Microsurgical Coverage Reconstruction in Upper and Lower Extremities

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ABSTRACT

Trauma is one of the main causes of upper- and lower-limb defects. Limb injuries frequently result in complex defects, hence reconstruction can be demanding. The basic principles of trauma management and methods of reconstruction are analyzed. Then, the evolution of free tissue transfer is reviewed with particular attention to the use of anterolateral thigh flap in reconstruction of upper- and lower-limb trauma cases. The anterolateral thigh flap is the workhorse flap in our department due to its versatility in the reconstruction of complex defects. Finally, the concept of free-style perforator flaps is presented. Microsurgery has supplied the armamentarium of the plastic surgeon with a very powerful tool. Essentially, microsurgery may almost always provide a solution in cases of complex defects that cannot be covered with the simpler options of the reconstructive ladder. The recently acquired perforator flap concept will gradually become the most popular method of microsurgical reconstruction, as it minimizes donor-site morbidity and replaces "like tissue with like tissue."

KEYWORDS: Upper-limb reconstruction, lower-limb reconstruction, anterolateral thigh flap, free-style perforator flap, microsurgical reconstruction

The majority of hand injuries are caused by industrial or agricultural accidents. About 13.3% of these injuries result in permanent disabilities. Furthermore, approximately half of all permanent disabilities are hand injuries.¹ Road traffic accidents are the main cause of lower-extremity trauma.² Injuries may be multiple, especially as lower limbs are not protected by airbags. A mangled lower extremity may require multiple procedures and years to rehabilitate. The management of extensive and complex defects is challenging and may result in leg amputation or shortening.

Limb amputation is a severe mutilation that compromises the patient's everyday routine by limiting self-sufficiency. Limb shortening is also responsible for an asymmetric gait and posture deformities. In the past 20 years, the evolution of microsurgery has radically changed the treatment of complex upper- and lower-limb wounds. Soft tissue reconstruction with well-vascularized muscle or fasciocutaneous flaps provides soft tissue coverage of metalwork, fills the dead space, and helps in the delivery of oxygen and antibiotics to the wound bed. Thus, the functional, morphologic, and

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cosmetic outcome is improved in most instances, avoiding the need for limb amputation or shortening.

BASIC PRINCIPLES OF TRAUMA MANAGEMENT

The basic principles of management of a trauma in the upper or lower extremity are the same as for any other area of the body: aggressive debridement with removal of all devitalized tissue, hemostasis, reduction of fracture, and administration of antibiotics. The surgeon should always be vigilant for potential compartment syndromes that are not uncommon in limb injuries. Even when in doubt, if one is suspicious of a compartment syndrome, he should perform a fasciotomy as the morbidity from fasciotomies is less than that from ischemia.

In patients with severe limb trauma with suspicion of vascular injury, arm or leg perfusion should be assessed clinically and, if necessary, an arteriogram should be considered in case microvascular reconstruction is planned. Extremities injuries often have associated nerve injuries. Nerve repair is feasible due to the evolution of microsurgery techniques. However, the results of nerve repair may be poor if the level of injury is at the proximal arm or proximal leg, due to the long distance the nerve has to grow to the motor end plate, the complex distribution of nerve fascicles, and the long distance from the spinal cord to the motor end plates. This fact has to be taken into consideration in cases of replantation.

The timing of reconstruction is a matter of debate among surgeons. There is evidence that early aggressive wound debridement and soft tissue coverage with a free flap within 5 days of injury reduces postoperative infection, flap failure, nonunion, and chronic osteomyelitis.^{3,4} Godina advocates the importance of radical debridement and early tissue coverage within the first 72 hours.⁵ In contrast, Yaremchuk et al prefer to perform serial debridement and transfer flaps between 7 to 14 days postinjury.⁶ An early reconstruction may underestimate or overestimate the amount of tissue to debride, and a delayed reconstruction may be at higher risk of infective and vascular complications. Generally, coverage by the 5th to 7th postinjury day is considered as having a good prognosis in terms of decreased risks of infection, flap survival, and fracture healing.⁷

TRADITIONAL METHODS OF RECONSTRUCTION

The traditional reconstructive ladder—direct closure, skin grafts, local flaps, distant flaps—applies to reconstruction of the upper and lower limb as in any area of the human body. However, the upper and lower limbs are sophisticated structures that have specific functions. Therefore, it may be more appropriate to think in terms

of the reconstructive triangle (form, function, and safety) as described by Mathes and Nahai⁸ regarding their reconstruction. According to the reconstructive triangle, the indicated technique for a certain defect should safely achieve a successful reconstruction and restore form and function.

Upper Limb

Today, most surgeons are more aggressive in salvaging an upper extremity than in preserving a lower extremity. The type of reconstruction depends on the extent and location of soft tissue defect. For example, defects up to 1 cm² on the fingertips have very good results when healing by secondary intention. Skin grafts can cover exposed muscle or fascia and even can be placed on healthy periosteum or healthy paratenon. The basic types of flaps that can be used in upper-limb reconstruction are random circulation flaps, axial pattern distant flaps, regional fascial or fasciocutaneous flaps, and finally free flaps.¹⁰ Random pattern flaps can be raised from the abdominal or inguinal area to cover soft tissue defects of the upper arm. The disadvantage is that the arm is immobilized for a period of up to 3 weeks. The most commonly used axial pattern distant flap is the superficial circumflex iliac artery flap (SCIA), also known as the “groin” flap.¹¹ It provides good-quality hairless skin, and the resulting scar is well hidden. The drawback of prolonged immobilization can be surmounted, as the SCIA flap can also be used as free flap.¹²

From the regional fasciocutaneous flaps, the island forearm flap provides great versatility in the management of complex hand injuries.¹ A distally based radial forearm flap can, for example, cover elbow defects. A distally based forearm flap with the antebrachial cutaneous nerve included can be used to reconstruct a degloved thumb. The posterior interosseous artery flap is mainly used to reconstruct the first web space. The flap has tedious dissection. However, its advantage is that the posterior interosseous artery is a vessel of secondary importance for hand vascularization.¹³ The latissimus dorsi pedicled flap is the muscle flap that can be used to reconstruct large defects of the upper extremity. The muscle provides well-vascularized tissue from a region far from the area of injury.¹⁴ It can also restore function when transferred to elbow, in cases where the triceps muscle has been damaged.

Lower Limb

After debridement, we should evaluate the soft tissue and bone defect. The choice of the soft tissue reconstructive procedure mainly depends on the location and extent of the defect. Usually, soft tissue reconstruction is mandatory for open fractures and for resection related to osteomyelitis. For the upper third of lower-leg reconstruction a

gastrocnemius flap, for the middle third a soleus muscle flap, and for the lower third a free tissue transfer are currently standard treatment.

Fasciocutaneous flaps may be used to cover small to moderate-size defects over exposed bone, nerves, or tendons. However, a small defect often requires a relatively large flap, and the donor site almost always requires a split-thickness skin graft. Hallock reported an 18.5% complication rate in proximally based flaps and a 37.5% complication rate in distally based flaps in a series of 67 fasciocutaneous flaps to the lower extremity.¹⁵

Muscle flaps have the disadvantage that they are often in the zone of injury. As already mentioned, the lateral or medial gastrocnemius flap can be used to cover defects of the proximal third of the leg and knee. The middle third can be covered with the soleus flap or a hemisoleus flap if we wish to preserve the function of half of the soleus muscle. Smaller defects can be covered with the tibialis anterior muscle bipedicle flap or other muscles of the anterior and lateral compartments. Nevertheless, these muscles have a less reliable blood supply. Defects of the lower third of the leg almost always require free tissue transfer. Cross leg flaps may be used as a last resort in cases where there is no recipient artery available. However, the cross leg flap has many disadvantages, as the prolonged immobilization may cause contracture formation and lead to the development of deep venous thrombosis.

The vacuum-assisted closure is a device that uses controlled negative pressure to provide evacuation of wound fluid, stimulation of granulation tissue, and a decrease in bacterial colonization. It can be used as adjuvant therapy in contaminated complex defects to improve local wound conditions.¹⁶ The device does not replace the need for debridement of necrotic tissue, but simplifies wound care for the nursing staff, and this is especially important in cases of multi-injured patients that are mobilized with difficulty.¹⁷

Regarding the coverage of foot defects, restoration of sensibility particularly for weight-bearing areas is of utmost importance. Evaluation of the foot defect includes the following: dimensions of the defect, localization (weight-bearing or non-weight-bearing areas), exposure of noble structures, age of the patient, and concomitant diseases. Hidalgo and Shaw in 1986¹⁸ provided a classification of foot defects and algorithm of reconstruction as follows:

Type I: Small soft tissue loss less than 3 cm² can be repaired by local flaps in weight-bearing areas and by skin grafts in non-weight-bearing areas.

Type II: Large tissue loss greater than 3 cm² without bone involvement, a free fasciocutaneous, musculocutaneous, or muscle covered with skin graft transfer is indicated.

Type III: Large tissue loss with bone involvement, a free osteocutaneous transfer is recommended.

EVOLUTION OF FREE TISSUE TRANSFER FOR RECONSTRUCTION OF SOFT TISSUE DEFECTS OF THE UPPER AND LOWER LIMBS

Free flaps have been in clinical use for three decades now. Since the first description of free groin flap transfer by Daniel and Taylor in 1973¹¹ and the transfer of a free gracilis flap by Harii et al in 1976,¹⁹ microsurgical technique has evolved and is nowadays a routine practice in many hospitals.

The muscle free flaps as the latissimus dorsi²⁰ or the gracilis flap¹⁹ are useful in case functional reconstruction is required, as in Volkmann contracture, and provide a large mass of well-vascularized tissue. This is particularly helpful in cases of osteomyelitis, which is common especially after lower-limb injuries. However, the disadvantages of the muscle flaps, such as the bulkiness and the increased donor-site morbidity, led to the development of muscle-sparing flaps like the fasciocutaneous flaps.

Refinements in surgical technique and instrumentation helped in the improvement of survival rate that at present is more than 95% in most microsurgical centers. Having ensured a high success rate for free flaps, the microsurgeons are nowadays more interested in improving the aesthetic and functional results and reducing donor-site morbidity. Taylor and Palmer with their anatomic study found that there was a mean of 276 cutaneous perforators of 0.5 mm diameter or greater. Each perforator was connected to the next by a system of "choke vessels" to form a continuous network of supra-fascial vessels through the integument.²¹ Afterwards, again Taylor et al demonstrated the use of a Doppler device to plan a skin flap around any of these perforators.²² The new concept of perforator flaps evolved through the work of other pioneers such as Nakajima, Allen, Koshima, Blondeel, Hallock, and Wei. However, initially there was confusion as to what is a "true perforator flap." In 2000, Wei et al clarified this definition and described true perforators as those cutaneous vessels that penetrate the muscle and then pierce the fascia to reach the skin.²³ Hence, plastic surgery has entered a new era, and numerous perforator flaps have been described.²⁴ However, in our department the anterolateral thigh flap remains the coronet of microsurgical reconstruction thanks to its versatility.²⁵

THE ANTEROLATERAL THIGH FLAP IN UPPER- AND LOWER-LIMB RECONSTRUCTION

Since its first description by Song et al in 1984,²⁶ the anterolateral thigh flap has been gaining popularity

Table 1 Types of Free Flaps at Chang Gung Memorial Hospital from August 1995 to December 2008 (N = 2619 Free Flaps)

Type of Flap	Number of Flaps
Anterolateral thigh flap	1294
Radial forearm flap	425
Fibular osteocutaneous flap	411
Gracilis flap	178
Others	311

among microsurgeons. In our department it is the workhorse flap for reconstruction of complex defects of the upper or lower limb (Table 1).

Anatomy

The maximum dimensions of the flap that can be harvested are a matter of debate. According to Koshima, the skin paddle could be up to 35 cm in length and 25 cm in width based on a single dominant perforator.²⁷ The axial vessel for the supply of the anterolateral thigh flap is the lateral circumflex femoral artery (LCFA). It sends perforators through the septum (septocutaneous) between vastus lateralis and rectus femoris or through the vastus lateralis muscle (musculocutaneous) to supply the area of the flap. The musculocutaneous perforators are the most common type. They are responsible for the blood supply in more than 86% of the cases. The septocutaneous perforators are responsible for the blood supply in ~12% of cases.^{25,28,29}

Operative Technique

With the patient in the supine position, a line is drawn between the anterior superior iliac spine and the lateral border of the patella. This line represents the axis of the flap and corresponds roughly with the intermuscular septum between the rectus femoris and vastus lateralis muscles. The main perforators for the anterolateral thigh flap are identified with the Doppler. They are usually located within an area of 5 cm around the midpoint of the axis of the flap.²⁵ The skin flap is designed to include all the main perforators.

In our department we begin dissection of the anterolateral thigh flap from the lateral side. After the perforators are visualized, we change to the medial side and complete our dissection from medial to lateral. We think this way of harvesting the flap is safer as the perforators have already been identified from the lateral side and their damage is almost always avoided. Dissection is always performed under loupe magnification (2.5 × to 4.5 ×). Initially, we try to include more than one perforator to have a backup in case one is damaged during dissection. Dissection of the perforator(s) to the main pedicle is performed using the “deroofting” techni-

que.³⁰ The muscles are cleaved along the length of their fibers to liberate the perforators while an assistant stretches the muscle fibers slightly with small hooks.³¹ The numerous tiny branches that the perforators give to the muscle have to be ligated carefully. It is better to use clips and avoid the diathermy and ligate as far as possible from the perforator. If we come across an unusually large side branch while dissecting a perforator, we should not ligate it immediately as it may come from the next nearest perforator. This will allow the two perforators to supercharge one another.³²

All through our dissection, we should irrigate the perforator with Xylocaine (lidocaine hydrochloride, U-Liang, Taiwan) 2% to prevent vasospasm and dryness. Also, it is very important that we watch that the pulsation is transmitted all throughout the length of the perforator. This is the most reliable sign that ensures our perforator safely irrigates the flap.

To avoid twisting of the pedicle, we may include a small cuff of muscle or fascia at the point of entrance of the perforator to the flap. Including more than one perforator also helps define the original orientation of vessels. Also, a fine suture that connects a branch stump of the main pedicle and the flap can be used to prevent torsion and twisting of the pedicle. This suture should be removed after inset of the flap.²⁸

The donor site can be closed directly when the width of the anterolateral thigh flap is less than 8 cm. If the flap width is more than 8 cm, we should use a skin graft to avoid compartment syndrome.²⁸

Advantages and Disadvantages of the Anterolateral Thigh Flap

The anterolateral thigh flap has many advantages over other free flaps including (a) the vascular pedicle is long; (b) the skin paddle is large and pliable with good color and texture matching³³; (c) inclusion of the lateral femoral cutaneous nerve can provide a sensory flap^{25,34}; (d) donor-site morbidity is minimal even when harvested as a myocutaneous flap^{35,36}; (e) it can be used as a flow-through flap to bridge vascular gaps³⁷; (f) part of the vastus lateralis muscle can be used to fill dead spaces and help avoid infection after surgery³⁵; (g) two-team approach is often possible, which shortens operation time.

The disadvantages of the anterolateral thigh flap are that it has anatomic variations and there is hair growth in some male patients. However, hair growth is a drawback mostly in cases of intraoral reconstruction and not so much in cases of upper- and lower-limb reconstruction.

Applications of the Anterolateral Thigh Flap in Upper- and Lower-Limb Reconstruction

Perhaps the main advantage in the use of the anterolateral thigh flap in reconstruction of complex defects of the

Figure 1 (A) A male patient sustained a complete degloving injury of his right palm. (B) An anterolateral thigh flap from his left thigh was used to cover the defect, immediately after adequate debridement. Secondary double-toe transfer from his left foot was performed 3 months later. (C, D) Useful hand function at 1-year follow-up.

upper (Fig. 1) and lower extremities is its versatility in design. While a thin skin flap (Fig. 2) can be harvested for reconstruction of the sole of the foot in one patient, a large part of vastus lateralis can be included in a musculocutaneous flap to obliterate dead space and fight osteomyelitis in another. Reconstruction of soft tissue defects in the extremities requires thin, pliable tissue. One could argue here that this would be a disadvantage to the use of the anterolateral thigh flap due to the bulkiness of subcutaneous tissue. However, the anterolateral thigh flap can be thinned using simple and effective procedures.^{38–40} According to Kimura and Satoh, the anterolateral thigh flap represents the best thin flap because more uniform thinning is allowed by the anatomy of its perforators.³⁹ Instead of thinning the anterolateral thigh flap, we can also harvest it as an adipofascial flap. This adipofascial flap, covered by a skin graft, can reconstruct defects in areas where minimum subcutaneous tissue is required such as the fingers (Fig. 3).

Osteomyelitis is a common complication mainly in lower-extremity injuries. Adequate debridement and coverage of the bone with well-vascularized tissue is of paramount importance in the treatment. Although muscle flaps are known to provide superior vascular supply, anterolateral thigh flaps have been used successfully in the treatment of osteomyelitis as they provide a large amount of well-vascularized tissue that can be used

to obliterate all dead spaces.⁴¹ Thus, we can avoid the morbidity of sacrificing a muscle flap like the latissimus dorsi flap.

High-energy injuries, apart from soft tissue defects, often cause vascular gaps especially to the lower extremities. The soft tissue and vascular defect can be reconstructed concomitantly if the anterolateral thigh flap is used as a flow-through flap. Moreover, the distal stump of the pedicle can be used to anastomose vascularized bone or another soft tissue flap, thus creating “mosaic” flaps.⁴² Furthermore, “chimeric” flaps (Fig. 4), hence different flaps based on the same vascular pedicle, can be harvested with the anterolateral thigh flap to reconstruct complex defects.⁴³ Park et al suggested that the anterolateral thigh flap is highly effective in the reconstruction of complex defects of the lower extremity.⁴⁴ Indeed, apart from skin and muscle defects, it can be used to replace tendon defects^{45,46} like the Achilles’ tendon, with the inclusion of the fascia lata (Fig. 5). Harvesting of the flap with vascularized fascia can also provide gliding surface for exposed tendons in reconstruction of the upper extremity. Finally, if more than one perforator is available, the skin flap can be separated in smaller skin flaps, each one of them based on one perforator (Fig. 6). This would help reconstruct defects in adjacent fingers, for example, without the need for separation at a later stage.

Figure 2 (A) A female patient suffered from right proximal sole trauma. (B) The anterolateral thigh (ALT) flap was used to resurface the injured heel well. (C) Patient at 2-year follow-up.

Figure 3 (A) A female patient sustained a degloving injury of her right index finger. (B) An adipofascial thigh flap harvested from her left thigh was used to resurface the exposed bone and was covered with a skin graft. (C) Patient at 6-month follow-up.

Figure 4 The so-called chimeric flap, which has one skin component and one muscle component.

The anterolateral thigh flap can also be used as a prefabricated flap. Lin et al have reported the temporary placement of plantar heel skin in the thigh with subsequent transfer back to the heel using free anterolateral thigh myocutaneous flap as a carrier.⁴⁷

Considering the plethora of options that it offers in reconstruction, we think that the anterolateral thigh flap could possibly represent the free flap panacea for coverage of complex limb defects.

FREE-STYLE PERFORATOR FLAPS

A free-style perforator flap is a new concept that has been developed as a result of the constant quest of the reconstructive surgeons for less donor-site morbidity and better aesthetic outcomes. It consists of a flap harvested in a free-style manner, based only on the preoperative knowledge of Doppler signals present in a specific region. This way, a flap can be raised from any anatomic region where an audible Doppler signal of a perforator is detected.⁴⁸ The free-style perforator flap (Fig. 7) can be transposed locally to cover defects in adjacent anatomic regions; hence it will be called a local free-style perforator flap,⁴⁹ or it will be transferred as a free flap to a distant area and then it will be called a

Figure 6 The so-called compound flap; each one of the flaps based on one sizable perforator.

free-style free perforator flap.⁵⁰ Free-style local perforator flaps may provide better aesthetic results for the coverage of a defect as the skin adjacent to it has similar texture, thickness, and color. Free-style free flaps give more autonomy to the surgeon as he does not need a detailed knowledge of the anatomy, as any perforator can potentially be traced to a source vessel. He can also choose a free flap from any area of the body based on factors as the best color, thickness, and texture match and least donor-site morbidity and can overcome anatomic variations.⁴⁸

A disadvantage of the free-style perforator flaps is that they are not an operation for the beginner. The microsurgeon needs to have superior microsurgical skills and be familiar with perforator flaps and intramuscular perforator dissection before he or she attempts a free-style perforator flap. Moreover, he or she needs to be experienced in using the Doppler device as, for example, in areas where large underlying vessels are present, the signal of the main vessel will obscure the signal of the smaller perforators.⁵¹ Other limitations of the technique are (a) the course of perforators may be unpredictable, (b) small and long perforators may be difficult to harvest and inset, and (c) intraoperative flap thinning

Figure 5 (A) Harvesting of the skin flap with a vascularized fascia lata. (B) It could be used to replace the tendon defect and also to provide the gliding surface for exposed tendons in limb reconstruction.

Figure 7 (A) A male patient suffered from a left leg skin defect 12 cm × 6 cm in size with bone exposure. Preoperatively, a significant Doppler signal was detected in a specific region. (B) The sizable perforator was confirmed during the dissection. (C) The free-style perforator flap was elevated. (D) The flap was transposed locally to cover the defect in adjacent regions.

should be more conservative compared with that for conventional flaps.⁵⁰

CONCLUSION

In the new era of perforator flaps, the reconstructive ladder is always of value in the coverage of upper- and lower-limb defects. However, the surgeon should shift from the traditional methods of reconstruction to perforator flaps to improve aesthetic results and minimize donor-site morbidity.

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