Tissue Coverage After War Trauma

13

Lucian Fodor and Yehuda Ullmann

13.1 General Considerations

The extremities are the most common site to be injured by war weapons [1,2]. The location of the injury also has prognostic role, the worst being for those injuries located below the knees [3]. Weapons cause soft-tissue damage by several mechanisms: blast injuries produced by rockets, grenades, mortar and land mines, gunshot wounds and burns. The most common combination is blast with fragmentation injuries [4]. Secondary lesions caused by mobilization of the fragmented bone or foreign bodies should also be considered during the patient's examination. It was reported that 70–80% of combat injuries are caused by fragments from explosive munitions [5]. First- and second-degree burns are also common in soldiers injured during wartime. Smoke inhalation is one of the major causes of death in a war scenario [6]. It should be remembered that nonconventional weapons are sometime used during war. Explosives that contain multiple metal objects are responsible for multiple site injuries with extensive soft-tissue destruction [7]. Vascular injuries are very common in these cases. Considering that life-saving comes before limb salvage, the overall limb salvage rate in wartime is about 80% [4], while the rate is higher for the upper extremity.

Fifteen to twenty years ago, several scores of severe limb injuries were postulated to help the surgeon decide between amputation and limb salvage. The most common scoring systems are the Mangled Extremity Severity Score (MESS) [8], the Predictive Salvage Index (PSI) [9], and the Limb Salvage Index (LSI) [10]. The MESS is based on the degree of bone and soft-tissue injury (1–4 points), ischemia time (0–3 points), systemic hypotension (0–2 points), and patient age (0–2 points). If the ischemia time is longer than 6 h, the points are doubled. A score higher than 7 points is considered as a high prediction for amputation [8]. The PSI score is based on the severity of the bone injury, the level of the arterial injury, the muscle injury severity, and the ischemia time [9]. A score greater than 8 points is predictive for amputation. The LSI greater than 6 points regarding the severity of the injury to the arteries, deep veins, nerves, bone, skin, and muscle and the length of the ischemia time is also predictive for amputation.

Although the MESS score is well accepted, after reviewing the mangled extremity injuries in Iraq and Afghanistan, Brown concluded that management of ballistic extremity injuries should be different in comparison to civilian high-energy injuries [11]. In those wars, three soldiers with a MESS score of 6 (out of 77 cases) underwent amputation. According to Brown [11], the presence of vascular injuries in a patient with prolonged hypotension in the military environment is the main factor leading to primary amputation. The implementation of damaged control resuscitation before surgery, by the

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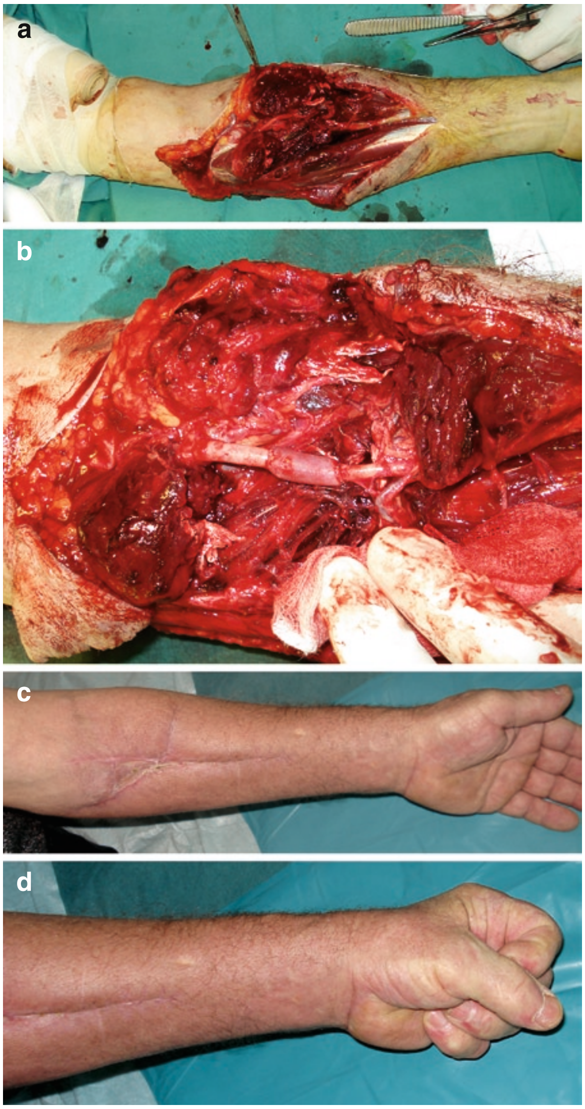

Fig. 13.1 (**a**) Gunshot wound, (**b**) Exposure and repair of ulnar nerve and radial artery using a venous graft. Skin graft was placed after the repaired muscles, (**c**) One year later. Active extension, (**d**) One year later. Active flexion

administration of recombinant factor VII, plasma, and blood, can increase the operating time by better general stabilization of the patient [12].

The validity of the severity scores as a predictive factor for amputation has been criticized by some authors [13,14] for not being updated and for not considering advances made in the surgical field, which allow preserving even severely injured limbs [14].

13.2 Physical Examination

The initial physical examination should focus on:

- Identifying the type of soft-tissue injuries (wounds, crush, burns)
- Evaluating the soft-tissue injury with regard to extent of skin lesions and muscle and tendon lacerations. If skin lesions are easily identified, clinical evaluation of the underlying lesions might be difficult, especially if the patient is unconscious. In unconscious patients, the surgeon should identify the potential injured structures by evaluating the trajectory of the weapon (entry and exit points of the bullet). In a conscious patient, the mobility maneuvers are important to identify the tendon or muscle injuries. Sometimes, local pain may restrict movement and make the examination more difficult.
- Identifying the nerve and vessels injury is widely described in Chaps. 11 and 12. We would like to emphasize the importance of identifying multilevel nerve and artery injuries (Fig. 13.1). After blunt or blast injuries, nerve contusion and neurapraxia with the nerve in continuity is frequent.
- Evaluation of skeletal injuries is described in detail in Chaps. 6 and 9.

Using different imaging methods to evaluate limb injuries should be done concomitantly with the general investigations (e.g., total body computed tomography) or after stabilization of the patient. Doppler ultrasound can be of benefit in quickly evaluating the distal limbs. CT angiography or common angiography may be less available during wartime.

13.3 Timing of Soft-Tissue Coverage

There are several reports showing that aggressive debridement of wounds, followed by flap coverage within a few days (the sooner, the better) results in fewer amputations and fewer bone nonunions [15,16]. The available evidence shows that earlier coverage (within the first 72 h) is associated with fewer complications and shorter hospitalization time [17]. The sooner the open wound is closed after the initial debridement, the lower the contamination rate and the greater the overall success. For years, it was believed that early wound coverage within 72 h using free flaps increases the rate of success [16]. However, recent studies show that the initial coverage period for the upper extremity can be extended up to 21 days with good success rates [18,19]. Yaremchuk [20] obtained good results even when the free-flap reconstruction was delayed considerably.

There is still controversy regarding the proper time of wound coverage during wartime. Due to multiple trauma, the location of the injuries and the severity of the damage, early flap reconstruction becomes a difficult and uncertain project. Kumar [21] reconstructed the limbs 7 days after the injury and reported low rates of flap failure and infection. Due to widespread use of negative pressure wound therapy, delay in reconstruction is no longer detrimental [21]. In a different study [22], the same author reported that the average time for flap reconstruction during wartime was 31 days. The high contamination rates of combat injuries with Clostridium is another reason to postpone definitive closure of these wounds [23]. Subacute limb reconstruction using flaps demonstrated a low total and partial flap loss with acceptable infection rates [22]. The subacute period was considered to be 72 h to 3 months.

13.4 General Strategies of Treatment

High-velocity injuries are associated with wider zones of injury, and treatment particularities should include extensive debridement, evaluation of the surrounding area, and identifying potential compartment syndromes. Because most wounds are contaminated with pieces of cloth, soil, and foreign bodies, aggressive debridement accompanied by thorough irrigation is necessary, while primary closure should be avoided. The preliminary evaluation in the emergency room is continued by a definitive evaluation in the operating room.

Evaluation of the injured area should include categorization of the major lesion according to its cause: blast, burns, or gunshot. Secondary lesions should not be neglected, as they may be very severe. Even a small fragment of bone or foreign body may damage the nerves and the arteries with serious consequences. A conscious patient may be evaluated using the needed imaging system and a rigorous clinical check up that could reveal possible damage to nerves or vessels. When such an injury is suspected, a careful exploration is worthwhile, depending on the general condition of the patient.

Often, mangled extremity injuries and blast injuries are associated with segments that cannot be reconstructed. These "spare parts", which are actually free segments, may be used to reconstruct other zones [24]. At the initial debridement, the wounds are washed with diluted antiseptics. For larger wounds, pulse-lavage is preferred. The wounds are left open or the skin edges are approximated over drains. Usually 48–72 h later, wound revision is performed with secondary debridement and thorough wound irrigation. When a burn and soft-tissue crush is present, a third and even fourth debridement is performed on the seventh to tenth day after the initial injury. This is the time period that is necessary for skin necrosis delimitation. The period of time mentioned above is a guideline, which should be adjusted in accordance with the general condition of the patient.

The management of vascular injuries in the extremities is widely reported in Chap. 11. However, we would like to emphasize the importance of choosing the order of anatomical reconstruction according to the severity of the injury and the time from injury. The order of reconstruction, either the bone or the arteries first, depends on the ischemia time. The time of injury is important when there are devascularizing injuries. The more proximal the location of the limb injuries, the more are the devascularized muscles, and the ischemia time is more critical. The muscle ischemia time is around 4–6 h. The temperature of the ischemic tissue is also important. The lower the temperature, the better the tissue response to the injury and the ischemia. However, there is a real risk of reperfusion injury when a significant amount of muscle has been affected. In this situation, with prolonged ischemic time, it is preferable to use a temporary vascular shunting. Temporary vascular shunting is described in military and civilian wars as being important during acid–base correction, hemodynamic instability, rewarming, during skeletal stabilization, and during transportation to an upper level of care [25–27]. At the initial debridement, the ends of the major nerves should be marked with sutures or clips if primary repair is not possible. The soft-tissue reconstruction should be done after skeletal stabilization, vascular, tendon, and nerve repair. The order in which these are performed can vary according to the type of injury, level of injury, and exposure of

Fig. 13.2 (**a**) Mangled thumb and thenar eminence, (**b**) Comminuted intraarticular fracture, (**c**) Osteosynthesis (**d**) One year after. Extension, (**e**) One year after. Flexion, (**f**) One year after. X-ray

important anatomical elements (Fig. 13.2). Ideally, soft-tissue coverage should be durable, low profile, mobile in joint areas, and sensate for regions where friction is present such as fingers, palm, and plantar areas.

In war injuries, particularly, there is subsequent significant local edema, which may lead to the development of compartment syndrome or to enlargement of the wound. Avoiding wound enlargement can be done by placing rubber bands in a crisscross manner along the wound edge. The VAC (Vacuum Assisted Closure) device prevents wound enlargement and actively reduces edema. Choosing the type of soft-tissue coverage should be done in accordance with the patient's overall status. Preservation of limb length is important but this should not interfere with function. Achieving stable and durable soft-tissue coverage of a functional limb is the goal of soft-tissue reconstruction.

Soft-tissue management usually necessitates several procedures. An average of 3.7 procedures was needed for limb injuries caused during wartime [28]. The blood supply to the lower extremity is poorer than to the upper extremity [29]. The skin in the anterior part of the calf is thin and the tibia can easily be injured. Due to its dependent position, the lower limb is frequently associated with post-traumatic venous stasis. As a weight-bearing organ, the lower extremity needs good support and the plantar area should have good sensory innervation.

When performing soft-tissue reconstruction, the concept of "reconstructive ladder" should be used only as a guide (Fig. 13.3). With recent advances in flap designs and available sophisticated devices such as VAC therapy, the treatment should be adjusted to utilize perfectly all the available armamentarium. Ideally, the surgeon who is involved in the debridement procedure should continue the reconstructive phase. It is easy to amputate but it is hard to reconstruct. We are in favor of preserving a limb when the life-threatening condition is ruled out. The patient should be the one to decide the outcome of the limb.

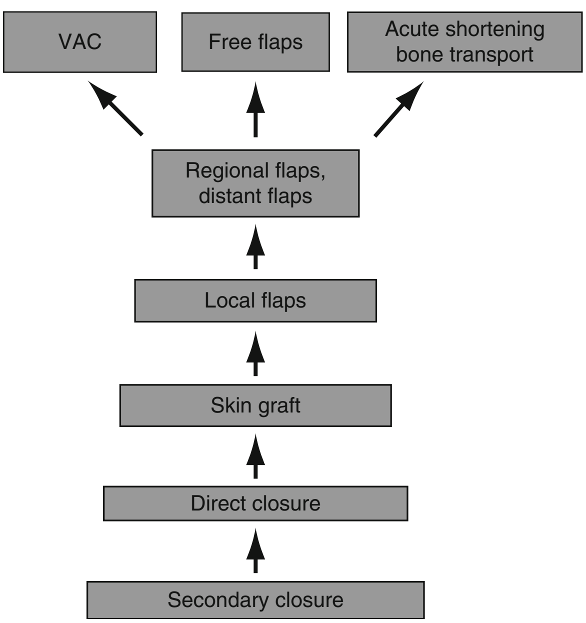

Fig. 13.3 The revised reconstructive ladder

13.5 Negative-Pressure Wound Therapy

Negative-pressure wound therapy has frequently been reported often to be helpful in closing wounds. VAC is a well-accepted method of closing wounds, or as a means to clean and prepare the wound for definitive closure, either by flap or skin grafting (Fig. 13.4). It acts by applying constant or intermittent negative pressure on the wound bed, and it is relatively easy to be applied. After completion of the debridement and hemostasis, a polyurethane foam dressing is trimmed to fit the size of the wound. A suction tube is placed inside the foam. A plastic sheath covers the foam to seal it and allow the suction from the deep site. The suction tube is connected to a pump, which can be set at different pressures. The most commonly used pressure is 50–200 mmHg. The VAC system decreases fluid excess, produces arteriolar dilation, improves microcirculation, and removes enzymes, cytokines, and collagenases as well as other factors that may inhibit wound healing [30–32]. The VAC system has also been reported to decrease bacterial contamination of the wound [33]. For closing larger wounds, a longer time period is needed and, in this case, the VAC is

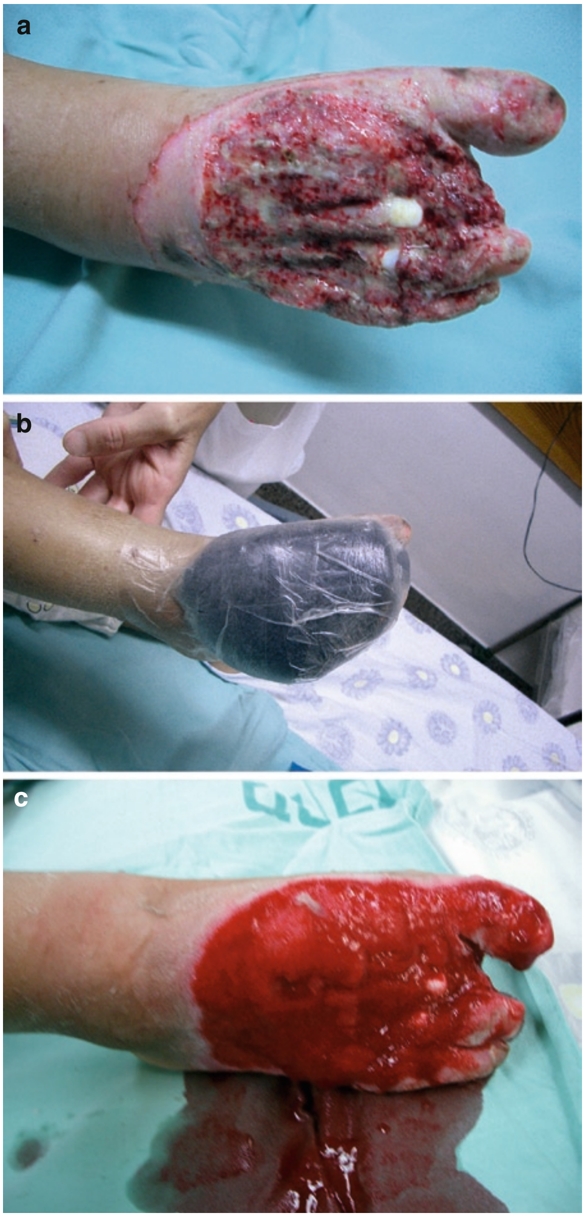

Fig. 13.4 (**a**) High-energy injury to the foot; exposed bone. (**b**) The wound is covered by the sponge of VAC system. (**c**) A few days later with good granulating tissue

used to prepare the wound for a safer closure by local or free flaps, thereby reducing hospitalization time and costs [31]. There are several reports that show the benefit of VAC treatment for acute limb injuries [34]. The main applications are:

- For initial wound care, because war wounds may be heavily contaminated and not ready for primary closure; reducing contamination and edema will allow adjustment to the best way to close the wound several days later.
- To cover exposed bones and tendons, keeping them wet and promoting the development of granulation tissue to cover them.
- To close fasciotomy wounds.
- For wound closure in a definitive method for patients in poor general condition.

Successful VAC therapy has been reported for temporary or definitive coverage of white structures (bones, tendons, nerves), as well as the hardware in mangled extremity and war injuries [18,28]. Possible complications of negative-pressure wound therapy are: minor bleeding, especially during dressing changes [35], pain, infection [36,37], and rarely, fluid depletion in older patients [38].

13.6 Skin Grafts

When no white structure is exposed and the wound bed has good granulation tissue, skin grafts can be used for coverage and definitive closure of the wound. Split thickness skin grafts (STSG) are thinner and have a better chance to "take". They can be used as meshed or unmeshed. Meshed grafts have the advantage of allowing seroma and hematoma drainage (Fig. 13.5). Maintaining good contact between the graft and the recipient bed is important for a successful take. Unlike skin grafts performed immediately on clean wounds, those related to war injuries usually need preparation by repeated dressing changes due to wound secretions and contamination, and only then can skin grafting be completed. The meshed graft may be applied after VAC treatment, which is helpful for preparing the graft bed for a better graft "take". The most common donor areas for STSG are the thighs and buttocks. However, the area can be adapted according to the wound distribution over the body areas. A 0.0010–0.0012 in. is the most common thickness for the graft. Full-thickness skin grafts are rarely used when

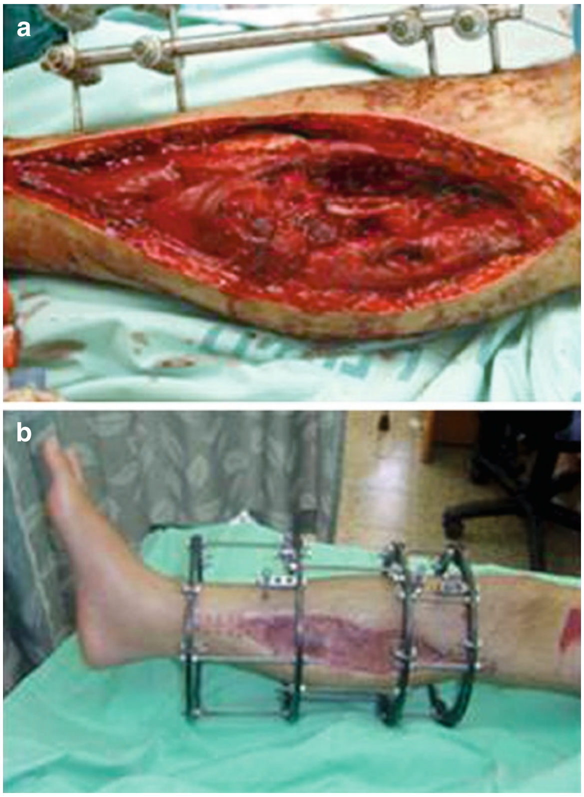

Fig. 13.5 Blast injury to the lower limb. Closure of fasciotomy with meshed skin graft

dealing with war injuries. However, they are used for covering the joint areas. There is a limitation in donor area availability, as it needs to be closed primarily.

13.7 Flaps

Hundreds of flaps are described for dealing with soft tissue lost from the extremities. However, not all can be applied for war injuries. The most commonly used flaps in these situations are presented here. There are no different general principles of wound management for upper extremities as compared to lower extremities. Choosing the ideal coverage method depends on the defect size, the patient's condition, the surgeon's preference, and the associated injuries. Principally, pedicled flaps are more often employed than free flaps for closing war wounds [21].

Local Flaps. These can be axial or island and are usually used to cover small- to medium-sized defects. Their applicability in war injuries is especially for small wounds such as those produced by gunshot. When a larger wound is present, these flaps have limited applicability because their blood supply may be compromised. While they are not widely accepted to cover wounds in the acute phase, they might be useful at a later stage, several weeks after the injury. During this time they behave like "trained" flaps with a greater chance of survival. The 1:1 to 2:1 proportions should be considered for random flaps in the limbs. When an axial flap is used, there are reports of using long and thin flaps in the noncompromised areas.

Cross-Limb Flaps. These types of flaps were widely used in the past but are rarely employed nowadays. As a principle, the flap is harvested from the contralateral limb, set into the wound, and kept connected for several weeks. Most often, a period of 3 weeks is enough for establishing the blood supply to the flap from the periphery and the wound bed, and disconnection of the pedicle may be accomplished. There are two main drawbacks of this method: the need for continuous immobilization of the limbs for about 3 weeks in order not to shear the flap pedicle and the donor area deformity, which usually requires a skin graft for closure. Generally, these flaps are used when no other reconstructive method is available or when a free-flap failure was encountered. The method has a high rate of success.

Regional Flaps. These flaps have good applicability, and are also indicated when the zone of injury is not extensive. They are categorized into fasciocutaneous, adipofascial, fascial, or neurovascular. They are reliable flaps when good planning and judgment is used. Medium to even large size wounds can be covered in this way.

Adipofacial Flaps. These flaps are used mostly to cover exposed structures on the hands and feet but also for exposed elbows, knees, and ankles.

Distant Pedicled Flaps. These flaps are rarely employed for the lower limbs for the same reasons as for not often using cross-limb flaps. The upper limb, being close to the thorax and the abdomen, is more favorable for these types of flaps. Soft-tissue injuries to the hand and the distal forearms can be covered by a groin flap or lower epigastric abdominal flap. Arm injuries can also be closed by lateral thoracic flaps. The reconstruction is done in stages. First the flap is harvested, insetted, and kept connected for 2–3 weeks. In the second stage, the flap is detached and trimmed for the final inset. The period of limb immobilization can be shortened if periodic flap ischemia is simulated by external compression. When white structures are exposed, they can be covered by the same type of flaps. Flaps based on the Crane principle can also be used. After 2–3 weeks of the flap inset, the limb segment is extracted only with granulating tissue, thus leaving the donor skin paddle in place. The granulating tissue is subsequently covered by skin graft.

Muscle and myocutaneous pedicled flaps have more often been applied for lower limb reconstruction. There is no need for microsurgical anastomosis. The gastrocnemius and soleus muscle flaps are the most used flaps for calf wound reconstruction. These flaps have the advantage of filling the deep soft tissue loss to avoid dead space. Fascial and fasciocutaneous flaps are used more for upper extremity reconstruction or for areas where a thin, pliable tissue is required for coverage. There are numerous reports that muscle flaps are useful for open bone fracture coverage. In the past years, it has been proved that fascial, adipofascial, and fasciocutaneous flaps are not less successful for fractured bone coverage and for dealing with osteomyelitis [39,40].

Free Flaps are indicated for:

- Large wounds, when a local or regional flap would not be sufficient for local or regional flap coverage.
- Vascular reconstruction; emergent flow-through free flaps are employed when soft-tissue defects and artery defects are present in an ischemic limb [29,41–44]. When the arterial defect is small, a T anastomosis can be used [45].
- Exposed white structures, such as bones, tendons, nerves, and major blood vessels.
- Functional reconstruction, when significant muscles have been destroyed; reconstruction of elbow flexion or ankle dorsiflexion is the problem most often encountered. Free functional muscle flap in the acute phase of mangled extremities was successfully reported in 12 patients by Tu [29].
- When sensate flaps are needed, such as for the plantar or palmar area.

The main free flaps used are:

- *Fasciocutaneous*: anterolateral thigh (ALT), scapular, parascapular, medial or lateral arm, and radial forearm. The radial forearm free-flap RFF, scapular, parascapular, and ALT flaps have the advantage of having a long pedicle (average 10–15 cm), which enables the anastomoses in a more proximal and healthy area.
- *Muscle or musculocutaneous flaps*: latissimus dorsi (LD), serratus anterior (SA), rectus abdominis, and gracilis. The first two have a longer pedicle, with a larger diameter of the pedicle vessels.
- *Fascial and adipofascial*: temporal fascia (TF) and RFF flaps are the most often used in this category. They are mainly used for hand and fingers when thin and pliable soft-tissue coverage is needed.
- *Visceral flaps*: the omentum has the advantage that it can cover a large wound and is very thin and pliable, so it easily fills even the smallest defect. Its major disadvantage is that it has a very short pedicle.
- *Bone flaps*: such as fibula, rib or iliac crest, are rarely employed in the acute phase. They are used to substitute for bone defects and it is extremely important to place them in a clean wound. Careful wound preparation is essential before flap insertion.

Techniques of flap harvesting are beyond the scope of this chapter. When a free flap is considered, a thorough examination of the recipient vessel should be made. Post-traumatic vessel disease is a condition affecting the vascular wall of the vessels surrounding the injured area [46,47]. Using an injured vessel for vascularization of the free flap may endanger its viability. A large distance between a healthy vessel and the defect may necessitate an interposition vein graft, which may be harvested from a noninjured area. For instance, when lower limb injuries are present, the upper limb may serve as a good donor site. The anesthesiologist should be told to spare one upper limb and not to place any intravenous line which can limit the donor area.

Isenberg [48] performed anastomosis at an average of 45.7 mm from the zone of injury in a traumatized lower limb. It is difficult to evaluate precisely the extent of zone of injury in war injuries, especially when blast explosions are associated. Inspection of the vessels under the microscope is the most accurate way to determine the level of the anastomosis.

Often one intact distal artery (e.g., anterior or posterior tibial) is enough for limb vascularization. When a single intact vessel is present and a free flap is desired, it may be anastomosed to the proximal or distal stump of the injured vessel, if good blood-reflow is proved. Flaps with long pedicles or vein grafts can be used to solve the problem. When this is not feasible, we suggest a cross-leg flap. In the event of bilateral injuries, an end-to-side anastomosis to the single vessel is performed. The veins are usually anastomosed to the comitant veins of the arteries; they have a smaller caliber in comparison with the superficial veins but are deeper and better protected from trauma.

War injuries are usually associated with a significant release of plasminogen and other procoagulant factors from the crushed tissue. The chance of thromboses is higher than after usual trauma [29]. Blast injuries are often associated with vessel disruption (small to medium size; perforator) and endothelial injury that result in thrombosis of large and small vessels. The ischemic tissues release toxic oxygen radicals that result in cytotoxicity and acute inflammation that may cause failure of the free flap. Using anticoagulants in this condition is recommended. Our protocol is to administer 5,000 units of heparin I.V. intraoperatively; vessel irrigation with diluted heparin (200 cc N. Saline with 5,000 units of heparin) is also a part of the protocol. After surgery, we administer low-molecular heparin (Clexane) 40 mg twice a day for 5–7 days and then reduced to once a day if the patient ambulates. The dose is adjusted according to body weight. This protocol also covers the prophylactic antithrombotic therapy after bone fractures. From the second postoperative day, aspirin is administered for 3 weeks.

Most of the centers where free flaps are performed are well equipped with trained personnel. However, successful free-flap reconstructions in low-resource conditions were also performed during the Balkan war. With a portable binocular microscope, microsurgical Chinese instruments and sutures, Tajsic [49] had a low rate of complications.

Perforator Flaps are rarely used for war injuries. These types of flaps are nourished by small perforator vessels, which are often present in the zone of injury and are most probably compromised. However, for the secondary procedures that are done a few weeks or months later, they are also part of the physician's armamentarium. In the acute phase, they can be used only for covering small gunshot wounds.

13.8 Specific Flaps According to Anatomical Area

1. Upper limb (Table 13.1)

Flaps from the adjacent area are called local flaps. Those from other areas of the same limb which require two stages are called regional flaps. Those from other parts of the body (trunk) are called distant flaps. The thicker the pedicled flap, the greater the chance of survival, due to more vascular plexuses that are included within the flap.

(a) Shoulder. Tissue loss at the level of shoulder can be easily covered with the surrounding muscles or fasciocutaneous flaps. The anterior and lateral surfaces of the shoulder can be covered by fasciocutaneous flaps from the anterior chest and by lateral upper arm flaps, while the posterior area can be easily reached by scapular and parascapular flaps. Pectoralis major, latissimus dorsi, SA, and trapezius flaps can also be used. A composite LD-rib flap can easily be used to reconstruct a defect of the humerus and the soft tissue with a single flap.

(b) Arm. There is a significant amount of muscle in this area, so rarely is there a need for flaps to close defects here (Fig. 13.6). The workhorse in this area is the pedicled LD (Fig. 13.7), which enables large wound coverage or a functional transfer to restore elbow flexion. Lateral thoracic flaps can also be used for coverage of wounds in this area.

(c) Elbow. The anterior part of the elbow is the typical area for scar contracture, thus it requires good tissue coverage after releasing the contracture. A brachioradialis muscle flap can be used for small- to medium-sized deep defects. For larger defects, the lateral arm flap represents a better choice. A pedicled, proximally based, radial forearm flap can also be used. Its advantage is that it is not bulky. A flexor carpi ulnaris flap, based on a superior pedicle, can be used for the medial part of the elbow. This is one of the last options because it sacrifices an active muscle. The anconeus flap has a limited arc of rotation. A pedicled LD flap can reach this area after humeral desinsertion. Fasciocutaneous free flaps may also be used.

(d) Forearm. The most vulnerable area is the distal half where there is no muscle coverage and the

Table 13.1 The most commonly used flaps for upper limbs

Anatomic region	Small to medium defects	Large defects
Shoulder	Local flaps	SA
	Pectoralis major	LD
	Scapular, parascapular	Trapezius
Arm	Local flaps	Pedicled LD
	Medial arm	Lateral trunk
	Lateral arm	Fibula for bone defects
Elbow	Local flaps	Pedicled RFF
	Brachioradialis	Pedicled LD
	Lateral arm	
Forearm	Local flaps	SA
		ALT
		Scapular, parascapular
		Epigastric, thoracic flap
		Fibula for bone defects
Dorsal hand	Local flaps	ALT fascial flap
	PIOP	RFF
		Groin
Volar hand	Pedicled RFF	SA
	Ulno-dorsal pedicled flap	Groin
	Reverse ulnar perforator	
	PIOP	
Fingers	Cross finger	Pedicled RFF
	Flag	RFF
	Moberg	Dorsalis pedis
	Kite flap	Groin
	Island metacarpal	

SA serratus anterior, *LD* latissimus dorsi, *RFF* radial forearm flap, *ALT* anterolateral thigh, *PIOP* posterior interosseous

tendons are easily exposed after trauma. The blood vessels and nerves are also easily injured. This is an area where skin grafts are less often used due to the need for good soft-tissue coverage. To reduce bulkiness and achieve good tissue quality, thin muscle free flaps, such as the serratus anterior (SA) muscle flap or thin fasciocutaneous flaps (ALT), can be used. We prefer not to use the contralateral RFF for forearm coverage as it sacrifices a major artery. The SA muscle is relatively thin, becomes thinner with time, and has a good aesthetic appearance. Scapular and parascapular flaps can also be used to protect the tendons and to enable their gliding. Rarely is there a need for a flap in the upper half of the forearm. Distant flaps, such as the epigastric and thoracic flaps, can be used but they need about 3 weeks of immobilization before they can be detached from their pedicle. We keep this solution as a last option. Bone defects in this area can be managed by acute shortening and distraction or free osseous flaps. A fibular free flap represents an excellent choice. These flaps are usually performed as secondary procedures.

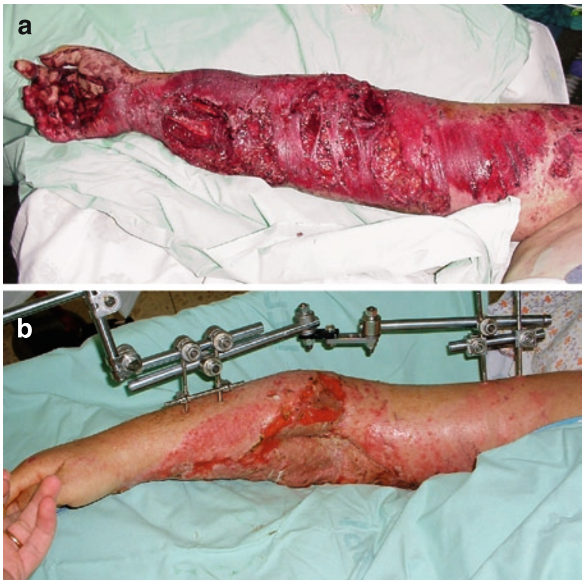

Fig. 13.6 (**a**) Severe crushed injury combined with elbow fracture. (**b**) Several weeks after fracture stabilization and skin graft

(e) Hand. Dorsal hand injuries can be closed with local flaps. Larger defects are better covered with a posterior interosseous (PIOP) flap, which can be taken either as a fasciocutaneous or fascia only flap. The ALT fascial free flap can also be used for large defects. A lateral arm free flap is relatively thin and is also described for use in this area. The palmar area is usually covered by a distally based RFF (Fig. 13.8). The RFF flap or SA has also been described. A PIOP pedicled flap can also be used to cover first web space defects while the ulnodorsal pedicled flap is more often applied to the ulnar part of the hand. Reverse ulnar perforator adipofascial flaps can also be used to treat dorsal or volar defects. A groin flap (pedicled or free) is less used for hand coverage as the first choice due to the prolonged immobilization needed and the delay in the rehabilitation process (Fig. 13.9).

(f) Fingers. Cross-finger, flag, and Moberg flaps have been widely applied for small defects located in this area. Island metacarpal fasciocutaneous flaps can be used to reconstruct the dorsal or the volar defects at the first and second phalangeal levels. Its application at the level of the distal phalanx is controversial and there is a high risk of venous congestion. Dorsal thumb defects are better reconstructed with a "kite-flap" elevated from the dorsal area of the index. When multiple digits are involved and the wounds are large (either dorsal or volar), a radial forearm flap (pedicled, perforator-based or free), dorsalis pedis, or temporoparietal fascia flap can be used. The "Crane principle", as described by Millard, is based on temporarily placing the hand in the abdominal subcutaneous tissue for about 2 weeks, time enough for granulation tissue to cover the wound. The granulation tissue is subsequently covered with skin grafts. An abdominal flap can also be used but it needs subsequent defattening procedures. Defects over multiple digits represent an indication for a radial forearm reverse pedicled flap to syndactylize the fingers involved. This procedure is better than using groin flaps, which are thicker and require finger immobilization. The fingers are kept attached to the groin for 2 weeks. It is rarely used. Fillet flaps represent a good choice for using the mutilated part to reconstruct other areas (Fig. 13.10).

2. Lower limb (Table 13.2)

(a) Thigh. Because the femur is surrounded by numerous muscles, it is very rare to use a flap to cover defects in this area (Fig. 13.11). However, when needed, vastus medialis, lateralis, tensor fascia lata, or inferiorly based rectus abdominis flaps can be used. The vastus lateralis is mainly used for covering trochanteric wounds in the pubic area. The rectus femoris is less often used due to donor site morbidity. The ALT or anteromedial thigh can also be used when the zone of injury does not include the donor area.

(b) Knee. Among the local flaps that may be used here are the medial, lateral, or bilateral gastrocnemius muscle flaps, when the zone of injury is not included in the popliteal area. The distal lateral thigh flap can also be used for defects in the knee area and the popliteal fossa. Medial saphenous neurocutaneous flaps can also be used for the reconstruction in this area. When this is not feasible, free flaps or cross-leg flaps can be employed.

(c) Calf. The anterior region of the calf is the most exposed and injured area in the lower limb. The upper and middle part can be covered by gastrocnemius or soleus flaps

Fig. 13.7 (**a**) Complex arm and elbow injury associated with soft tissue defect, median, ulnar nerve, and brachial artery injury. (**b**) LD muscle flap is harvested. (**c**) Isolation of the vascular pedicle in order to enhance the flap mobility. (**d**) After flap inset. The arm and elbow soft-tissue defect is covered. (**e**) One year later

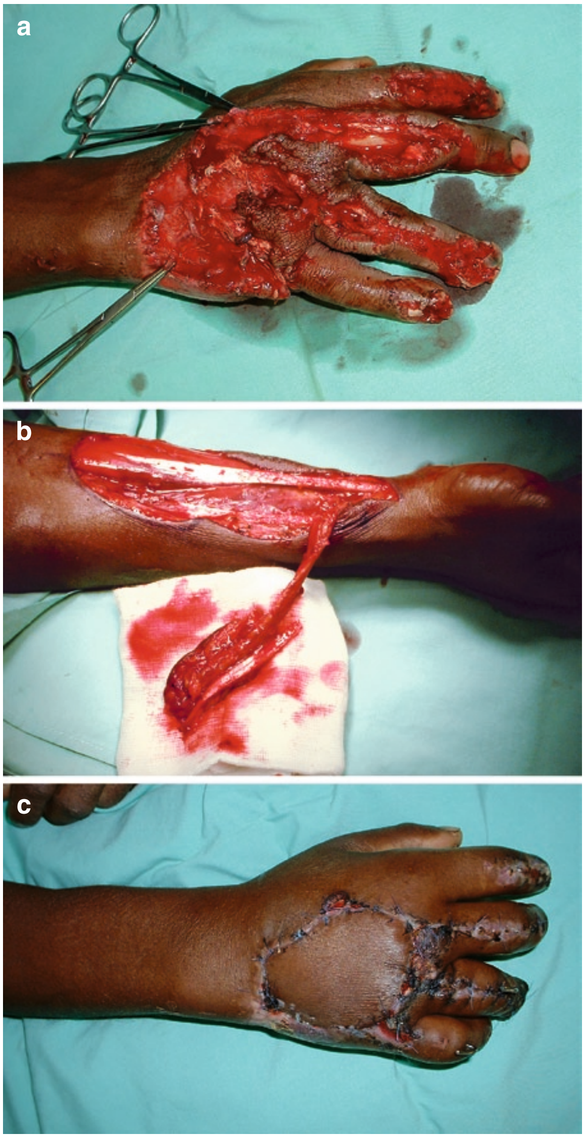

Fig. 13.8 (**a**) Soft-tissue injury associated with extensor tendon defect. (**b**) The pedicled RFF is raised together with palmaris longus tendon in order to reconstruct the extensor tendon. (**c**) Three weeks later

(Fig. 13.12). Small wounds (e.g., gunshot) can be covered by anterior tibialis or extensor digitorum longus flaps. The flexor hallucis longus is supplied by the peroneal artery and can be used for the distal third of the calf; however, the muscle is thin. Supramaleolar skin flaps from the lateral aspect of the leg can also be used. A peroneus brevis muscle flap is suitable for coverage of the distal Achilles tendon. Sural or saphenous neurovascular island flaps can also be used for small-sized wounds, even in the lower third of the calf. Large wounds are better covered by free flaps. According to the defect size and the extension of the zone of injury, the most commonly employed flaps are LD, SA, and ALT. Composite osteocutaneous flaps, such as fibula or SA-rib flaps, are the most commonly used [50–52].

(d) Ankle and foot. The dorsal part of the ankle and foot is best covered by thin flaps, such as fasciocutaneous or adipofascial flaps, such as ALT, groin flap, and parascapular flap. For small-to-medium-sized defects, reverse sural neurocutaneous flaps can also be used for the posterior aspect of the foot (Fig. 13.13). A medial plantar flap is suitable for restoring small-sized defects. Lateral calcaneal or peroneal muscle flaps can also be used for small defects. Good support and soft-tissue coverage is mandatory for the plantar area. For large defects, either muscle flaps (Fig. 13.14) covered by a skin graft or sensate fasciocutaneous flaps can be used. Some authors prefer to use sensate fasciocutaneous flaps [29,53]. Sensate ALT and lateral arm flaps are preferred to muscle flaps [54,55]. The RFF flap is less used nowadays for foot reconstruction because it sacrifices a major artery, and also has more donor site morbidity compared to the ALT flap.

13.9 Complications of Soft Tissue Coverage

(a) Early. Immediate complications are wound dehiscence, wound infection, and partial or total flap necrosis. Wound dehiscence and infections are

Fig. 13.9 (**a**) Mutilated hand with bone, flexor, and extensor injuries. (**b**) After debridement. (**c**) Groin flap in order to get good tissue quality in the metacarpal area for a further digital transfer

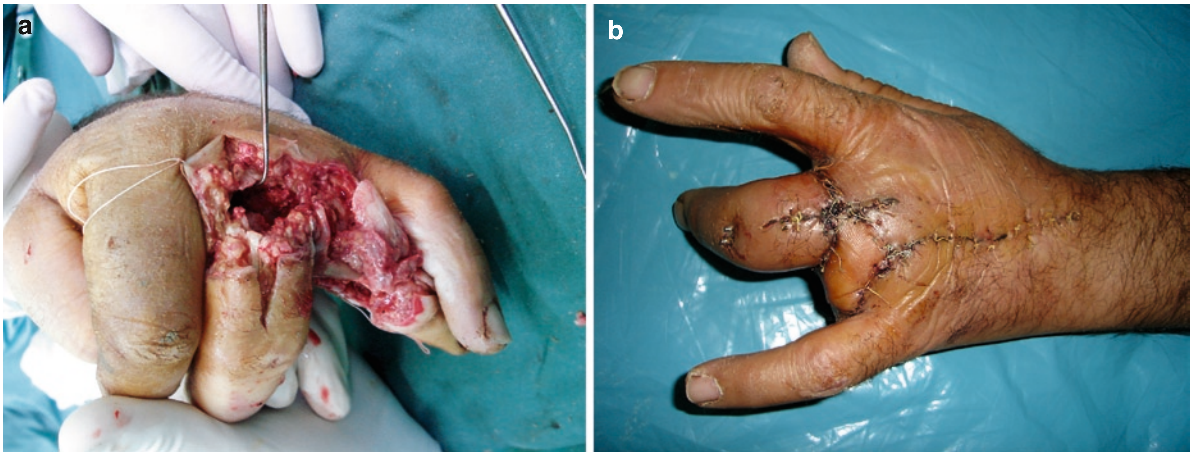

Fig. 13.10 (**a**) Complex finger injury with impossible salvage for the fourth finger. (**b**) A fillet flap was used from the fourth finger

Table 13.2 The most common flaps for lower limbs

Anatomic region	Small to medium defects	Large defects
Thigh	Local flaps Tensor fascia lata Pedicled rectus abdominis Vastus lateralis ALT	LD
Knee	Local flaps Gastrocnemius Distal lateral thigh Neurocutaneous flap	Free flap Cross-leg
Calf	Local flaps Gastrocnemius Soleus Anterior tibialis Extensor digitorum longus Peroneus brevis Sural flap Saphenous flap	LD SA ALT Fibula, SA-rib or iliac crest for bone defects
Ankle and foot	Local flaps Sural flap Medial plantar Lateral calcanean Peroneus brevis	ALT Lateral arm Muscle flap with SG

LD latissiums dorsi, *ALT* anterolateral thigh, *SA* serratus anterior, *SG* skin graft

Fig. 13.11 Good granulating tissue covering the muscles after blast injury to the thigh

quite often seen after these types of injuries because the wounds are contaminated. Wound debridement, secondary suture, or skin graft is usually the preferred treatment. Partial flap necrosis is more often encountered for pedicled or local flaps when the zone of injury was not correctly estimated. When the necrosis is small, conservative treatment followed by skin graft is enough for completion of the closure. When large wounds are present, they can be treated by the VAC system and skin grafting when the granulation tissue is adequate. When a free-flap failure occurs, a cross-limb, other free flap, or distant pedicle flap can solve the problem. Infection is the main complica-

Fig. 13.12 (**a**) Harvesting of the medial hemisoleus muscle. (**b**) Isolation of the perforator vessel coming from the posterior tibial vessels. (**c**) Before tunneling to cover the tibia. (**d**) Two weeks after skin grafting the muscle

tion associated with the treatment of war-induced wounds. When it affects the major arteries, it may lead to limb amputations [53]. When the soft-tissue infection is restricted to the superficial layers, irrigations and/or local and systemic antibiotics are enough for management. Deep layer infection needs to be evacuated and drained. Antibiotic treatment is a must in these circumstances. The rate of infection is variously reported in the literature. Godina [16] reported a very low rate (1.5%) of infection and a 0.75% flap failure when the free-flap reconstruction was done within the first 72 h in this series. Because of environmental contamination and evacuation procedures, even with multiple washouts and debridement, the infection rate can be very high. The traditional recommendation of fracture fixation and wound coverage within 6 h from injury is not always feasible during

Fig. 13.13 (**a**) Several weeks after complex injury to the ankle. The hardware is exposed in the wound. (**b**) Harvesting of the sural neuromiocutaneous flap. (**c**) Two months after

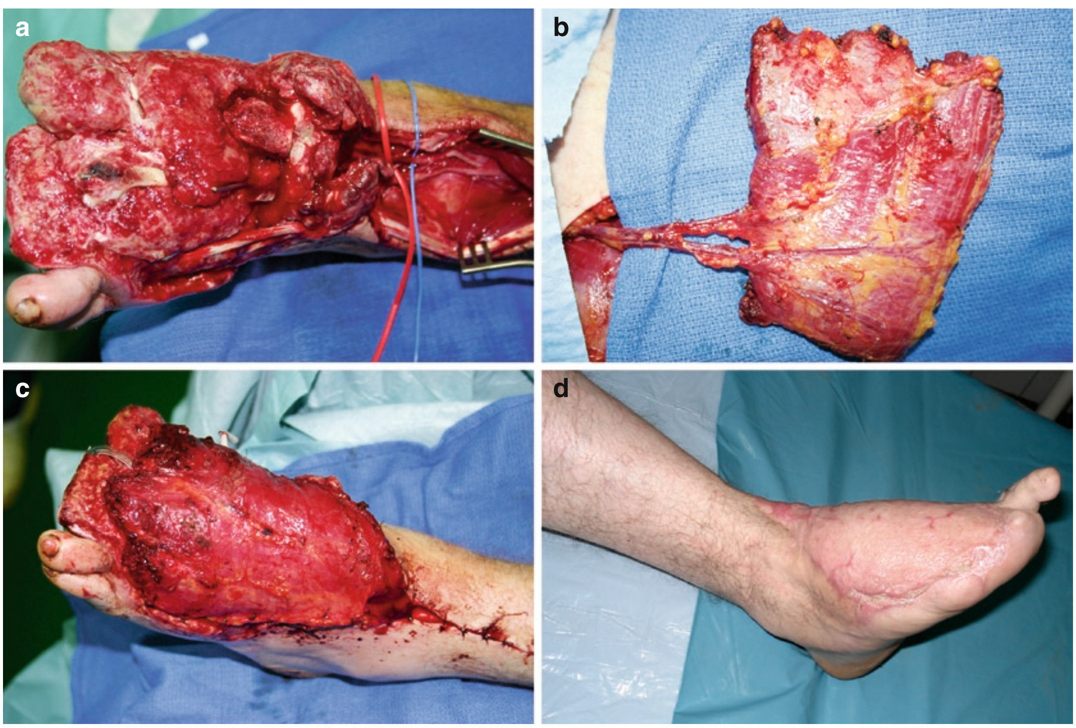

Fig. 13.14 (**a**) Complex injury with metacarpal fractures, tendon lacerations, and desinsertions and soft-tissue defect. (**b**) The lowest three strips of the SA muscle are harvested. (**c**) The flap is inset. The artery was anastomosed end-to-side to the anterior tibial vessels and the vein is anastomosed end-to-end to the comitant vein. (**d**) One year later

wartime when evacuation from the battlefield and transportation may be delayed. Murray [56] reported a 2–15% rate of osteomyelitis associated with war injuries.

(b) Late. Late complications are represented by scar problems and functional impairment. Scars are more often constricting than hypertrophic or keloid and represent a minor problem compared to the functional impairment. They can easily be corrected by techniques of scar release. Functional impairment may be associated with bone, nerve or tendon injuries. Arthrolisis, neurolysis, and tenolysis can help in improving function. Secondary procedures are often necessary after war injuries. The goal is to improve mobility, sensibility, and tissue quality. It is wise to wait several months for soft-tissue maturation before starting the secondary procedures. Bone and nerve grafting have priority and should be done as soon as possible. All secondary procedures, which require immobilization such as bone or nerve grafts, should be done first.

Fig. 13.15 (**a**) Severe crush injury associated with prolonged ischemia. (**b**) The muscles are not viable and above knee amputation was performed

Amputation is inevitable at times, either due to severe limb injuries (Fig. 13.15), or possible life-threatening complications such as sepsis [57]. When complications are severe or life-threatening (septic shock, etc.), amputation of the limb represents a life salvage procedure. A nonsensate limb (especially a weight bearing one) is less desired than a good prosthesis. Reflex sympathetic dystrophy, joint stiffness, and hypoesthesia associated with functional impairment lead to limb amputation. Korompilias [57] reported an early return to work for patients who had early amputations. The medical costs and time off work are reduced in these situations [58,59]. The decision regarding the amputation level should be taken by the orthopedic and the plastic surgeons together [60]. There are situations when an above-knee amputation can be converted to a below-knee one by using a fillet flap or other flaps to preserve length.

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