a motor vehicle accident. (B–D) A deep inferior epigastric perforator (DIEP) flap was used for soft tissue coverage. The tissue was severely redundant. (E) After debulking procedures, good contour is provided. (F) The DIEP flap offers an acceptable, well-concealed donor site while providing ample tissue for reconstruction.

vessels, along with a deep temporal fascia so that a sandwich type of fascial flap can be elevated.⁶⁸ The temporal parietal flap is elevated in a temporal region of the scalp with a “T” or “Y” shaped incision (Fig. 11). The donor site is well hidden by the hair. To limit donor-site scarring, this fascial flap has been elevated reliably with endoscopic assistance using a 4-cm preauricular incision.^{69,70}

Five other fascial flaps were widely used for reconstruction of the upper extremity: the scapular fascia flap, anterolateral thigh fascia flap, the serratus anterior fascia flap, the radial forearm fascia flap, and the lateral arm fascia flap. The scapular fascia flap is reliably elevated on the large-caliber circumflex scapular vessels and can be used to cover the entire dorsum or volar aspect of the hand.^{71–75} The main disadvantage of the scapular fascia flap is patient positioning. At times, the lateral position of the

patient can hinder simultaneous operating on the affected upper extremity.

The anterolateral thigh fascial flap has several advantages over other fascial flaps.^{76–78} This flap is based on large-diameter vessels of the descending branch of the lateral femoral circumflex pedicle. An extremely large area of fascia on the anterolateral thigh can be harvested on this pedicle. One disadvantage of the anterolateral thigh fascial flap is that the main pedicle may course through the vastus lateralis muscle sending perforators out into the fascia. This is only considered a disadvantage if the surgeon is not interested in performing a perforator fascial flap as it necessitates meticulous and sometimes tedious dissection through the vastus lateralis muscle.

The serratus anterior fascia flap has gained popularity for coverage of soft tissue defects in the hand because of its reliable blood supply, minimal and

Figure 10 (A, B) A 33-year-old man sustained a milling cutter injury to the dorsum of his right hand. (C, D) A parascapular fasciocutaneous flap is designed and harvested to provide soft tissue coverage of the hand defect. (E) The final results at 1-year follow-up illustrated good form and function.

rather inconspicuous donor site, and ease of dissection.^{52,79} This flap is based on branches from the thoracodorsal artery (Fig. 12). The serratus anterior fascia flap has been used with great success over exposed extensor and flexor tendons of the hand, permitting excellent tendon excursion and maintenance of total active range of motion (Fig. 13). The serratus anterior fascia flap has advantages of having a very long pedicle of large caliber with a very versatile size of the fascia.^{80–82} Reports have observed flap measurements as small as 2.5 cm × 3.5 cm or as large as 20 cm × 30 cm. Care must be taken during the dissection of this flap to avoid injury to the long thoracic nerve creating a palsy of the serratus muscle.

The radial forearm fascial flap can be harvested as a distally based, pedicled flap supplied by the ulnar artery. This flap, however, is reliant on an intact palmar arch and ulnar artery. An Allen's test is performed to ensure patency of the ulnar artery and palmar arch. The radial forearm fascia flap can also be harvested as a free flap based on the radial artery proximally. Many surgeons, however, may be reluctant to use a flap from the nontraumatized forearm to reconstruct the contralateral, traumatized upper extremity.

The lateral arm fascia flap is based on the posterior radial collateral artery, a terminal branch of the profunda brachii artery. The advantage of this flap is that can be harvested from the same

Figure 11 A 53-year-old woman sustained significant burns to her hands and face. (A) The contracting to the back of the hand was released exposing the extensor tendons. (B, C) A temporal parietal fascia flap was designed and elevated for closure. (D) The final result of the healed hand.

limb as a soft tissue defect without compromise to function.^{83–86} Smaller defects are readily closed with this fascia flap. The radial nerve is extremely intimate with the posterior radial collateral artery and must be protected during the dissection.

Venous Flaps

Venous flaps use superficial veins and overlying skin to provide soft tissue coverage of small defects of the hand and fingers.^{87–90} The superficial veins are anastomosed to digital or palmar arteries usually as a “flow-through” flap. For extensor surfaces, this flap has a proximal and distal vein anastomosed to veins on the back of the hand or finger. As a pure venous flap, perfusion is obtained through partially deoxygenated blood.⁹¹ As such, venous flaps usually undergo various phases of congestion, epidermolysis, desquamation, and partial necrosis before

definitive healing occurs.⁹² Venous flaps offer advantages of being a relatively easy dissection, as well as being, within the local area, thin, pliable, and small. Unfortunately, these flaps are not as reliable as standard flaps due to the lack of normal physiologic blood flow; that is, arterial inflow to the capillary bed to the venous outflow infrastructure.

Composite Tissue Flaps

Many of the free flaps listed above can be harvested with more than one type of tissue.^{93,94} The defect in the upper extremity may necessitate the use of skin and muscle (myocutaneous flap), skin and bone (osseocutaneous flap), skin with vascularized tendon, or a chimerism of tissue.^{95–99} Myocutaneous flaps were more popular before the advent of perforator flaps to ensure viability of the overlying skin.¹⁰⁰ Skin paddles can

Figure 12 (A, B) A dorsal hand defect in a 42-year-old woman; extensor tendons are exposed. (C, D) A serratus anterior fascia provides thin coverage to the tendons. A split thickness skin graft (STSG) is placed on the fascia. (E, F) The final results at 1-year follow-up illustrating good form and function.

accompany any of the muscle flaps if added volume is required. The fibula osteocutaneous flap represents the most commonly used composite tissue where bone and skin are required (Fig. 14).¹⁰¹⁻¹⁰³ The flap is based on the peroneal artery, which has an external diameter of 2.0 to 3.0 mm. The skin paddle can vary in size but may be taken as large as 10 to 18 cm centered over the middle third of the fibula.

The skin is supplied by septocutaneous perforators that arise posterior to the fibula. Other flaps that can incorporate bone for composite reconstruction of upper-extremity defects include the scapular flap, the lateral arm flap, the radial forearm flap, the ulnar artery flap, the serratus muscle flap, the anterolateral thigh flap, and the groin flap (Fig. 15).^{102,104} The radial forearm flap can be harvested not only with bone or fascia but also with the palmaris longus tendon for

reconstruction of a missing extensor tendon.¹⁰⁵ The palmaris longus tendon remains as a vascularized tendon graft incorporated into the fasciocutaneous radial forearm flap. This composite flap provides functional restoration of the extensor tendon while at the same time accomplishes the need for soft tissue coverage (Fig. 16).

Chimeric flaps are often required to close the large and complex wounds seen in the upper extremity. Chimeric flaps use different portions of tissue that are based on their separate vascular pedicles but merge into one single parent pedicle. The subscapular vascular system offers an excellent example of the chimeric principle (Fig. 17). The scapular skin, parascapular skin, serratus muscle, latissimus muscle, lateral or angle of the scapula bone are readily harvested together or in part based on the subscapular artery, which

Figure 13 (A–C) A 25-year-old woman with an avulsion injury to the right palm. Radial debridement is performed prior to definitive closure. (D) A serratus anterior free fascia flap is used for thin coverage. (E–H) The final result at 5-year follow-up. Good contour and function are provided.

supplies the scapular circumflex and thoracodorsal branches.

Spare Parts

An important concept that warrants special attention is that of “spare parts” for soft tissue closure. After injury or cancer ablation surgery, some remaining tissue may be

devoid of its native function and rendered useless. Such tissue that is otherwise not salvageable can be used to restore soft tissue coverage in another part of the upper extremity. Nonplantable amputated parts can be filleted and used as acute free flap coverage of defects, padding at the amputated stumps, or for the reconstruction of salvageable digits (Fig. 18).^{22,106–109} This special group of free flaps probably represents the only true indication

Figure 14 (A–C) A 32-year-old woman sustained a gunshot injury to the right forearm. A segmental loss of ulna was observed. A soft tissue defect and loss of flexor tendons were also observed. (D) The wounds were debrided. (E–G) A free fibula osteocutaneous flap was used to provide bone stabilization and soft tissue coverage. (F, G) Wound closure and fixation noted after the osteocutaneous flap is inset.

for an emergency free flap for coverage of upper-extremity defects. The tissue would otherwise be discarded, and another flap from another donor site would be required to fill the defect. An emergency free flap, in the sense, is one that is performed at the initial surgical procedure and debridement. More often than not, however, the

wounds require a second look to allow the tissues to demarcate and be properly debrided to avoid infection or other tissue loss. The optimal free flap can then be planned and executed in the daytime and not in the middle of the night when many of these wounds present themselves.

Figure 15 (A, B) A 25-year-old man sustained a mutilating hand and forearm injury during an industrial accident. (C) The wounds were debrided. A segmental loss of radius and a significant soft tissue defect is observed. (D–F) A scapular and parascapular osteocutaneous flap (lateral edge of scapula) is designed and harvested on the scapular circumflex pedicle. The flap is inset to provide abundant soft tissue coverage. The lateral scapula fills the segmental bone loss in the radius. (G) The final result at 1-year follow-up.

Figure 16 (A) A reverse radial forearm flap is designed using a template from the dorsal hand wound. (B) The flap is elevated based on the radial artery. The palmaris longus tendon is harvested with the flap to provide a vascularized tendon graft for a segmental loss of the EDC to the index finger. (C) The flap is transposed dorsally. (D, E) The flap is inset while the donor site is grafted with STSG. (F) Final result at 9-month follow-up showing good extension and flexion.

Occasionally, the reconstructive options to restore function may include using in situ tissue or remaining digits to reconstruct lost digits or tissue (Fig. 19). This type of reconstruction requires an insight into understanding staged procedures such as toe-to-hand surgery versus immediate use of tissues available in what is left in the mangled hand.

SECONDARY PROCEDURES

Mutilating hand injuries often require further surgeries to resolve issues of stiffness, contractures, adhesions, nonunions, and procedures designed to restore function. Malalignment or nonunion of fractured bones should be treated first to obtain skeletal stability before secondary procedures that necessitate early motion. The osteotom-

Figure 17 Chimeric flap offers multiple tissue paddles on separate branches of a present pedicle. The subscapular system is a good example of flaps that can be part of a larger chimeric flap if significant tissue is required for a given defect in the upper extremity.

Figure 18 (A, B) A mutilating hand injury in a 53-year-old man after a chain saw accident. (C) After debridement, the damaged parts are examined for possible salvage. (D, E) The long finger and dorsal skin was salvaged and transplanted to provide a sensate claw hand.

Figure 19 (A) A 26-year-old woman with H₁N₁ flu in shock required pressors for the treatment of hypotension. She developed ischemia and necrosis of all the digits to her hands. Ultimately she required amputation at the observed levels. (B) Exposed proximal phalanx of the thumb. (C) The remnant of the index finger was transposed (pollicized) on its neurovascular bundle to reconstruct the thumb. (D, E) The thumb's length was restored and the first web space deepened to provide a functional prehensile thumb and hand.

ized or grafted bone is immobilized to promote healing. Stiff joints, contractures, and tendon adhesions may need capsulotomies, volar plate release, collateral ligament release, or tenolysis procedures to restore motion (Fig. 20). Early aggressive rehabilitation is needed to prevent recurrence (Fig. 21). Alternative procedures such as tendon grafts or transfers, nerve grafts or transfers, functioning muscle transfers, joint replacement, or even amputations should be considered after stable coverage has been obtained and a functional deficit still exists (Fig. 22).

CONCLUSION

The challenges of soft tissue coverage of the upper extremity require a working knowledge of a wide variety of flaps. Pedicle flaps, as well as free tissue transfer, have important roles as a means of coverage depending on the size, location, and function of lost tissue. Free flaps can be tailored to meet the needs of the soft tissue defect while respecting the donor-site morbidity. As the hand surgeon weighs the pros and cons of each possible flap to obtain definitive soft tissue coverage, he or she must also integrate priorities of function and contour. The choice

Figure 20 (A, B) A 51-year-old man sustained an electrical injury to his right hand. An ALT flap was used to cover exposed flexor and extensor tendons. (C) A secondary neurolysis, nerve graft, and tendon graft procedure was required at the time of the flap debulking. (D) Secondary capsulotomies and tenolysis procedures were performed to promote function and range of motion.

Figure 21 (A) Aggressive active and passive range of motion therapy was required to maintain motion. A continuous passive motion machine offers 24-hour therapy. (B, C) The final results at 1-year follow-up.

Figure 22 (A) The functional deficit after a mutilating forearm injury in an 18-year-old woman. The extensor muscle was destroyed. (B) A gracilis functional muscle transfer was designed. (C) The gracilis muscle harvested prior to transfer. The distal tendon is split to provide separate extensor pollicis longus (EPL) and EDC extension. (D) The gracilis muscle is placed in a tunnel under the fasciocutaneous flap. (E, F) Nine-month follow-up after gracilis muscle reinnervation. Good restoration of extension is observed while flexion is preserved.

of flap should also take into consideration the need for staged reconstruction and secondary procedures. New flaps and new applications will undoubtedly be described in the future to add to our reconstructive repertoire and improve upon the standards that we uphold today.

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