Chapter

Multidisciplinary Management of Severe Extremity Injuries

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Abstract

Management of severe extremity injuries begins with controlling bleeding and stabilizing hemodynamics. There is no agreement regarding the selection of amputation or limb salvage for severe extremity injuries. The injury severity scoring system should be carefully and judiciously used. The important factor for the management of open fractures is how early the injured area of soft tissues is covered. Inappropriate management would increase complications and prolong the treatment period. Multidisciplinary management by specialists, in the emergency department, orthopedics, plastic surgery, vascular surgery, and rehabilitation, insisting on employing their own individual abilities as much as possible, would not only help to salvage limbs in severe extremity injuries but also provide highly satisfactory functional and aesthetic outcomes for patients.

Keywords: severe extremity injury, management, reconstruction, salvage, amputation

1. Introduction

The goal of treatment for severe extremity injuries is limb salvage; however, complicated life-threatening injuries and mangled extremities may lead to indication of amputation. To achieve an optimal outcome in patients with severe extremity injuries requires multidisciplinary management that begins with resuscitation and evaluation of life-threatening injuries, following initial surgical management, definitive treatment, and postoperative care. Initial surgical management includes control of bleeding sites by vascular ligation and/or shunting, debridement of devitalized soft tissues and foreign materials, and stabilization of the fracture by external fixation. Definitive treatment includes internal fixation of long bones, vessel reconstruction with anastomosis and/or grafts, nerve repair, and soft tissue coverage within the appropriate time frame. This chapter describes the multidisciplinary management of severe extremity injuries based on the morphological and functional characteristics of upper and lower extremities.

2. Initial assessment and management

Initial assessment begins with the primary survey, in which the patients' life-threatening injuries are evaluated based on the Advanced Trauma Life Support (ATLS) manual [1]. Establishment of an airway to avoid asphyxiation, maintenance and management of breathing, and circulation management by hemostatic procedure, and possibly transfusion, should be performed. Persistent bleeding should be detected early. Elastic or compression bandage or tourniquet is used when the bleeding cannot be stopped directly. Examination for bleeding sites in other regions than the extremities should be made. After the patient has been made hemodynamically stable, the next step is the secondary survey in which injuries are systematically surveyed to determine whether or not they require immediate medical treatment.

3. Extremity evaluation

The most important thing in the initial examination of extremity injuries is to evaluate whether or not the injuries are life-threatening and/or if they could cause dysfunctions. Meanwhile, if there are life-threatening complications, the initial diagnoses of minor injuries such as fractures with slight deformity or dislocation and/or ligament injuries are difficult and often likely to be missed. To preserve function of the extremities, the evaluation should be performed with careful attention to the maintenance of blood flow in the extremities, prevention of infection, proper treatment of surrounding skin and soft tissue injuries, and the prevention of secondary injuries. Tests of sensibility, motor function of and pulse in the bilateral extremities are periodically performed and recorded.

3.1 Peripheral nerve assessment

Systematic neurological assessment is essential. Sites exhibiting paresthesia, their distribution, and the ability of locomotor activity of muscles innervated by the peripheral nervous system should be examined. Muscle strength is evaluated by manual muscle testing. Definitive diagnosis can be made by examining the lesions in the operating room and confirming the presence or absence of any nerve injuries. However, in the case of blunt nerve injuries, often making a diagnosis is not easy, even when the lesion is open. In such cases, electrical nerve stimulation and observation of funiculus with an operating microscope would help in making a diagnosis. Especially in patients with multiple injuries, evaluation of nervous function is often initially difficult. Repetitive reevaluations should be made concurrently with the other surveys after the patient's condition has been stabilized.

3.2 Vascular assessment

Extremity vascular injuries are classified into two groups depending on the type of causes: penetrating injuries made by knives and such, and blunt injuries due to fractures, dislocations, etc. Delay of diagnosis and treatment for extremity major arterial injuries influences the functional prognosis. Especially, blunt injuries of lower limb arteries often require fasciotomy and/or amputation and are associated with higher mortality [2]. Therefore, to avoid sequelae (e.g., residual disability) associated with extremity arterial injuries, early and accurate diagnosis is indispensable.

When right and left difference in peripheral artery pulsation or skin color, continuous bleeding, and/or the sign of an expanding hematoma are observed after an injury, extremity arterial injury is suspected. However, because there are some cases that in spite of the extremity major artery injury, apparent ischemic signs cannot be initially seen due to the presence of a collateral circulation, extra careful attention is required. For the diagnosis of extremity arterial injuries, examinations by Doppler-derived arterial pressure measurement [3, 4] and helical CT angiography [5, 6] are adopted.

Diagnosis of the presence or absence of arterial injuries should not be made easily only by the evaluation of the capillary return sign and/or the Doppler-derived arterial pressure measurement. Suspected patients should undergo early angiography for a definitive diagnosis of the presence or absence of arterial injuries. However, revascularization should not be delayed due to putting a high priority on angiography. If ischemia due to arterial injury is suspected, early revascularization is necessary to save limbs, so it is also necessary to take surgery with information of the minimum contrast CT.

3.3 Soft tissue and bone assessment

When open injuries are found on the skin and soft tissues, diagnosis is easy from local findings. However, closed injuries of the skin and soft tissues are likely to be missed. When pulsation, mobility, dysesthesia, tire mark, and/or cutaneous abrasions are found on the skin, closed injuries are suspected. Open wounds should not be washed out before coming to the hospital or before debridement at the emergency department, because bacterial culture swabs are taken from the open wound. Then antibiotics are rapidly administered by infusion for the prevention of infection and a tetanus inoculation should be given. The administration of antibiotics from the prehospital period might help to lower the risk of infection at the site of a severe open fracture [7]. The confirmation procedure to determine whether or not the open wound, even if small, is in the communicating area of the fracture is performed under proper anesthesia in an operating room.

In the treatment of amputated extremities, tissues are wrapped with saline-soaked gauze, put into a plastic bag, and stored in ice water at 4°C.

3.4 Injury severity score

When we have to decide amputation or limb salvage depending on the degree of injury, the severity of extremity injury is evaluated based on the extremity assessment. Severity evaluation systems are the Gustilo-Anderson classification (**Table 1**) [8, 9], the Mangled Extremity Syndrome Index [10], the Predictive Salvage Index System [11], the Mangled Extremity Severe Score (MESS) (**Table 2**) [12], the Limb Salvage Index [13], and NISSSA (Nerve Injury, Ischemia, Soft Tissue Injury, Skeletal Injury, Shock, and Age of the patient) Score [14]. Among them, the Gustilo-Anderson classification and MESS are well-known severity evaluation systems. Although the Gustilo-Anderson classification is essentially designed to apply to

Gustilo-Anderson Classification
Type I
Open fracture is transverse or short oblique fracture with minimal comminution
Wound is less than 1 cm with minimal soft tissue injury
Type II
Open fracture is simple transverse or short oblique fracture with minimal comminution
Wound is greater than 1 cm with moderate soft tissue injury
Type IIIA
Adequate soft tissue coverage of a fractured bone despite extensive soft tissue laceration or flaps, or high-energy trauma irrespective of wound size
Type IIIB
Extensive soft tissue injury loss with periosteal stripping and bone exposure
Usually associated with massive contamination
Wound requires local or free flap coverage
Type IIIC
Open fracture associated with arterial injury requiring repair, regardless of degree of soft tissue injury

Table 1.
Gustilo-Anderson classification.

	Points
Skeletal / soft-tissue injury	
Low energy (stab; simple fracture; civilian gunshot wound)	1
Medium energy (open or multiple fractures, dislocation)	2
High energy (close-range gunshot or military gunshot wound, crush injury)	3
Very high energy (above + gross contamination, soft tissue avulsion)	4
Limb ischemia	
Pulse reduced or absent but perfusion normal, less than 6 hours	1
Pulse reduced or absent but perfusion normal, more than 6 hours	2
Pulseless; paresthesias, diminished capillary refill for less than 6 hours	2
Pulseless; paresthesias, diminished capillary refill for more than 6 hours	4
Cool, paralyzed, insensate, numb extremity for less than 6 hours	3
Cool, paralyzed, insensate, numb extremity for more than 6 hours	6
Shock	
Systolic BP always > 90 mm Hg	0
Hypotensive transiently	1
Persistent hypotension	2
Age (years)	
< 30	0
30-50	1
> 50	2

Table 2.
Mangled Extremity Severity Score (MESS).

intraoperative findings, it is actually often used from the initial evaluation. This classification method provides indices for the infection rate and the bone union period following the treatment of open fractures. MESS is composed of injury mechanism, severity and duration of limb ischemia, severity of shock, and patient's age. When the score is ≥7, amputation is likely to be selected [15–18].

4. Surgical management

Surgical management for extremity injuries is performed under the condition of stable hemodynamics with controlled bleeding. The management procedures include damage control surgery, fracture management, revascularization, extremity fasciotomy, nerve repair, and soft tissue debridement and coverage. When the bleeding cannot be controlled in an unrepairable extremity injury, limb amputation is selected.

4.1 Damage control surgery

If bleeding from the extremities continues, it is stopped by compression. If the compression does not work, bleeding is controlled using tourniquet and damaged blood vessels are treated by ligation or vascular repair. Patients should undergo revascularization within 6 hours, and if the ischemic time is prolonged, vascular shunt should be constructed. If the arteries and veins are both damaged, shunting is required for each artery and vein. However, if it is impossible, veins are occluded by ligation.

4.2 Fracture management

When the open fracture of extremities is severe, debridement and skeletal stabilization are performed in the operating room after the evaluation and stabilization of concomitant injuries that could be life-threatening. For the initial skeletal stabilization, external fixation is useful.

4.2.1 Debridement and stabilization

At the initial surgery, thorough debridement of mangled tissues and foreign bodies is performed. Low-pressure irrigation is used for the lavage. A delay in the debridement is likely to lead to high rate of infection and/or amputation [19–21]. The grade of the Gustilo-Anderson classification is evaluated by the assessment of conditions of conserved soft tissues and fractures. It is difficult to accurately evaluate the grade of the soft tissue injuries and the presence or absence of infection at the initial surgery. In most cases, a second-look and/or third-look debridement is required. External fixation is often selected as the initial skeletal stabilization for severe open fractures. When there are major vessel injuries, prompt skeletal stabilization and revascularization should be required. If it takes a long time for skeletal stabilization, a vascular shunt should be made to shorten the ischemic time. The defect of the surrounding soft tissues is reevaluated within 72 hours in the operating room, and additional debridement or definitive fracture fixation and soft tissue coverage are performed.

4.2.2 Definitive fracture fixation

Definitive fracture fixation is performed when the patient's condition, even with concomitant injuries, is stable. It is ideal that for the treatment of open fractures, external fixation has been changed to internal fixation, and soft tissue defects are promptly covered. For relatively low-grade open fractures of long bones, fixation with intramedullary nailing is considered preferable. However, because there is little difference in the outcomes between reamed and unreamed medullary nailing for long bone open fractures, the benefit of these procedures remains controversial [22–24]. External fixation of fractures offers a safe and effective management option for children (**Figure 1**) [25].

4.3 Revascularization

Factors influencing the functional prognosis after the main extremity artery injuries are proper treatment of the fracture and soft tissue injuries, including the nervous system, and the length of ischemic time. Because irreversible degeneration of muscle tissues is caused by ischemia of 6 hours or longer, the period between injury and revascularization should be as short as possible. The revascularization procedure includes vascular repair, vein grafting, inserting bypasses, stents, and/or shunts, which should be performed by surgeons with extensive experience in treating such injuries. When there are multiple levels of vessel injuries, revascularization should be started caudally from the most proximal vessel to the injury. If revascularization is likely to take up to 4 hours or longer, a temporary shunt should be constructed. In severe extremity injuries, revascularization after constructing a temporary shunt will decrease the amputation rates (**Figure 2**) [26]. When there is a defect of the vessels or the tension in the anastomotic site is strong, revascularization is performed after vein grafting (**Figure 3**). When there is a problem with venous return due to the injuries, revascularization of veins is performed.

4.4 Extremity fasciotomy

The fracture and bruising cause the muscles to swell, and the inner pressure of fascial compartments to rise. The compartment syndrome is the state that muscles are swollen further with lowered perfusion pressure, and the nervous system and muscles become ischemic. Diagnosis is determined from the present medical history

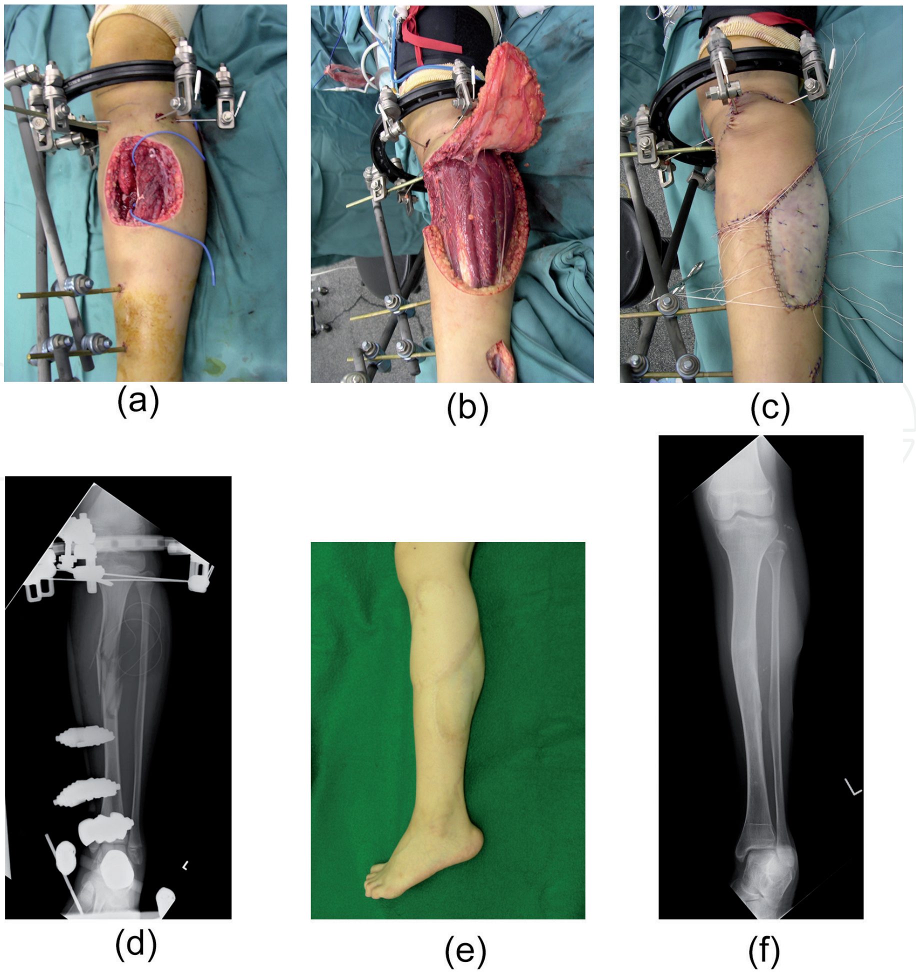


Figure 1.
(a) Open fracture of the left lower extremity was accompanied by a moderate soft tissue defect on the anterior lower extremity. (b) The fasciocutaneous flap was elevated from the lateral side. (c) Moderate soft tissue defect was covered by a fasciocutaneous flap, and skin grafting was applied to the donor site. (d) Intraoperative X-ray. (e) Postoperative view 84 months after surgery. (f) An X-ray of the leg 84 months after surgery, showing good bone union.

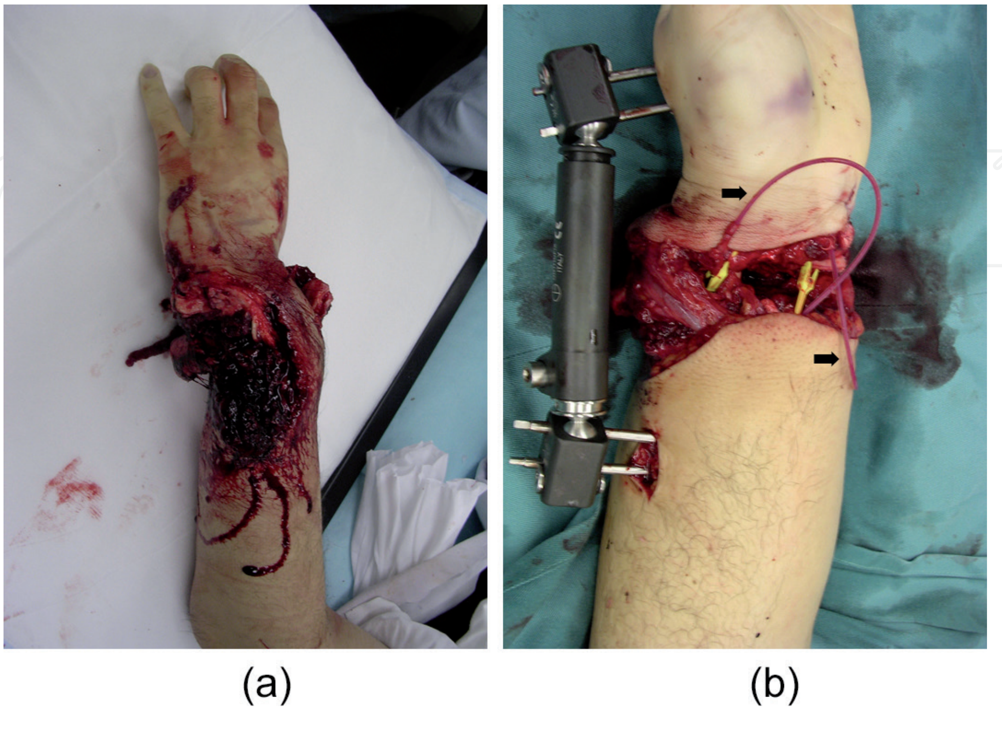


Figure 2.
(a) Crush injury of the left forearm was accompanied by injuries to the radial and ulnar arteries. (b) Temporary vascular shunts (arrowheads) were placed into the radial and ulnar arteries before definitive vascular repair.

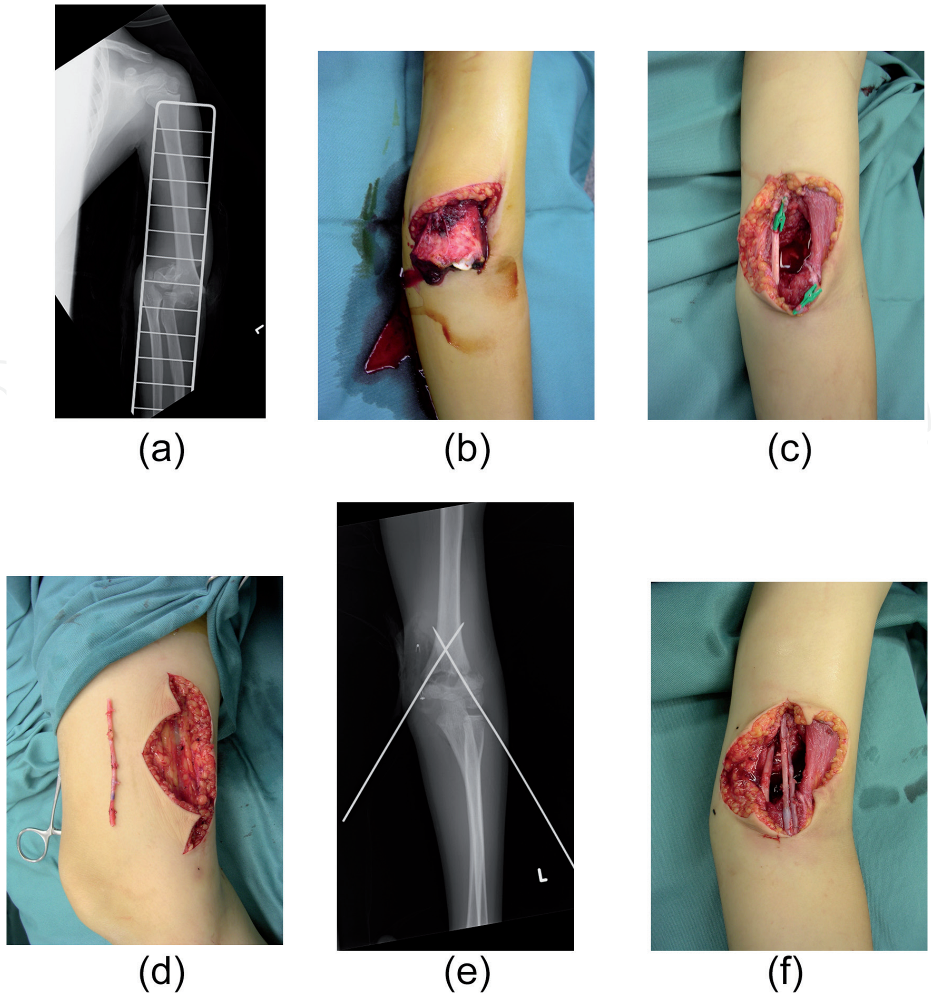


Figure 3.
(a) Preoperative X-ray. (b, c) The supracondylar fracture is accompanied by brachial vessel injuries. (d) The saphenous vein was harvested from the right thigh. (e) X-ray findings after Kirchner wire fixation, intraoperatively. (f) The saphenous vein was cut in half, and then the two veins were interposed in way of grafting to repair the defects in the brachial artery and vein.

and findings in physical examinations. Signs and symptoms are swelling in the overall area of the injury site, severe pain that cannot be alleviated by analgesics, increase of pain in the stretch test, and dysesthesia in the compartment region. Even though the compartment syndrome develops, peripheral arterial pulsation is usually palpable. During 48 hours after the injury, clinical signs and symptoms are periodically checked. Because clinical signs and symptoms cannot be checked if the patients have impaired consciousness or are under the effect of sedatives, inner pressure of the compartment is measured if the compartment syndrome is suspected. When the compartment inner pressure is ≥35–40 mmHg, a fasciotomy is performed (**Figure 4**). The open wound after a fasciotomy is treated by delayed primary closure and/or skin graft.

4.5 Nerve repair

Nerve injury that occurs concomitantly with fractures and/or dislocations is treated by repositioning and simple fixation. It is important that nerve repair is carefully performed using an operating microscope or surgical loupes. Factors other than surgery, such as the patient's age, nerve injury at higher level, and the degree of injury, influence the recovery of nerve damage. In cases with life-threatening concomitant injuries and/or those with severe extremity injuries, nerve repair can be performed later, within 2 weeks, with good prognoses. If the torn nerve fiber can be identified, marking with a nylon suture at the end of the nerve fiber or fibers is

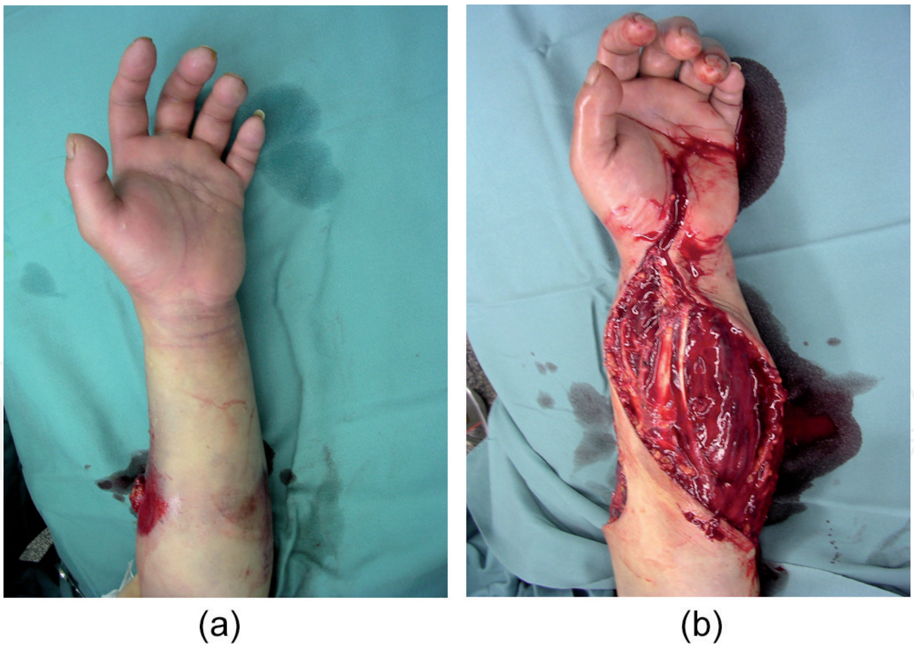


Figure 4.
(a) The left forearm was wringed by a industrial press machine, and the injury progressed to the compartment syndrome. (b) Fasciotomy was performed to alleviate the compartment pressure.

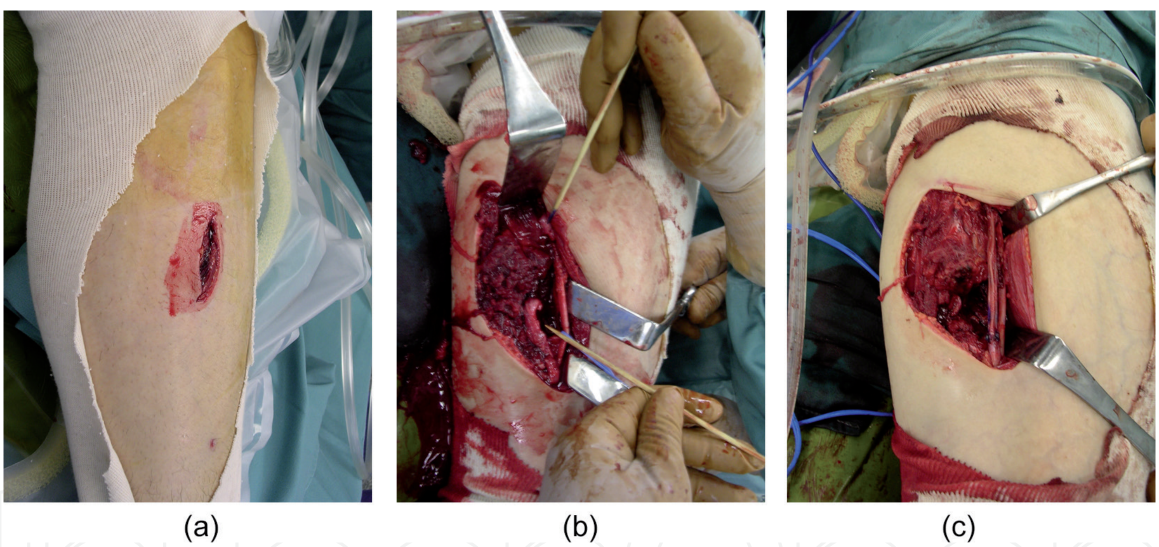


Figure 5.
(a) A penetrating wound was located in the middle of the right thigh. (b) The tibial nerve was ablated and crushed. (c) The sural nerve was divided in thirds and used as a cable graft to repair the severed tibial nerve.

recommended for later surgical repair. To treat a complete tear of nerve fibers, the nerve fibers are sutured together after the cut ends are reinnervated. When there is a high tension at the suture site or suturing is difficult or impossible because of nerve gaps, autologous nerve grafting [27] (**Figure 5**) or reconstruction with artificial nerve conduit [28] is incorporated into the treatment.

4.6 Soft tissue debridement and definitive coverage

In open fractures, the degree of soft tissue injury is associated with prognosis [29]. Soft tissue wounds in severe extremity injuries have a high risk of infection and treatment should be begun immediately. There have been a few reports on immediate wound closure and primary wound closure [30–32]. However, because it is difficult to accurately evaluate the degree of soft tissue damage and the presence or absence of

Figure 6.
(a) An open fracture located in the distal third of the left lower extremity, accompanied by massive soft tissue defect. (b) Intraoperative X-ray after intramedullary nailing fixation. (c) The anterolateral thigh fasciocutaneous flap was harvested from the right thigh. (d) The anterolateral thigh fasciocutaneous flap was applied to the soft tissue defect. Six months after internal fixation, autogenous bone grafting and transposition of the fasciocutaneous flap was performed on the tibia defect. (e) Postoperative view 12 months after bone grafting. (f) X-ray at 12-month follow-up showing adequate bone union.

infection in severe extremity injuries, the number of cases in which immediate wound closure and primary wound closure are possible is limited. In most cases with severe extremity injuries, second-look and/or third-look debridement are required. Open wounds had been recommended to be treated with moist dressings after debridement. Recently, although NPWT (negative pressure wound therapy) is used for open fracture wounds during the period after the debridement until coverage [33], there has been no evidence that it is more useful than conventional moist dressing [34, 35].

Because the infection rate becomes higher with the passage of days after the injury of an open fracture, the open wound should be closed early if the patient's general condition is stable and there is no local infection [36, 37]. For the coverage of the defect of soft tissues after the bone fixation, a flap is recommended [36–41]. Even if wound coverage cannot be performed at the initial debridement, good functional prognosis can be expected when soft tissue coverage is performed within 72 hours after an injury [36, 38, 40]. For an extensive soft tissue defect, a free flap transfer is useful (**Figure 6**). A free flap transfer enables reconstruction of a soft tissue defect by an end to side or a flow-through type vascular anastomosis without sacrificing major vessels, even if the recipient vessels that can be anastomosed are limited [42].

5. Complications

Complications associated with severe extremity injuries include infection and/or necrosis, pseudoarthrosis, osteomyelitis, venous thromboembolism, and rhabdomyolysis. If these complications occur, additional treatment is required and the treatment period would be prolonged.

5.1 Wound complications

Wound complications are caused by insufficient debridement and/or infection. The infection rate becomes higher with a higher grade of the Gustilo-Anderson classification. To prevent infection in severe extremity injuries, it is important to perform early and thorough debridement of necrotic tissues and construct coverage with tissues that have abundant blood flow.

5.2 Venous thromboembolism

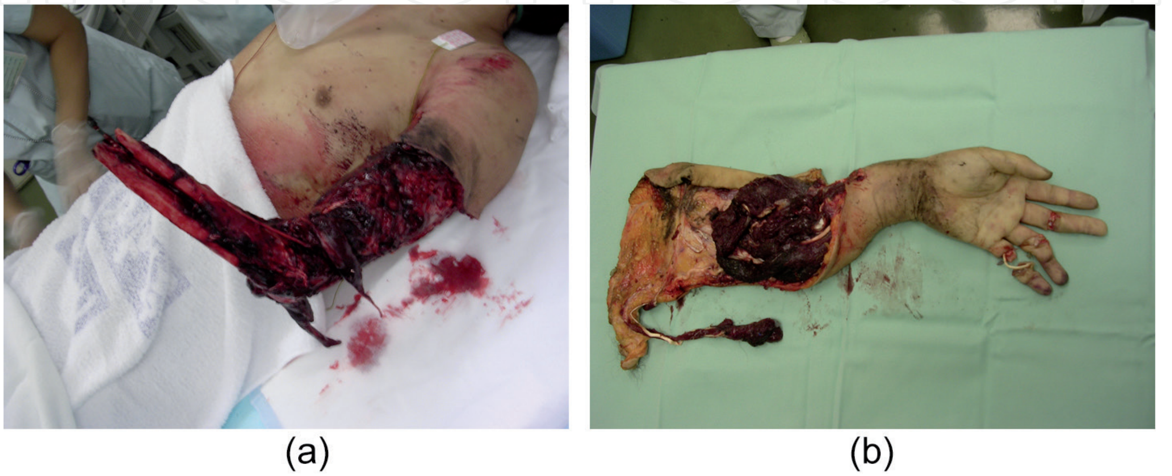
Deep vein thrombosis (DVT) and pulmonary embolism (PE) occur in 2–58% of trauma patients [43–45]. Because severe extremity injuries have a high risk of DVT and PE, mechanical and pharmacologic prophylaxes are necessary [46].

5.3 Rhabdomyolysis and myoglobinuria

Rhabdomyolysis and myoglobinuria are observed in the crush syndrome, compartment syndrome, and reperfusion syndrome. Various substances released from necrotic striated muscle cells circulate throughout the body, causing hyperkalemia, metabolic acidosis, hypermyoglobinemia, and acute renal failure. Transfusion and correction of electrolytes are fundamental to preventing acute renal failure.

6. Amputation versus limb salvage

There is, as yet, no agreement on the selection criteria for amputation or limb salvage [47–49]. The injury severity scoring system is reported to be a good indictor in a few reports [50–53] but considered negatively in others [54–56]. Because the indications for amputation differ depending on the patient's age (whether an adult or a child), and occupation, the injury severity scoring system should be used carefully and judiciously [57–60]. Indications for amputation are as follows: (1) life-threatening



(a) (b)

Figure 7.
(a and b) The left upper extremity was avulsed by an industrial machine. This mangled limb was not salvageable.

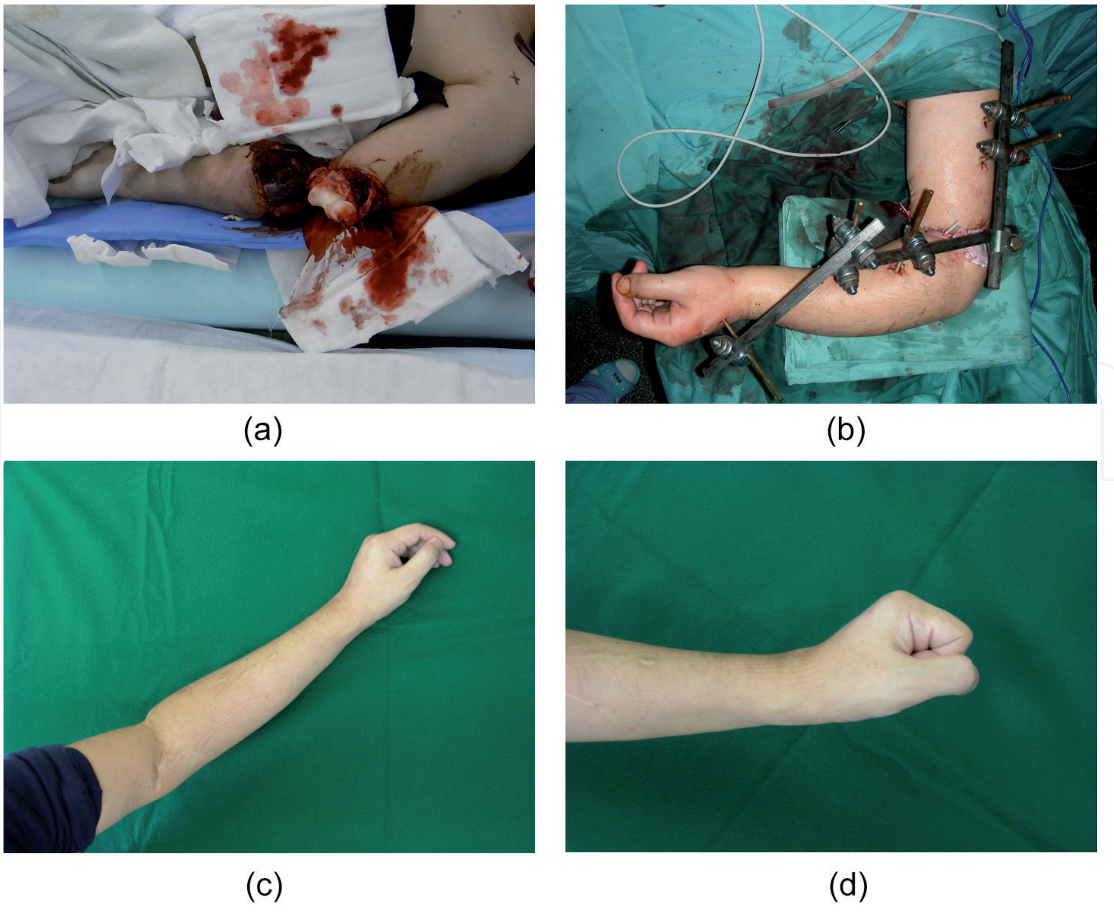


Figure 8.
(a) The left upper extremity was ablated at the elbow, the median and ulnar nerves were preserved; however, the radial nerve was avulsed in the middle third of the upper arm. (b) Immediate revascularization to the brachial vessels was performed followed by external fixation. (c and d) Postoperative view 12 months after reconstruction and a modified Riordan operation was performed on the radial nerve to cure the palsy.

bleeding cannot be controlled, (2) preserving open injuries to the extremity is likely to cause the patients' mortality, and (3) the injuries are so severe that a specialist judges the salvage of the extremity to be impossible (**Figure 7**). Ultimately, the decision regarding choosing limb salvage or amputation should be made in discussion with the patients themselves and their family members (**Figure 8**). Primary delayed amputation, if deemed necessary, should be performed within 72 hours after the injury.

7. Conclusions

For the treatment of severe extremity injuries, multidisciplinary management is required from the primary survey through rehabilitation. Unless severe extremity injuries are treated properly within the proper time frames, complications may occur, resulting in severe sequelae. Multidisciplinary management by specialists, in the emergency department, orthopedics, plastic surgery, vascular surgery, and rehabilitation, insisting on employing their own individual abilities as much as possible, would not only help to salvage limbs in severe extremity injuries but also provide highly satisfactory functional and aesthetic outcomes for patients.

Conflict of interest

The author declares that there is no conflict of interest regarding the publication of this chapter.

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