Amputations in Disasters

33

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33.1 Introduction

Mass casualties related to either natural or man-made disasters are a reality of our lives, affecting large populations happening in both developed and developing countries. The earthquake that hit Haiti on January 12, 2010, caused around 237,000 deaths and nearly 300,000 wounded and left about 1 million homeless—revealing just how unprepared most countries are to deal with mass casualties and disaster-related injuries. A large percentage of the injuries typically seen in these situations are to the limbs [1, 2]. An overwhelming number of casualties; delayed presentation; crush injuries and crush syndrome; lack of adequate medical facilities and sometimes expertise, regional and cultural; and other factors influence the decision to amputate, to save lives, or to preserve function.

Despite improvements in both orthopedic and vascular reconstructive surgery, including the introduction of new technologies [3, 4] over the last 50 years, amputation is often the necessary treatment for severe extremity trauma. While limb-salvage techniques have lowered the rate of amputations in noncombat civilian and combat military situations, the current amputation rate of war-related amputations is now twice that experienced by military personnel in previous wars [5, 6]. The rise in amputation rate is likely due to the improvements made in soldier's protective equipment.

Both mass casualty injuries in civilian population, caused predominately by either crash or high-speed accidents, and military trauma often due to a blast require damage control approach. The choice to perform an amputation and save patient's life is one of the most important and challenging decisions facing the civilian and military surgeon. Given our current geopolitical situation, it is likely that surgeons will continue to be confronted with these complex patients.

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As a rule, making the difficult decision for amputation should not be seen as a failure of treatment but rather as a life-saving or function-preserving operation. The approach used is multidisciplinary and takes into consideration medical, surgical, and psychological factors, the availability of postoperative care, continuation of care, rehabilitation and prosthetic resources, and community reintegration. It is of major importance to have the patient and patient's family involved in the decision-making process and obtaining informed consent, with documentation, when possible. Participation of the local medical community and if available local religious and cultural representatives or social service staff versed in the provision of relief care to assist the patients and their family in making life-altering treatment decisions.

In 2011 HAS Amputation Following Disasters Working Group developed conclusions and recommendations in the areas of amputation management in disasters. The goals of the group were to come up with best practice recommendations in the areas of team planning, operative technique, pain management, rehabilitation, medical records, and outcome tracking. This initiative can be great platform for developing optimal care in disasters [7].

The following chapter will review the subject of amputation during natural disasters and mass casualties with emphasis on a staged approach to minimize postsurgical complications, especially infection.

33.2 History

The history of amputation is as old as human kind.

Hippocrates, who stated that war was a "proper school for surgeons," was one of the first to describe amputation. He recommended performing amputation within the insensate necrotic area of the extremity for the purpose of minimizing pain and bleeding [2, 8, 11]. In contrast, in the first century BCE, Celsus recommended amputation within the healthy part of the extremity, dividing the bone above the level of the soft tissue incision. He also advocated the usage of ligatures for the purpose of hemostasis [3].

The introduction of gunpowder in the thirteenth century and its later extensive use in the fifteenth and sixteenth centuries were a major turning point in battlefield surgical procedures [4, 9]. Open fractures and severe damage to the soft tissues were common, which necessitated a more extensive surgical approach to amputation. In 1536, Ambroise Paré, a military surgeon, [5], rediscovered Celsus' principles: amputation through viable tissue and the use of the ligatures. While running out of boiling oil, which was used at that time for wound cauterization and sterilization, Paré learned that cold, not heat, is more beneficial for the control of wound bleeding. Pare is also credited with inventing artery forceps.

In 1588, William Cloves described the first successful above-knee amputation and, in 1593, Fabry, in his monograph on gangrene, reported the first amputation through the thigh [5].

The introduction of Morel's tourniquet in 1674 (the Spanish windlass) and Petit's tourniquet in 1718 were significant steps in the control of hemorrhage and allowed for a better technique of amputation and the creation of more functional stumps [10].

The Napoleonic Wars led to further improvements in battlefield surgery. Jean Dominique de Larrey, of France, is considered one of the founders of military medicine. A legendary surgeon in Napoleon's army, he designed horse-drawn carts called "flying ambulances" to carry surgeons and medical supplies into the field of battle. Larrey [12] and Guthrie of Great Britain advocated early primary amputation. They found that early amputation was associated with a lower incidence of infection and less hemorrhage. Larrey, who was the first in 1803 to disarticulate the hip, amputated 200 limbs and disarticulated 11 shoulders one night in 1812 in the battle at Berezina River.

Another French surgeon, J. Lisfranc de St. Martin, in 1815 published a book on partial foot amputation. He also popularized the formation of flaps for better coverage of the amputation stump. In 1844, James Syme described ankle disarticulation.

The introduction of ether anesthesia in 1846 and the subsequent development of antiseptics led to more precise surgery and a lower risk of wound infection.

Nikolai Ivanovich Pirogoff (1801–1881), the most renowned military surgeon in Russian history, performed hundreds of amputations during the Crimean War (1853–1856), in which France, the United Kingdom, the Kingdom of Sardinia, and the Ottoman Empire fought against Russia. The inability to provide ankle disarticulation to his soldiers, who required Syme's amputation (which he admired), led him to come up with what is known as the "Pirogoff amputation" [95]. The Pirogoff amputation is a surgical salvage procedure for the complex injuries of the forefoot, where there is considerable loss of the osseous and soft tissues. Part of the calcaneus together with the fat pad is rotated and fused to the tibial plafond, which allowed for a longer stump, eliminating the need for below-knee amputations, and allowed for weight bearing. Pirogoff also introduced nurses on the battlefield and published the *Atlas of Human Cross-Sectional Anatomy* based on sawed frozen sections.

During the American Civil War (1861–1865), the approach to amputations evolved further [13]. General anesthesia was available for the surgeons. There were nearly 55,000 amputations performed during the war. At the beginning of the war, surgeons learned, based on experience from the Napoleonic Crimean wars, that timing plays a crucial role in the outcome of amputations. Primary amputations were performed early after the initial injury, in crush injuries, gunshot fractures with extensive comminution, open fractures, partial or complete amputations, combinations of fracture and open joint injury, and fractures associated with nerve or vessel injury. An indication for secondary amputation was an infected wound. Later in the war, indications for amputations became more refined: gunshot fractures to the femur were not an indication for primary amputation and the use of splints helped to treat long bone fractures non-surgically.

World War I (1914–1918) brought artillery into the battlefield, which caused over 7 million deaths, 19 million wounded, and half a million amputations. Fitzmaurice-Kelly [14] in 1916 reported on a method for skin incisions, which was made as distally as possible in order to allow it to retract with the subcutaneous tissue, while the muscle and bone were divided more proximally. This facilitated the preservation of the residual limb length and the prevention of infection and secondary hemorrhage. This procedure was called a "Guillotine" amputation, since the muscle and bone were cut at the same level. It was subsequently replaced with the construction of the flap, which after being left for some time facilitated a better closure of the wound.

World War II (1939–1945) was plagued with heavy civilian casualties from massive aerial bombardments. The use of more modern medical support (blood and plasma transfusions and antibiotics) as well as surgical advances (arterial repair), early evacuation, and better splinting made the salvage of many limbs possible.

While the mortality rates of the subsequent wars have significantly decreased, the amputation rate has remained high (~13 %), which is likely due to more destructive weapons. In contrast to above-knee amputations carried out during World War I, below-knee amputations predominated during World War II. In 1943 Norman T. Kirk indicated that guillotine amputations in a war setting should be performed as distally as possible and completed later under calmer conditions.

Recent advances in the field of amputation include new ways of wound debridement and decontamination, tissue presentation, wound coverage by regulated negative-pressure-assisted wound treatment (RNPT), and fracture reduction and stabilization with minimally invasive devices and new techniques in vascular reconstruction. Based on extensive experience with vast number of combat casualties treated during armed conflicts and mass casualty incidents of the second half of the twentieth and beginning of the twenty-first centuries, these techniques combined with improved prostheses and rehabilitation programs have greatly improved the outcome for amputees.

33.3 General Principles

33.3.1 Introduction

The decision to perform an amputation is made to save the patient's life or preserve extremity function.

The general principles of trauma care, including rapid triage, application of the principles of Advanced Trauma Life Support [15] care of life-threatening injuries, and early stabilization of the affected extremity, are applied. In the case of exsanguinating hemorrhage from the extremities, hemostasis with the use of tourniquets is the highest priority. The appropriate resuscitation is performed and the adequate antibiotics and tetanus toxoid (as part of the Tdap vaccine) are administered prior to wound management.

War extremity wounds are characterized by high-energy injury, extensive soft tissue damage (Fig. 33.1), and prolonged injury to operation time. The mechanism of crush injuries, specifically after earthquakes, is more of a prolonged low energy trauma with extensive soft tissue damage and often late (>12 h) presentation (Fig. 33.2). These factors lead to an increased risk of infection and inevitably higher amputation rates [16–18].

A multidisciplinary approach to this type of injuries may ultimately improve an outcome and maximize functional rehabilitation but unfortunately often not possible.

33.3.2 Crush Injury

Crush injuries may lead to *compartment syndrome* with or without associated skeletal injury [19]. In this situation the pressure within closed myofascial compartment is increased to an extent that microcirculation is compromised leading to compromised function [20]. If released timely, by performing fasciotomy, these changes can be reversed. When an injured extremity is exposed to substantial crushing force for a prolonged period of time and the volume of the compressed, crush tissue is substantial, and irreversible changes can take place, including muscle cell death and systemic manifestations. This is known as *crush syndrome*.

Fig. 33.1 Extensive soft tissue damage

Fig. 33.2 Late presentation

The *crush syndrome* may develop after 1 h in a severe crush situation, but usually requires 4–6 h of compression for the systemic manifestations to occur. At the early stages, there are very subtle local changes. When the extremity is trapped under rubble for prolonged periods, depending on the muscle mass and other circulatory factors, the venous return from the involved compartment is impaired and some of the toxic metabolic products are not part of the systemic circulation. Restoration of perfusion can lead to reperfusion injury with associated cardiac, renal, and circulatory manifestations. For this reason treatment of the crush syndrome is primarily focused on preservation of the patient's cardiac, renal, metabolic, and circulatory fluid volume with IV hydration and administration of IV $NaHCO_3$ in advance of the release of the entrapped extremity or extremities and thereafter until sufficient urine output is maintained and clinical evidence that rhabdomyolysis is improving. This treatment of crush syndrome is different from the treatment of acute compartment syndrome [21, 22].

There is well-reported evidence from different disasters showing a high rate of infection leading to an increase in deaths and associated secondary amputations when fasciotomies were performed in the presence of crush syndrome [6, 16, 17, 21, 23–28]. In hypoxic tissues, the body's inherent infection control and healing are impaired increasing the risk of infection and decreasing appropriate wound healing compared to other traumatic injuries.

Fasciotomy is not indicated in treatment of the crush syndrome unless the peripheral circulation is absent or severely compromised and directly observed to be working over a 1–3 h time frame. In this specific instance, compartment decompression is done to reestablish peripheral blood flow. Another indication for fasciotomy is with unique open fractures.

Only when damage to the extremity is significant and risk of reperfusion-related systemic changes is significant should amputation be performed to save the patient's life. An instance may be if the patient is to undergo another lengthy operative procedure or procedures and the ability to directly observe the injured limb or limbs is lost.

Amputations in this situation should be done in a stage fashion. As much limb length as possible should be preserved. Wounds should be well debrided and covered with a dressing allowing discharge fluid to be drain. Any obstruction to the wound discharge may lead to major complications, both local and systemic with significant risk to patient's remaining limb and life.

33.3.3 Blast Wound Amputation

Blast-related injuries create a wide zone of soft tissue injury with gross contamination of materials brought into the wound from the environment. Land mine blasts create an "umbrella effect" (Fig. 33.3a, b) with the tearing of the soft tissues, stripping them off the bone, and extending proximally away from the visible site of the injury [29–31].

After general trauma care is initiated (ATLS), the initial local extremity care is centered over bleeding control utilizing rapid tourniquet placement above the site of bleeding. Applied in the field it has been shown to have lower mortality rate compared to when applied in the emergency room [20, 32]. Vascular injuries of the affected extremities can be subtle. It has been shown that in the absence of vascular changes on physical examination, up to 25 % of patients demonstrate positive findings on the angiography assessment [33]. Meticulous wound care is of primary importance. Thorough irrigation and debridement, even of small wounds, is essential to clean deep contamination and devitalized tissues. Wound care in blast injuries requires stage approach and can be very challenging. The wounds are left open and the patient returns to the OR in 24–48 h for a second inspection, further debridement, and possible closure [34]. Coverage of trauma wounds with new-generation negative-pressure technology (RNPT), regulated negative-pressure-assisted wound therapy, and regulated, oxygen-enriched negative-pressure-assisted wound therapy has showed beneficial effects in treating the soft tissue blast injury in comparison with the gauze dressing therapy in swine [35].

Compared with gauze dressing treatments, RNPT reduces bacterial load more efficiently, initiated granulation tissue formation earlier, and increased the inflammation faster. Negative pressure ranging from −10 to −25 kPa on the RNPT group showed beneficial effects in treating the infected soft tissue blast injury.

Safety precautions should be taken in treatment of blast injuries due to the wide area of injury with high susceptibility to major and profuse bleeding. To avoid uncontrolled bleeding, treatment should be deferred until bleeding control has been achieved, vacuum pressure should be maintained at the low level of the efficacy range (50–70 mmHg), fluid collection should be controlled and restricted by the device to limit uncontrolled hemorrhage (blood loss), and dressing should allow visible detection of bleeding.

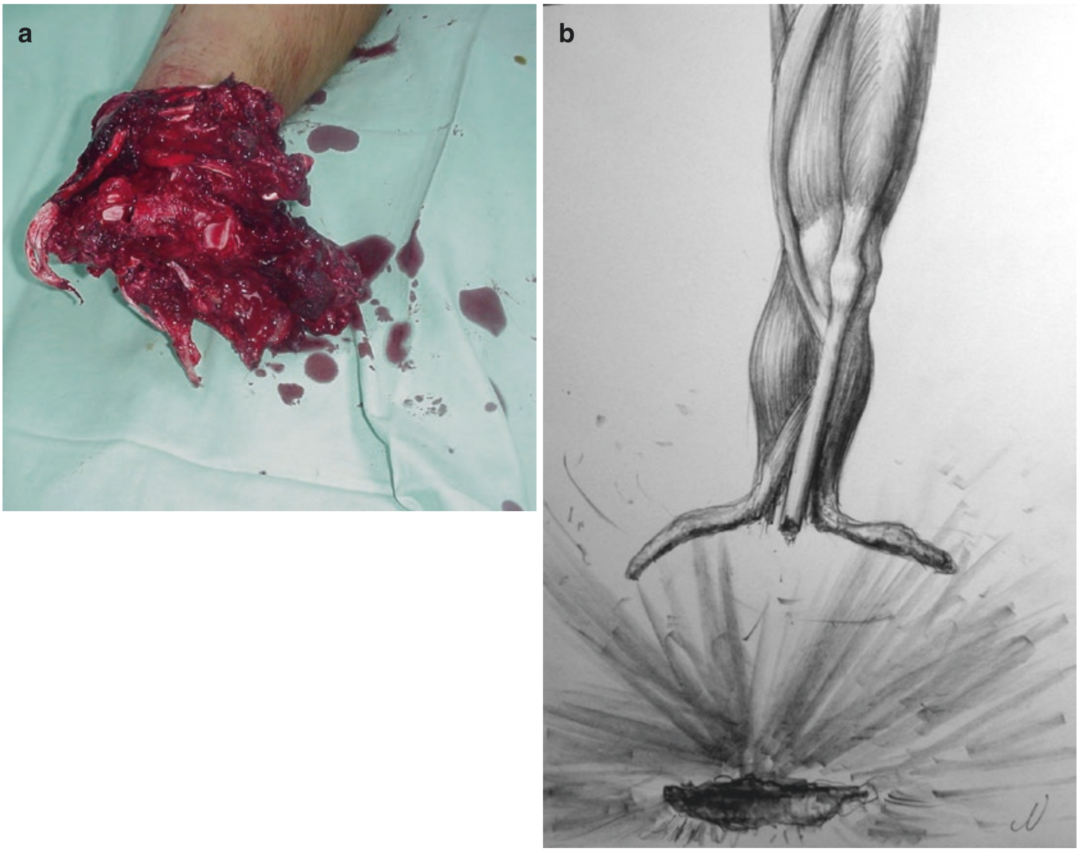


Fig. 33.3 (**a**) Blast amputation. (**b**) "Umbrella" effect

Immediate skeletal stabilization is essential [36]. Wound coverage is performed as soon as soft tissue condition allows. Rotational flaps are favored in a disaster setting over free flaps due to multiple factors. There is a high risk of infection with blast injury. In the case of suicide bombings, transmission of bacteria or viruses is introduced by penetration of biologic material contaminated with hepatitis B or C into the patient's extremity [37] or from the environment [38].

33.4 Anesthesia

In preparation for deployment to the disaster zone, it is of major importance to have appropriate equipment, medications, and adequate manpower. Lessons learned from 2010 disaster in Haiti [39] support optimization of the patient's condition prior to the amputation and appropriate antibiotics administration rather than rushing with procedures that can have devastating complications. No amputation performed in a field hospital should be done without appropriate pain management [40]. Type of anesthesia is based on the patient's condition and resources available. Total intravenous anesthesia (TIVA) and ultrasound-based regional anesthesia (USRA) can be ideal techniques for patients in disaster settings. It is much easier to control patient's pain after the amputation if regional, epidural, or spinal anesthesia is used [32, 41, 89]. This approach proved itself in the field [32, 42, 43]. Use of continuous peripheral nerve blocks has been used successfully for pain management during amputations and the immediate postoperative recovery phase [42, 44]. Management of perioperative somatic pain and phantom limb pain (PLP) is of major importance.

33.5 Indications for Amputations

The ultimate goals of treatment of extremity wounds are the preservation of life and maximizing extremity function. In this context, the decision-making process for the patient considered for amputation is based on multiple factors.

In situations of high-energy penetrating trauma and where the damage to the affected extremity is beyond salvage, completion of the amputation is the only option.

When vascular injury is irreparable, the amputation is to be performed.

Indications for amputation are based not only on patient's factors but also on surgeon's or facility factors and their ability and availability to provide care that will determine what option to choose: to amputate or to salvage injured extremity.

33.5.1 Patient Related

In certain situations the need for amputation is obvious. When the patient's general condition is at risk, the safest approach is used. When the situation permits addressing the patient's mangled extremity in a more comprehensive way, multiple factors are considered. Patient's age, immune status, and comorbid conditions, preinjury functional status of the currently injured extremity, and other extremity and concomitant injuries will have important impact in the decision to amputate or salvage.

Different scores have been used to establish objective criteria in decision-making process to amputate or to salvage [45–51]. The Ganga Hospital Open Injury Score described by Rajasekaran et al. [52, 53] to specifically address the question of salvage in open Gustilo-Anderson III-B injuries while not yet widely accepted seems to have very promising use.

Local healthcare systems and sociocultural factors ultimately play role in decision-making process when amputation is considered. Informed consent should be obtained, time and circumstances permitting; family of the affected patient should be informed and involved in this very challenging process. While in some countries and cultures, the life of an amputee can be reasonably maintained with appropriate artificial prosthesis, in others, the loss of limb may create functional, social, and mental handicaps. When operating in foreign countries, an international medical team facing difficult treatment dilemmas should always have local medical and cultural authorities involved in some of these life-altering decisions.

33.5.2 Surgeon and Facility Related

The surgeon's skills, level of the facility where the surgical care is provided, and the ancillary services are among the factors that will determine the surgical approach and outcome. An error is to ignore the factors related to the event itself, since a large number of casualties (demand) with a lack of qualified, credentialed healthcare providers (supply) would create an imbalance. Choices will have to be made to allocate time and resources in a manner different than if there were ample providers from multiple specialties that matched or exceeded the number of casualties, where the individual patient's needs can be attended in a more comprehensive way. The dual loyalty in a disaster is to do the most good for the most casualties while trying to do the most for the individual cannot be understated. After a disaster and during ongoing rescue and recovery efforts which may be hampered by sporadic weather and other factors, the geography of the area will impact the timing and mode of transportation of the injured to an appropriate medical facility and will determine how fast and how many can receive most optimal care.

33.6 Surgical Technique

33.6.1 General

The surgical management of the extremity is carried out in a staged fashion after the initial airway and breathing are secured and patient is appropriately anesthetized. The following steps are to be followed:

33.6.2 Hemostasis

If significant bleeding is encountered, immediate direct pressure at the site of the bleeding is applied in order to control the hemorrhage. This is followed by the rapid placement of a tourniquet above the site of the bleeding. The use of a tourniquet is necessary to ensure that the amputation is not compromised. The combat application tourniquet system (CATS) used in the prehospital setting by the US Army has improved survival by 23 % relative to application in the emergency department [54–56]. A sterile hemostatic dressing is then applied.

33.6.3 Secondary Examination

A secondary examination is then performed to exclude other injuries. A careful examination of the neurovascular function, bone, and soft tissues of the injured extremity is essential. If an X-ray assessment is possible, it is performed in order to evaluate the integrity of the bone and the presence of radio-opaque or space occupying foreign bodies, especially in the case of blast injuries.

33.6.4 Wound Care

In the case of blast or crush injury, all viable tissues should be preserved since the exact extent of the tissue damage cannot be immediately established.

Wound care is of utmost importance following life and limb salvage. Effective wound management can determine later need for reamputation or even life salvage. Wound infection is a major factor determining the outcome of blast and crush injuries. It affects the late viability of soft tissue as well as bone infection and will determine the future complexity of the wound healing and rehabilitation.

Negative-pressure technology, one of the most important non-pharmacological platform technologies, has been developed for the wound management field and has been used over the last two decades [3]. This treatment modality *should be used cautiously* to avoid increasing blood loss.

In situations such as trauma, mainly in blast and crush injury and heavily contaminated combat injuries, when tissue oxygen concentration is reduced, the anaerobic indigenous flora can multiply quickly and induce fast spread of local infection and sepsis. The presence of aerobic or facultative infections creates a habitat that supports growth of anaerobes by reducing the oxygen concentration in the infected tissue. This may be of greater significance when applying occlusive dressings, creating an airtight sealed environment, as in RNPT.

The open length-preserving amputation (in the past open circular amputation) [56] does not preserve length [57] and might be challenging as far as residual limb healing and rehabilitation are concerned. Early aggressive debridement, usually within 2 h, is performed with a skin incision made as distal as possible through the skin and fascia. All viable tissue is preserved for use during definitive reconstruction when, and if, needed. Wound edges are secured [3] to avoid further damage to the skin flaps by the retaining sutures. Wound should be irrigated with normal saline. Preferably it should be warm, low-pressure pulse irrigation or simple low-pressure flow through sterile tubing. To avoid cell damage and due to the lack of evidence of the antibiotic containing solutions, we recommend normal saline if available, or in a resource constrained, austere environment, tap water has been proven to be as efficacious under 0.46–0.54 PSI [7].

The next debridement is performed within 48–72 h and repeated again as needed. The definitive soft tissue flaps are fashioned in the later stages, since the degree of soft tissue viability is difficult to assess at the initial stage. After the initial debridement, the wound is not closed primarily but rather covered with light sterile dressing. *A wound is not to be covered with occlusive dressing that may lead to an increase in ischemic changes and infection* (Fig. 33.4a, b). Fasciotomy and revascularization, if needed, using shunts or definitive vascular reconstruction, as well as skeletal stabilization with either internal or external fixation, are carried out based on the level of care available.

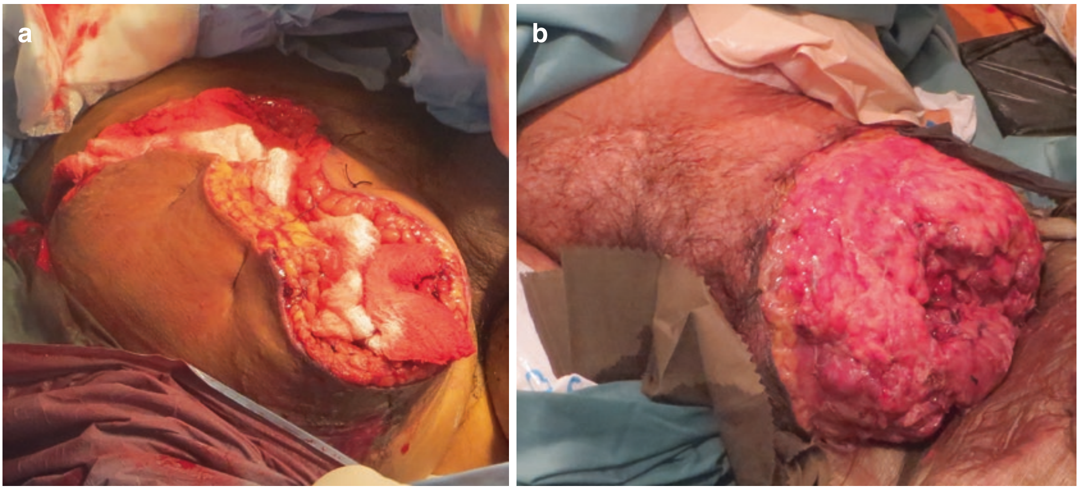
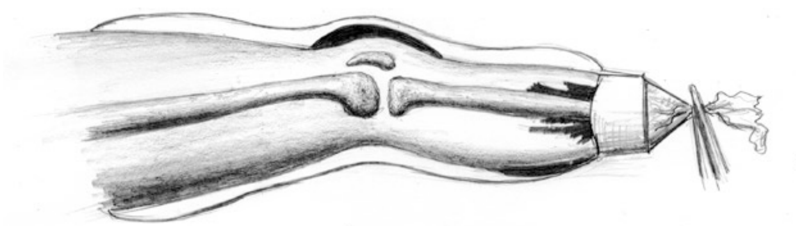


Fig. 33.4 (**a**, **b**) Occlusive dressing and its local sequelae

Fig. 33.5 Skin traction



Skin traction (Fig. 33.5) used in the past to prevent skin retraction and transportation casts [57] is no longer commonly used because of improvements in wound management and transportation times. Various wound coverage techniques can be used, including local flaps [58–63], free tissue transfer [64–66], and split-thickness skin grafts [67, 68], and some new technologies like top closure tension-reduction system and others [69] may be applied as a second choice for method of closure. Multiple surgical debridements are the rule prior to definitive delayed wound closure.

33.6.5 Level of Amputation

The following are the factors to be considered when deciding at what level to perform a lower extremity amputation:

It should be carried out at the level of viable tissues. In the acute setting, skin vascularity is sometimes assessed by a trial skin incision [17]. Most of the time, the decision of the level of the amputation is based on clinical factors: skin color and temperature, presence of peripheral pulses, extent of the skeletal damage, and gross infection. When definite amputation is performed in a more delayed fashion, other diagnostic modalities, such as ankle/brachial index, transcutaneous PO_2 measurements [70], arterial Doppler studies, Xenon 133, laser Doppler, and thermography, have been used to predict the healing potential of the amputation wound.

Bone cutting is carried out in consideration of the soft tissue coverage, so that when the closure of the wound is performed, the skin is not under tension.

Stripped of soft tissue attachments comminuted and devascularized bone fragments should be removed to avoid future local infection due to sequestrum formation. Large bone fragments with soft tissue attachment and preserved blood supply should be stabilized using either external or internal fixation, to allow preservation of the longest optimal amputation stump.

33.6.6 Soft Tissue Management

Quality of the soft tissue management is the key for successful care of amputation. Initial approach should be based on comprehensive but careful debridement of amputation wound and better if done in a stage fashion. While often used in civilian and vascular trauma, myoplasty and myofascial closures [71–73] are not recommended in the treatment of combat-related injuries [74]. Myodesis is the preferred method of soft tissue stabilization [39, 75]. To perform myodesis, muscular fascia is either sutured to the periosteum or reattached to the bone by drilling holes in the bone cortex. This technique allows to stabilize the muscle layer of the soft tissue envelope making it more stable and well padded. Myofascial closure and myoplasty may then be used to supplement primary myodesis.

33.6.7 Arteries

Initial bleeding control should be accomplished using direct pressure and tourniquet in acute presentations. Double ligation of transected arteries, however, is often advocated as an early solution to secure bleeding from the larger vessels.

33.6.8 Nerves and Tendons

During initial wound care, both nerve and tendon length should be preserved as much as possible to allow for future reconstructions. When the level of amputation is determined and wound closure is to be performed, the level of neurotomy proximal to the wound can minimize risk of symptomatic neuroma formation. Their ends should be tagged with nonabsorbable sutures.

When a large nerve is to be cut, it is recommended to do ligation prior to transaction to minimize bleeding from the vasa vasorum.

33.6.9 Skin Management and Wound Closure

Wound closure is performed only when initial soft tissue inflammatory response to the trauma is passed and there is no angry, inflammatory tissue reaction. Closure of the wound is done in variety of ways. The important basic principle is not to complete skin closure under skin tension.

Pallor of the skin layer will be indicative of skin being overstretched. Inappropriate wound closure may result in skin necrosis leading to infection and possibly sepsis Fig. 33.6.

The unique skin-stretching technology and device may apply both stress relaxation and mechanical creep for delayed primary closure of large skin defects which otherwise would have required closure by skin grafts, flaps, or free tissue transfer (Fig. 33.7) [99]. These types of devices employ distribution of dynamic, selective, vector-oriented forces over a wide area of attachment, continuously or cyclically, in both noninvasive and invasive attachment to the skin, so that surrounding skin can be stretched, allowing safe primary closure of wound margins by conventional methods. The notable advantages of using this system for external skin stretching include:

1. The application of both acute intraoperative stress relaxation and pre- and postoperative mechanical creep for high- and low-tension wound closure, respectively.
2. It serves as a topical tension-relief platform for tension sutures, alleviating the typical tearing and scarring inflicted by tension sutures.
3. Undermining of the skin edges and adjacent tissue can be avoided, minimizing compromise to skin viability and reduce the risk of infection.
4. Skin can be further approximated as a bedside procedure by mechanical creep.
5. Surgical technique is simplified.

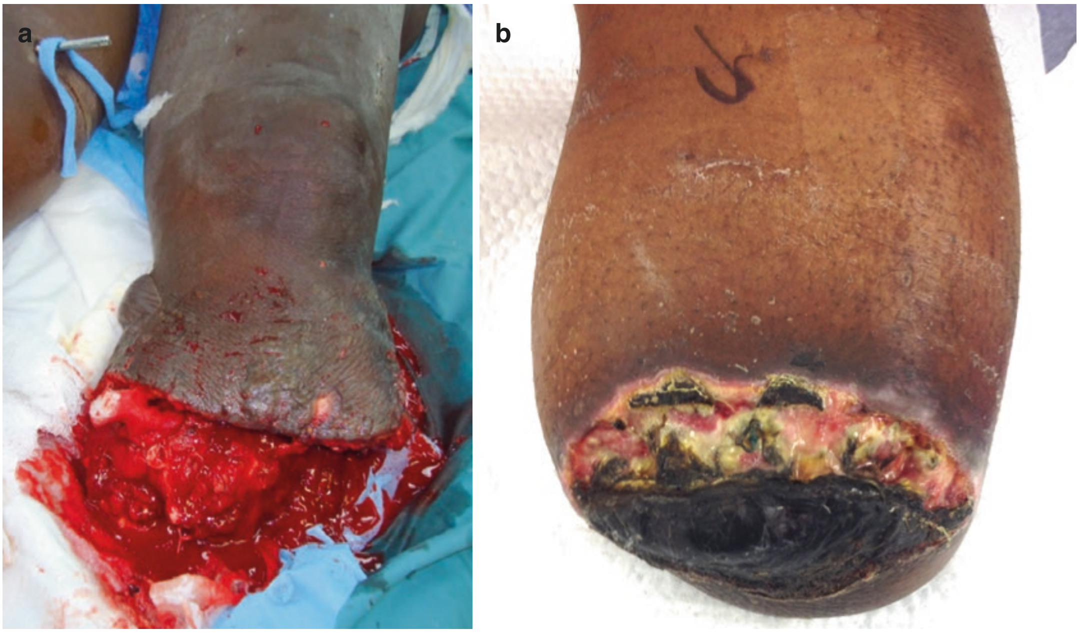


Fig. 33.6 (**a**, **b**) Amputation wounds closed prematurely dehisced, necrotic, and infected

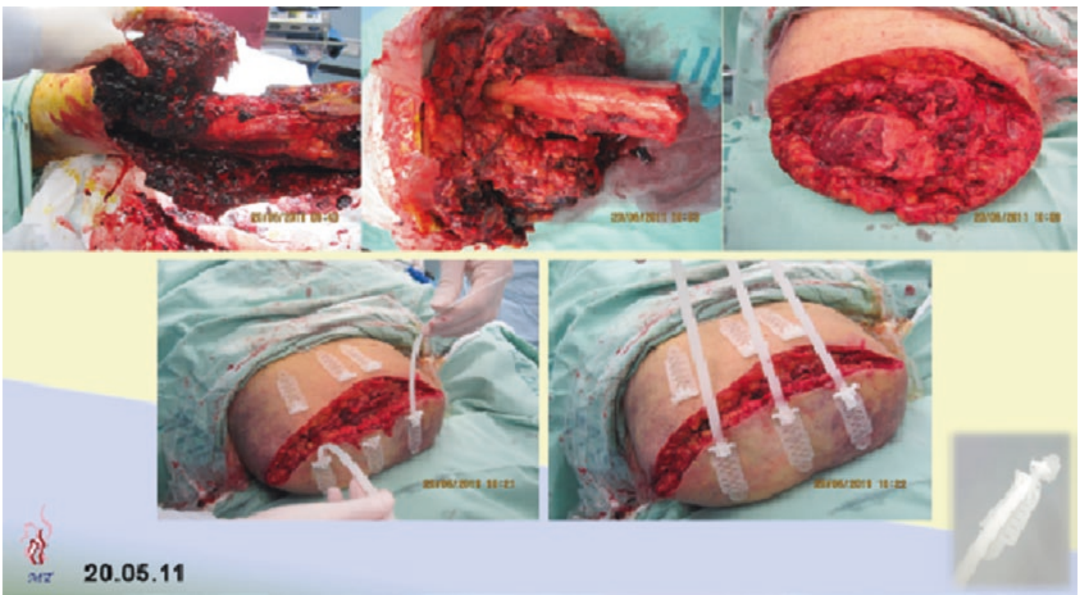


Fig. 33.7 Gradual primary wound closure

6. Drainage of hematoma or infection can be easily performed bedside together with dressing change and delayed closure of the wound.

The weight-bearing area of the residual limb should be sensate and actively controlled.

Scars should not be located in the weight-bearing areas of the residual limb.

Avoidance of significant *flexion contractures* should be taken into account.

33.7 Upper Extremity Amputations

Salvage of the upper extremity versus amputation has paramount importance in patients with severe injury. While planning upper extremity amputation, the surgeon should aim for a pain-free functional extremity. Preservation of maximal limb length is a key.

33.7.1 Finger and Ray Amputations

33.7.1.1 Fingertips

Based on the pattern of the injury, the fingertip is either left to heal by secondary intention or soft tissue coverage achieved by either local flap or skin graft (Fig. 33.8a, b).

33.7.1.2 Digits

Index Finger

Distal to PIP Joint: tissue is debrided, digital nerves are identified and allowed to retract proximally, and bone is shortened to allow to close skin preferably on the dorsal surface of the digit.

Proximal to PIP joint amputation: consider either similar to distal to PIP joint approach or, if no finger prosthesis will be available, perform index ray amputation transecting second metacarpal. This will improve hand function.

In case of multiple finger injuries, an attempt should be made to salvage affected digits.

33.7.2 Wrist Disarticulation

Between transradial amputation and wrist disarticulation, priority is given to wrist disarticulation.

The main reason is preservation of pronation and supination.

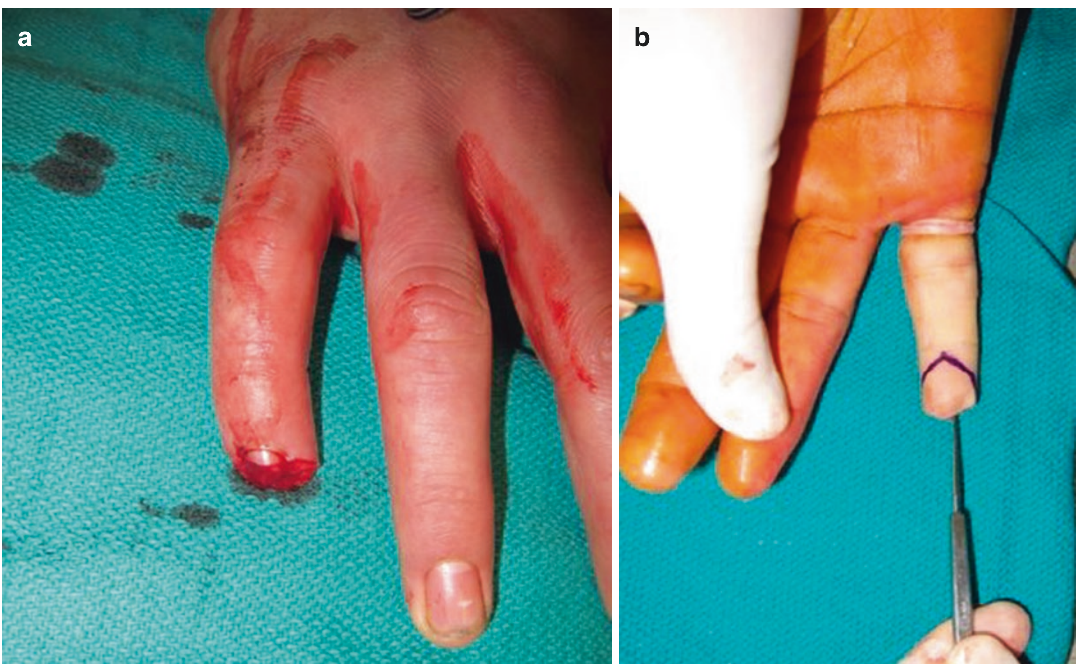


Fig. 33.8 (**a**, **b**) Fingertip amputation

The following are the steps:

1. Prep and drape arm as high as axilla.
2. Tourniquet is used and applied to appropriate level of pressure (100 mmHg above systolic pressure).
3. Longer palmar and shorter dorsal flaps are created (2:1). Radial and ulnar arteries should be identified and double-ligated proximal to the level of wrist. Radial, ulnar, and median nerve should be identified, infiltrated with local anesthetic, and transected as proximal as possible. All tendons should be transected at the wrist level.
4. Radial and ulnar styloids are excised.
5. Hemostasis is performed.
6. Wound closure. Drain is used and skin closed with 2.0–3.0 Nylon
7. Dressing: Petroleum-based dressing is applied on the incision site, followed by a gauze and then bandage in a snug but not very tight fashion to prevent swelling but not to create excessively painful compression to the stump. Drain is removed in 24–48 h and sutures in 14–20 days.

33.7.3 Forearm Amputation

The longer the stump, the better range of motion.

The steps are similar to the wrist except the flaps are equal in length. Fishmouth incision is made.

Flexor digitorum superficialis (FDS) flap is then fashioned long enough to be carried around bone ends. Other muscles sectioned at the level of the bone. FDS is sutured to the dorsal fascia.

Ulna is left slightly (1–3 cm) longer than radius in the proximal forearm, while radius is left longer than ulna in the distal forearm.

Similar technique for the wound closure and dressing is applied.

If appropriate microvascular expertise is available, replantation is performed. Elbow function is of highest priority. At least 4–5 cm of the ulna is needed for the elbow function (Fig. 33.9a–g).

33.7.4 Transhumeral Amputation

As much of the length of the humerus as possible is preserved. Humerus is amputated at least 4 cm proximal to the elbow joint to allow appropriate prosthesis placement. Posterior and anterior fishmouth skin flaps are created. Posterior triceps muscle is cut about 4–5 cm distal to the humerus cut, while anterior muscle flap is about 1.5 cm distal. After thorough debridement, vascular ligation and nerve cuts wound is covered with sterile non-obstructive dressing. It is then closed in a staged fashion.

33.8 Lower Extremity Amputations

When an amputation is performed above the ankle, the transtibial below-knee amputation is considered to be the most effective compared to transfemoral amputations. This is carried out for the preservation of the knee joint, adequate oxygen consumption [16], and reduced perioperative mortality [76].

Attempts should always be made to preserve the lower limb at the lowest possible level. The shortest length for below-knee amputation should be at the level of the tibial tubercle, so that the extensor knee mechanism is preserved. When performing the definitive closure of the amputation, better stump shape and easier prosthetic fit are achieved with a residual tibial length of 15 cm or less [60, 77].

If prosthetic service is available following amputation, below-knee amputation is the preferred option. If there is no access to prosthetic fitting and injury is to the foot while the hindfoot plantar skin is preserved, the choice is between Pirogoff, Syme, and Chopart amputation [93]. This may allow patients to ambulate and weight bear without a prosthesis [95].

Fig. 33.9 (**a**–**g**) Forearm replantation

33.8.1 Below-Knee Amputation

33.8.1.1 General Principles

This the most common type of trauma-related lower limb amputation, both on the battlefield and in civilian life. Blast, mainly from a land mine or booby trap, is one of the most common mechanisms. In natural disasters it is often a crush injury and mangled extremity with open fracture/fractures.

Because of the nature of the battlefield and wounds caused by blast injury, a guillotine amputation was commonly used in the past. Experience of the recent years both in the military settings and during natural disaster does not support this method of amputation in disasters [7]. Wound complications following this technique are high due to different reasons, including soft tissue retraction, exposed bone, and others.

The following is required to have below-knee amputation leading to functional lower extremity [67]:

1. A functional knee joint with no more than 20° loss of extension
2. A proximal tibia with a patellar tendon attachment
3. An adequate soft tissue envelope with the mobile muscle covering distal end of residual limb
4. Full-thickness skin covering load transfer areas

In some instances, when the proximal tibial fragment is short and/or there is soft tissue deficiency to cover the distal stump, osteoperiosteal grafts that have been harvested from the removed limb can be used in the case of primary amputations. An unstable proximal tibiofibular joint in the case of a short residual limb can lead to the lateral displacement of the fibula due to the pull of the biceps femoris, which may cause prosthesis wear difficulties. This is addressed by the arthrodesis of the proximal tibiofibular joint. Another way of creating a more sturdy and even "end-bearing" stump is by making a distal synostosis between tibia and fibula, which is a technique modernized and popularized by Ertl [78], Dederich [79], and others [80, 81]. In recent years, the "Ertl's technique" has gained more popularity mainly due to the stable weight-bearing platform.

33.8.1.2 Amputation Technique

The level of amputation is determined mainly by the extent of the soft tissue injury. All reasonable attempts should be made to save tibial tubercle, so that active knee motion will be possible. Modern prostheses take advantage of the longer residual limb.

Different techniques are use to performed below-knee amputation. We prefer technique described by Burgess [99].

No matter what type of amputation is performed, the skin flaps must be created with enough length to avoid closure under the tension. We prefer long posterior flap about 7 cm longer than limb diameter (Fig. 33.10).

A muscular cut is made approx. 5–7 cm distal to the bone transection, which allows for appropriate padding or bone coverage and myoplasty (suturing muscle, fascia to the anterior tibial cortex, via either periosteal layer or drilling holes through the cortex of the tibia for suture placement). By creating a myodesis effect (where the antagonistic muscles and fascia groups are sutured together), the triceps surae retraction risk is minimized. Posterior flap consists of medial and lateral gastrocnemius and soleus. Soleus debulking might be required to facilitate approximation of the wound edges.

No redundant soft tissue, neither "dog ears," nor crevices are created at the final closure of the wound.

The skin should not adhere to the underlying bone, and there will preferably be no scar formation in the areas of the prosthesis contact.

A bone cut is made with either a cooled power saw or Gigli saw. An approximately 45° bevel is made in the anterior tibial cortex and the cortical edges are smoothly contoured by using a bone file to prevent skin breakdown with prosthetic use. No periosteum is striped off the bone. No periosteum should be removed in order to prevent the formation of ring sequestra or bone overgrowth.

A fibular cut was traditionally made approximately 1 cm proximally to the tibial cut with proximal laterally facing facet. The creation of distal tibiofibular bridging may require this approach to be changed.

The major blood vessels are dissected and separately ligated by using double ties in order to prevent the development of arteriovenous fistulas and aneurysms.

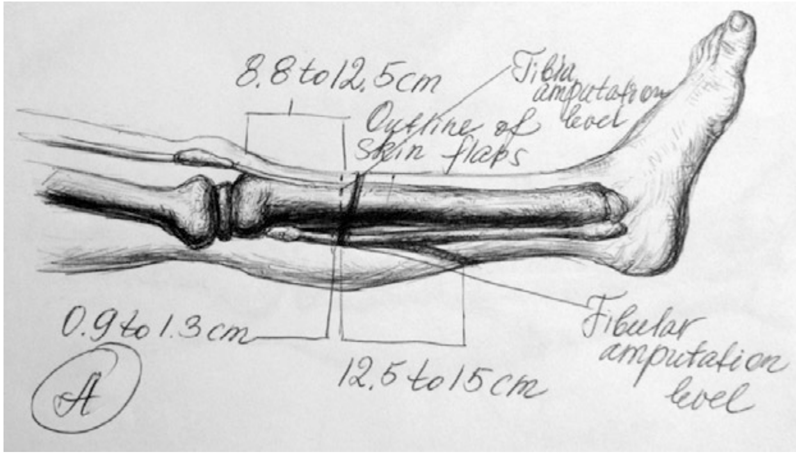


Fig. 33.10 Below-knee amputation with posterior flap

Tibial, superficial peroneal, deep peroneal, saphenous, and sural nerves should be transected 3–5 cm proximal to the level of amputation. The nerve ends are often injected with long-lasting anesthetics to reduce postoperative pain (Fig. 33.11). If bleeding from vasa nervorum is encountered it should be cauterized.

Different techniques had been introduced to overcome a problem of wound closure (Fig. 33.7) [96–98].

Prior to wound closure or the application of the dressing, the tourniquet is taken down and hemostasis is performed. The wound is irrigated with an irrigation solution of choice. A drain is placed for the prevention of hematoma. Nylon #3.0 or #2.0 sutures are used to close the skin. It is usually done is a stage fashion (Fig. 33.11a–c). After a sterile dressing is applied, the extremity is placed in plaster splints in extension, making sure that the patella is free of pressure [100]. Plaster is marked with the date of the surgery and any other instructions that might be needed (Fig. 33.12). The dressing and splint are changed between 2 and 10 days following surgery based on the condition of the wound at the time of closure.

33.8.1.3 Postoperative Management

As soon as the wound condition permits, a rigid light dressing is applied up to the mid-thigh while keeping the knee in extension. Adequate pain management is of major importance and a multidisciplinary team is needed to provide comprehensive care. For more specific types of flaps and types of amputations, we recommend the *Atlas of Amputations and Limb Deficiencies: Surgical, Prosthetic, and Rehabilitation Principles*, ed. 3 AAOS, [13].

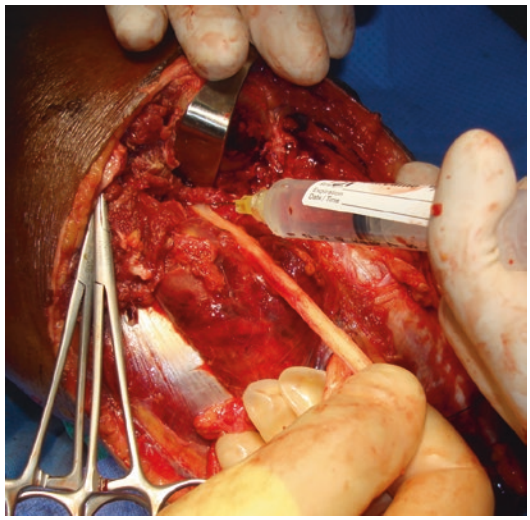


Fig. 33.11 Injection of tibial nerve with long-lasting anesthetic

33.8.2 Knee Disarticulation

Superior weight-bearing properties and better energy consumption favor knee disarticulation compared to above-knee amputations. However, difficulties with soft tissue coverage make this type of amputation challenging. More proximal reamputation is often required. Different surgi-

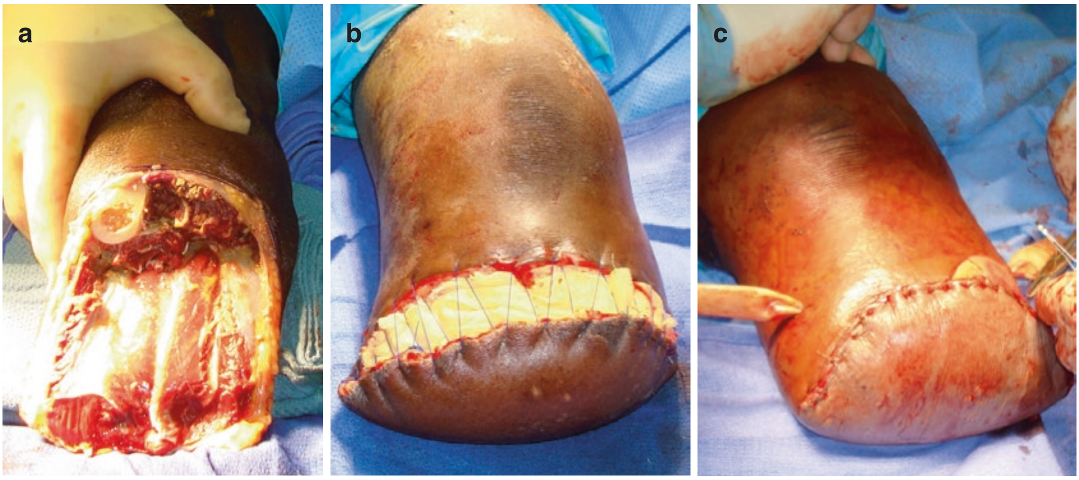


Fig. 33.12 (**a**–**c**) Staged wound closure

cal techniques [67, 68, 82–84] addressed the size and shape of the amputation stump and its coverage, so that an appropriate prosthesis can be used. This procedure is not used as often as transfemoral amputation due to inability to cover the distal femur with sufficient soft tissue. For this reason, the muscle-balanced transfemoral amputation is preferred. Application of the Circular cast with a window to accommodate potential knee swelling (Fig. 33.13).

33.8.3 Above-Knee (Transfemoral) Amputation

33.8.3.1 General

When the extent of the injury to the bone and soft tissues below the knee is so severe that it is impossible to reconstruct the residual limb, an above-knee transfemoral amputation is indicated. The velocity and cadence of the gait and increased energy expenditure make this type of amputation inferior to more distal amputations.

33.8.3.2 Level of Amputation

Preservation of maximal residual length is important for optimal prosthesis fit and function. If a more proximal amputation is required, the trochanteric part of the bone is saved to enable a better prosthetic fit. Muscle atrophy in a transfemoral amputation is a common occurrence and

Fig. 33.13 Application of the Plaster of Paris with open patella and mark of the operation date

is related to both the residual limb length [85, 86] and the quality of the muscle stabilization [87]. The preservation of adductor magnus is important to maintain adduction strength and muscular balance.

33.8.3.3 Amputation Technique [88]

As in a transtibial amputation, the surgical approach is staged: after the initial surgery, the wound is left open and is definitively closed only when the soft tissue conditions permit.

If the femoral shaft is fractured, it should be reduced and fixed prior to the final closure.

The patient is positioned supine and the hip is flexed while supporting the thigh with a rolled sterile blanket.

A tourniquet is used but is deflated prior to final soft tissue closure in order to assure proper hemostasis.

A skin cut is performed in a way that no suture line and corresponding healing scar are placed at the distal end of the stump, which may interfere with the prosthesis use. We prefer "fishmouth" incision (Fig. 33.14a–c). The subcutaneous dissection is minimized to preserve perforating the fascial blood vessels.

The major blood vessels are dissected and separately ligated by using double ties in order to prevent the development of arteriovenous fistulas and aneurysms. They are cut at the level of bone cut.

The sciatic nerve is dissected, and if bleeding from the central vasa nervorum is encountered, it is either cauterized or ligated together with nerve as far as proximal as possible. Infiltrating the sciatic nerve with a long-acting local anesthetic may minimize postoperative pain [88]. Smaller nerves are dissected and cut proximal to the bone cut.

Muscles: The quadriceps femoris is cut at the tendinous portion just above the patella, and the adductus magnus is detached from the adduction

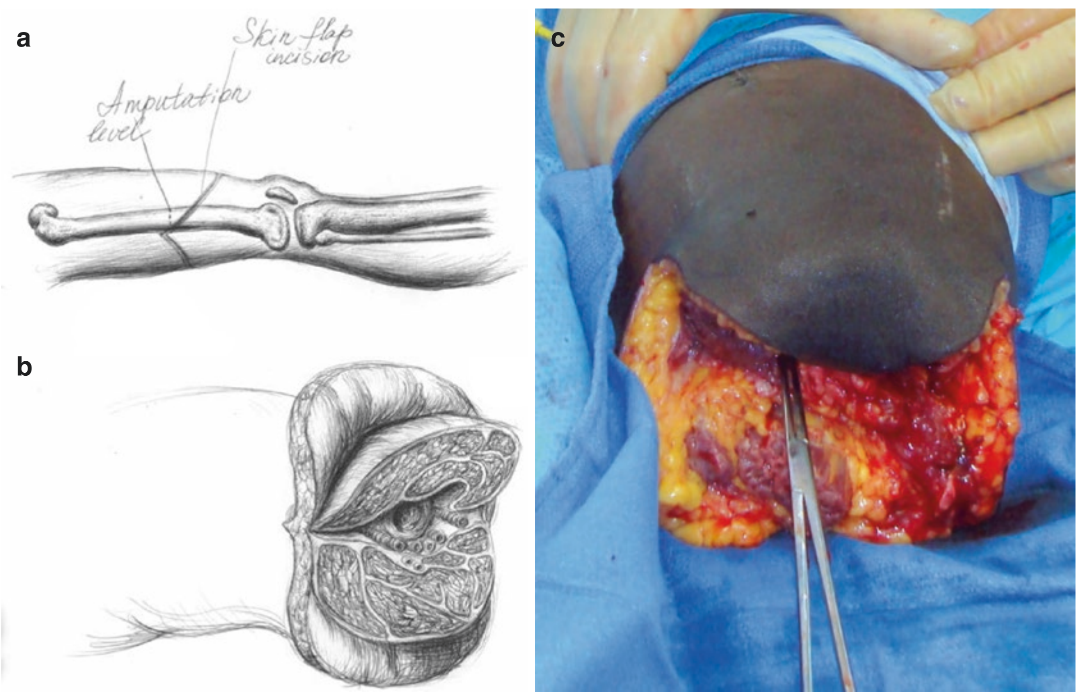


Fig. 33.14 (**a**–**c**) "Fishmouth" incision

tubercle and, if needed, from the linea aspera in order to allow for its transfer to the lateral cortex of the femur where it is anchored under slight tension. Hamstrings and posterior muscles are divided slightly distal to the bone section, while the tensor fascia is cut at the level of the bone section.

The myodesis and myoplasty of the adductor muscle are performed keeping the appropriate muscle tension. This is carried out by reattaching the adductor magnus to the lateral femoral cortex (Fig. 33.15a, b).

The bone edges are smoothened with a rasp and the wound is well irrigated after the tourniquet is deflated and final hemostasis is performed.

Based on the mechanism of the limb injury, closure of the wound is then addressed.

If the limb is damaged by a blast or crush injury, or patient is presented with delay and wound is either contaminated or infected, wound closure is then performed in stages. If treatment is in the austere environment and transfer to medical facility is delayed, skin traction may be used.

When closure is performed, the quadriceps is then wrapped around the distal femur and sutured posteriorly to the posterior deep fascia.

A drain is placed under the muscle flaps and brought lateral and proximal to the planned site of skin closure.

A sterile dressing is then applied. While a variety of dressings are available, we prefer to use semirigid dressing, utilizing a heavy plaster splint, which minimizes hip flexion and helps control swelling (Fig. 33.16a, b). The sutures are removed 2–3 weeks after the surgery. Temporary prosthesis fitting is carried out 5–8 weeks after the amputation.

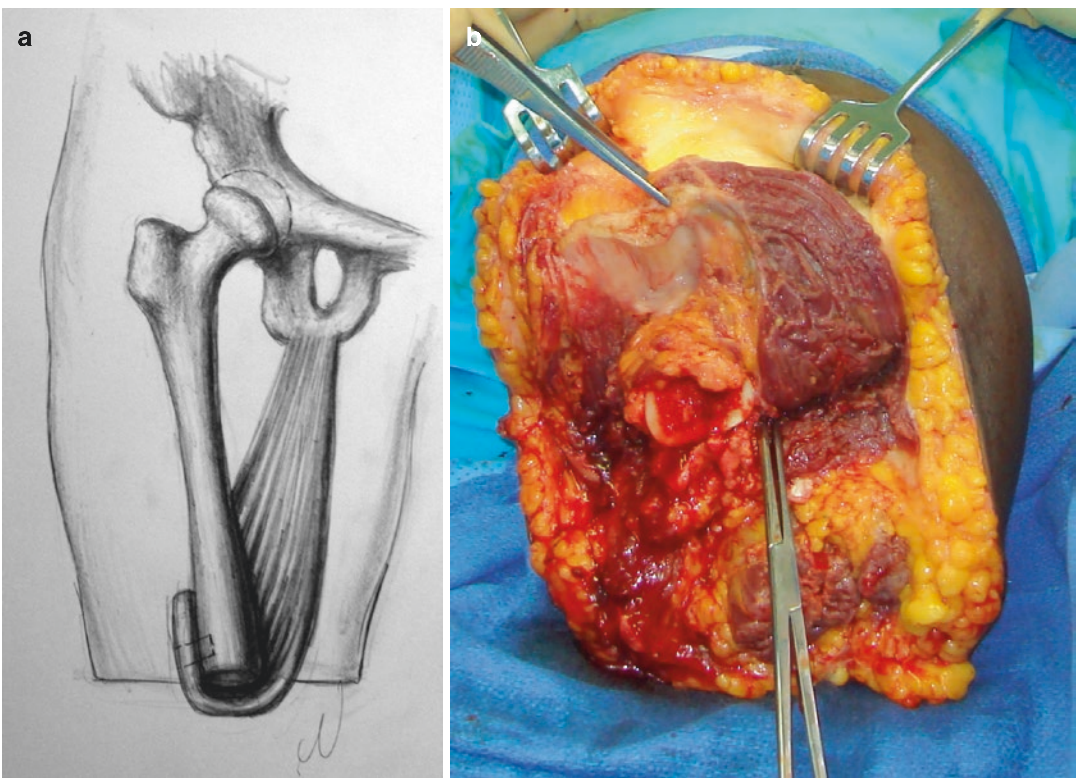


Fig. 33.15 (**a**, **b**) Reattaching the adductor magnus to the lateral femoral cortex

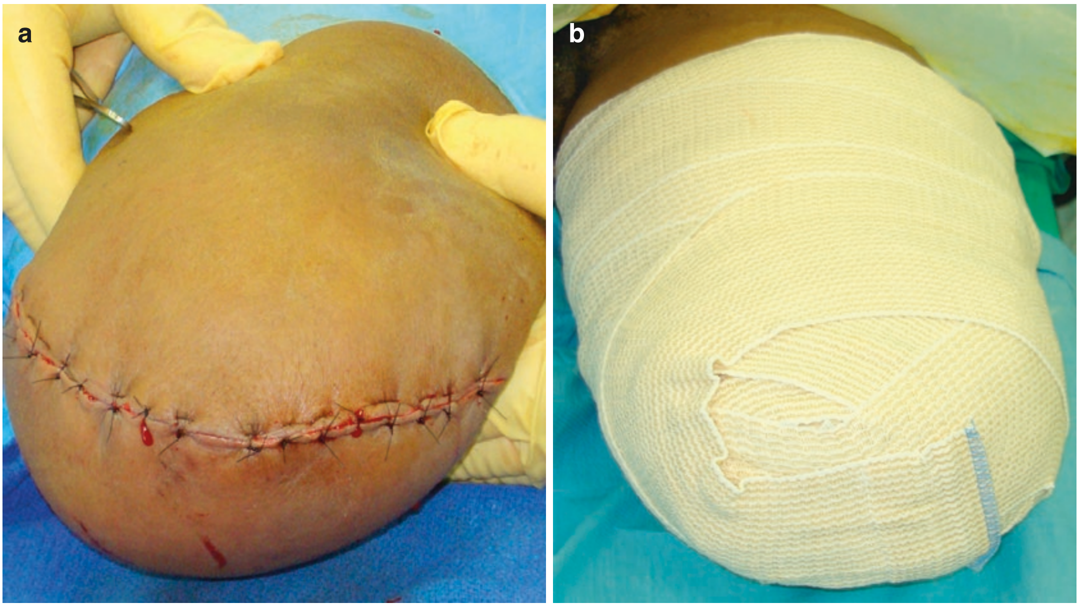


Fig. 33.16 (**a**, **b**) Semirigid dressing with heavy plaster splint

33.8.4 Hip Disarticulation

In a battlefield setting, or in an austere environment, this procedure can be required in case of a life-threatening hemorrhage or infection. It is usually performed in the regional center by a well-experienced and skilled team. There is very high risk of mortality when procedure is performed in the field hospital. For more detailed coverage of this particular subject, we recommend the *Atlas of Amputations and Limb Deficiencies: Surgical, Prosthetic, and Rehabilitation Principles*, ed. 3 AAOS, [13].

33.9 Complications

Hemorrhage and infection are complications common to all operations. Amputations also have certain unique complications.

33.9.1 Early Complications

The early complications of amputation are delayed hemorrhage, skin flap breakdown, and infection [90].

33.9.1.1 Delayed Hemorrhage

Postoperative bleeding at the stump site occurs due to a missed vessel, which retracts into the surrounding tissues, vasospasm, or failed suture ligation of arteries. When postoperative bleeding is noted, it is imperative to remove the dressing in order to visualize and suture the bleeding vessel. The wrong decision is to reinforce the dressing, which only serves to cover the offending vessel.

33.9.1.2 Skin Flap Breakdown

Skin flap breakdown is due to technical error or poor blood flow to the flap (Fig. 33.17). The technical errors include closing the stump under tension, aggressive handling of skin edges with instruments, and excessive use of the cautery device when achieving hemostasis. To avoid technical errors when performing definitive amputations (as opposed to a guillotine amputation), great care must be taken to plan the incision to allow for adequate skin flaps and to close the wound in multiple layers of absorbable suture to minimize tension at the skin level. Please refer to the section on amputation technique for a description of the process. In young trauma patients, such as those who suffer devastating extremity injuries in war zones, perfusion to the skin is

Fig. 33.17 Skin flap breakdown

Fig. 33.18 Infected amputation stump

rarely a challenge, but in elderly patients who undergo amputation for peripheral vascular disease, crush injury to the skin with aggressive use of instruments leads to necrosis at the approximated skin edges. Minimal or no use of forceps on the skin edges will help avoid this complication. Excessive cauterization near the wound edges causes focal areas of necrosis, which lead to skin breakdown. A lack of adequate skin coverage is at times a problem when trying to salvage a below-knee amputation. Microvascular free tissue transfer techniques are available to allow for myocutaneous free flap coverage of the distal tibia when primary wound closure cannot be achieved. It allows for adequate tissue coverage to avoid revision to an above-knee amputation [91].

33.9.1.3 Infection

Early surgical infection is a risk in all blast and crush amputation wounds (Fig. 33.18). Gas gangrene and necrotizing fasciitis are dreaded complications. Gas gangrene is caused by the alpha-toxin produced by *Clostridium perfringens*. The alpha-toxin has been identified as phospholipase C confers the virulence to *G. perfringens* [25]. The recommended treatment of necrotizing fasciitis is intravenous wide-spectrum antibiotics, penicillin and clindamycin, and surgical debridement with supplemental hyperbaric oxygen treatment (HBO). One of the alternative ways to substitute for HBO in cases where HBO is contraindicated or not available is RO-NPT [26].

33.9.2 Late Complications

The late complications of an amputation include stump instability, ulceration, neuroma, heterotopic ossification, phantom limb pain, and contractures.

33.9.2.1 Stump Instability

Stump instability is due to an excess amount of muscle tissue left at the weight-bearing surface of the stump. The excess muscle acts as an unstable platform within the prosthesis, ultimately decreasing the utility of the prosthesis. Management of this complication is surgical excision of the excess muscle tissue followed by a repeat course of rehabilitation and prosthesis fitting.

33.9.2.2 Ulceration

Ulceration after surgery is a result of pressure on the skin at the stump from either immobility or from pressure in the prosthesis. Immobility pressure ulcers are usually the result of being bed bound. The posterior aspect of the stump ulcerates due to constant pressure. This may be avoided by floating the stump off the bed on pillows. Other methods to avoid immobility pressure ulcers include specialized pressure relieving mattresses and adjusting the position of the bed every 2 h. Prosthesis pressure ulcers occur because of (1) changing of the size of the stump over time and (2) lack of adequate tissue to cushion the tibia.

33.9.2.3 Neuroma

Neuroma formation after amputation is a debilitating complication that may prevent the patient from achieving maximum mobility [91]. The initial therapy is neuroma prevention, which is achieved through careful surgical technique and avoiding excessive stretch of the nerve and use of electrocautery on the nerve itself. The treatment of neuroma formation is a surgical excision or ultrasound-guided regional nerve blockade. Ultrasound guided peripheral nerve blockade with bupivacaine and methylprednisolone has been described with good results [21].

33.9.2.4 Heterotopic Ossification

Heterotopic bone formation is a well-described phenomenon that causes pain in the amputated limb [27]. The first descriptions of heterotopic osseous formation are from the American Civil War [28]. The presence of heterotopic bone in the adult population has been brought to the fore by the wars in Iraq and Afghanistan. In one study, 64 % of those patients who underwent an amputation for high-energy trauma developed heterotopic ossification [23]. Heterotopic bone formation may cause stump breakdown by causing pressure ulceration within the prosthesis. The treatment of heterotopic bone includes rest, refitting of stump sleeve, and ultimately excision of the heterotopic bone.

33.9.2.5 Phantom Limb Pain

Phantom limb pain for greater than 6 months occurs in up to 65 % of all patients who undergo an amputation. At 2 years, phantom pain was present in 59 % of patients [24]. In patients with existing pain, the limb pre-amputation has been found to have a higher incidence of postoperative phantom limb pain [24]. Fifty to eighty percent of American servicemen requiring amputation due to war-related injuries experience phantom limb pain [6]. A novel treatment approach is the use of mirror visual feedback therapy, which works to "shrink" the size of the phantom limb and ultimately the pain associated with the amputated limb [92].

33.9.2.6 Contractures

Contractures after an amputation are due to improper surgical technique leading to a muscular imbalance in the patient's stump, a lack of proper fixation of the extremity in extension during the initial postoperative phase, and/or a lack of adequate physical therapy and rehabilitation [94]. Contractures are a severe problem because inability to fit the prosthesis may make it impossible to walk. A maximum of 20° angulation is allowed to achieve ambulation with below-knee prosthesis.

Conclusion

Choosing an amputation over a limb-sparing procedure should not be considered a failure of treatment, depending on the time of presentation to the treatment team a life-saving, function-preserving operation or a reconstructive operation. It is one of the most challenging decisions orthopedic surgeons face. Given the current geopolitical situation, it is very likely that surgeons will continue to be confronted with these complex decisions. The functional outcome following amputation is affected by the severity of injury, the quality of medical, surgical, rehabilitation, and prosthetic care, as well as psychological and social services support. Development of a team approach with each of these disciplines represented is recommended by the World Health Organization "classification and minimum standards for medical teams in sudden onset disasters."

After a sudden-onset disaster, in certain resource constrained, austere environment settings, for many severe extremity injuries, amputation is the most effective method to rapidly return the patient to an active and productive life. Time-permitting, exhaustive efforts should be dedicated to involve the patient if available, the family, and local religious and cultural authorities in the decision to amputate with long-term consequences of living as an amputee discussed and accepted.

The increased incidence of devastating extremity injuries due to high-velocity missile and blast injury and the widespread use of body armor continues to mandate amputation in the management of combat casualties. Aggressive debridement and careful attention to detail during the definitive amputation revision optimize the chances for successful rehabilitation. Advanced technologies such as RO-NPT together with TRS have been recently employed in order further reduce wound infection and allow for better tissue management for both avoiding amputation and downgrading complexity of the amputation surgery. More field experience and data are required to establish role of these new developments for a regular practical use.

Technical, cultural, facility, and surgical skill factors should all play significant roles in the decision-making process when amputation is considered. Given what we have learned to date, a staged approach to amputation should be implemented whenever possible to minimize the risk of local and systemic infection. Since field amputation is an evolving medical skill set that will inevitably grow with the increasing incidence of disaster, education from medical school through residency, and subsequent CME certification courses, in its purposes, techniques, planning, and approaches should be of critical importance to all orthopedic surgeons.

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