Extremity Injuries Including Replantation

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Frequency alone makes extremity injuries important; in addition, extremity wounds often pose serious threats to the livelihood or, at least, to the life style of the patient. Quantitation of this threat is very important in making decisions concerning management and will be discussed later in this section.

A problem in the management of trauma to the extremities (and indeed in preparation of a chapter on the subject) is that multiple organ systems are often involved in a single injury and each system may be considered the domain of a surgical specialty. Thus, one wound, including injury to bone, blood vessels, tendon and nerve, may require the expertise of orthopaedic, vascular, plastic and neurological surgeons. Practice in this regard varies considerably from one geographic location to another, but, to some extent, the segmented approach exists in most locations. Recognition of this problem underlines the need for a team concept in planning and executing the management of extremity injuries. It should be emphasized that one physician must be in charge of the over-all effort.

EVALUATION OF PATIENTS WITH EXTREMITY INJURY

The presence of injury to an extremity is usually relatively obvious but the cardinal principle in managing all patients is to determine the presence and severity of life-threatening associated injuries prior to focusing attention on the extremity. Active hemorrhage is the only manifestation of extremity injury that has a high priority in treatment, and this can usually be controlled by direct pressure while the possibility of head, chest and abdominal trauma is evaluated. Although fractures should be splinted early, the treatment of extremity injuries is properly subordinated to the management of trauma to life-supporting systems. When such injury has been managed or found not to be present, attention is properly turned to the extremity wound.

The evaluation (and treatment) of extremity injuries requires detailed knowledge of the anatomy and physiology of the involved organ systems. This is emphasized because the current curriculum in many medical schools, particularly in gross anatomy, does not adequately prepare the student to deal with extremity injuries. Such knowledge may well be more appropriately acquired in the post-doctoral segment of education; but, it must be acquired by those called on to treat patients with extremity wounds.

A systematic approach to the injured patient comprises six relatively distinct steps in management:

1. Treat immediate threats to life.
2. Obtain history.
3. Perform a physical examination.
4. Initiate appropriate measurements.
5. Order and interpret additional diagnostic tests.

The initial management of the multiply injured patient
is discussed earlier in this section and the reader is referred to page 218. The purpose of this step is to keep the patient alive long enough to reach Step Two.

The history initially obtained from a trauma patient is not the leisurely and complete medical history recorded for electively hospitalized patients although, ultimately, exactly the same information should be obtained. The immediately important questions are: (1) How did the injury occur; (2) when did the injury occur; and (3) was the patient's general condition prior to injury (including allergy and medication history)? How the injury occurred is important for at least two reasons. Knowledge of the mechanism of injury and patient-noted sequelae are helpful in forming an assessment of the severity of tissue damage and the likelihood of associated organ injury. Injuries involving great force and/or high velocity are more likely to involve extensive tissue injury. Equally important is some assessment of the extent of bacterial contamination and even of the type of contamination. Heavy contamination or the likelihood of particularly virulent organisms greatly influences the management of wounds in any location. A very good example of this is the human bite. When the wound occurred is as important as how it occurred. The increasing likelihood of infection when wound treatment is delayed has led to the general dictum that primary wound repair should not be performed in wounds more than 4 hours old. This is a rule to which exceptions may be made in both directions. Heavily contaminated wounds should not be closed primarily even if seen immediately after wounding. Again, the human bite is an example. On the other hand, wounds occurring when the skin was clean and the mechanism of injury did not involve heavy contamination may be successfully closed up to 8 hours after injury. Other factors enter this decision such as the vascularity of the anatomical area involved and the cosmetic or functional desirability of primary closure. It may be added that the time from wounding to closure includes time spent waiting in the hospital emergency room.

The initial questioning should disclose the presence or absence of major intercurrent illness. A history of allergy, particularly to medications, and knowledge of medication the patient is taking are clearly important.

Complete physical examination should be performed in all patients with extremity injury when the nature of injury leaves any doubt that multiple injuries may have occurred or when it seems likely that general anesthesia will be required for treatment. Complete physical examination involves removing all clothing. Both positive and negative findings should be very carefully recorded. During examination and evaluation, every effort should be made to avoid additional bacterial contamination of open wounds. Caps, masks, sterile gloves and instruments should be used by all personnel involved in the evaluation, and open wounds should be covered. The presence of extremity injury is usually not difficult to detect if the patient is examined. Furthermore, relatively accurate assessment of the extent of injury is possible by clinical methods. Unconscious patients, inebriated patients and small children present frequent exceptions to this generalization. The presence of skeletal injury is noted by eliciting pain on gentle longitudinal compression of each long bone area. Muscular or joint injury is determined by range of motion and active motion maneuvers. These are described in greater detail elsewhere. The presence of vascular injury is detected by distal color or temperature changes, inequality of distal pulses or the presence of penetrating wounds near major vessels. Neural injury is detected by both sensory and motor testing. It is important that the findings be documented and, if there is doubt about the validity of the examination, this also should be documented.

After examining the patient, provisions for measuring and recording a number of physiological values may be indicated. These measurements are not specific for extremity injury and therefore will not be further discussed here. They include such things as arterial blood pressures, central venous pressure, urine output, hematocrit, etc.

A large variety of ancillary diagnostic procedures may now be considered in dealing with extremity injuries. The Doppler instrument is helpful in rapid evaluation of circulation. The most useful additional diagnostic studies involve radiography and special radiographic procedures. The indications for special procedures such as arteriography will be discussed in the section dealing with arterial injury.

Treatment is perhaps the most important step in management and is the subject of the remainder of this section. Of course, treatment is not really a distinct step but begins with the initial contact and continues throughout the evaluation, measurements, etc.

PRINCIPLES IN MANAGING EXTREMITY TRAUMA

The goal in the treating of extremity injuries is restoration of normal function and appearance. In simple injuries, this is usually possible. As injuries become more complex and it is clear that return to normal function and appearance cannot be reasonably expected, decisions in regard to treatment become more complicated. In these situations, advice on treatment should be based on the answers to three questions. The first question is, "What result in function and appearance can reasonably be expected from the proposed management regimen?" Answering this question involves a good deal of knowledge about specific injuries and the healing characteristics of the many tissues that may be involved, as well as the potential results of reconstructive operations. In general, stabilization of bones is usually possible by primary or at least by secondary procedures including bone grafting. Methods of restoring circulation have become highly successful in the past 30 years. Management of muscle and tendon injuries is usually satisfactory, although management of multiple tendon injuries in the distal part of the upper extremity continues to pose problems which are discussed in the
section dealing with the hand. Most skin defects can be successfully dealt with by either primary or secondary procedures. The extremity injuries that are most likely to produce unsatisfactory results and are the most unpredictable are injuries to peripheral nerves.

The second question is, “What is involved in reaching this result in terms of hospitalization, immobilization, discomfort, loss of work, etc.?” This is basically an estimate of the cost of the proposed treatment to the patient, physiologically, emotionally and financially. Again, a good deal of knowledge about the specific procedures that are to be proposed, healing times, rehabilitative treatment, etc. is required in formulating an answer.

The third question is, “How do the answers to the first two questions relate to this specific patient?” Answers to the first two questions allow a management plan to be formulated based on an ideal patient for whom the proposed management regimen is important and who is physically and psychologically likely to tolerate it well. Age, intercurrent disease and the importance to the individual patient of the extremity involved are important in modifying the treatment plan. In general, the patient would be well advised to opt against lengthy procedures of questionable outcome in managing lower extremity injury, whereas a similar amount of time might well be invested in managing upper extremity injury. The final treatment plan should be weighed against the advisability of amputation. Amputation produces a highly predictable end result and is an option that is not available in areas other than the extremities.

In attempting to achieve the best possible end result, it is pertinent to look at those factors that influence success or failure. Perhaps the most important of these factors is the extent of the injury. This has been alluded to earlier. In the extremity, at the present time, the most critical injuries are those to peripheral nerves. Most other injuries in the extremities can be repaired with the expectation of an excellent degree of recovery. Joint injury is a second area in which repair by the best current techniques may result in less than satisfactory function. In considering the extent of injury, it is important that the severity of injury not be increased by maneuvers such as inappropriate movement of the patient, unsterile probing, and so forth.

The second factor (negative) in success is the development of infection. All open wounds must be considered to be contaminated to some extent. Prevention of further contamination in the process of management and steps taken to minimize the development of clinical infection are of paramount importance in determining the final outcome. Such steps include adequate preparation, adequate debridement, avoidance of foreign body, the use of antibiotics and appropriate decisions regarding secondary closure of wounds.

The third factor (positive) is the appropriate surgical repair of the injured structures. This includes adequate reduction of fractures, accurate suture of muscles and tendons, successful vascular anastomoses and careful approximation of wound edges to whatever extent this is possible and advisable.

The final factor is adequate follow up and rehabilitation, including physiotherapy, education of the patient, etc. An excellent anatomical result can be totally negated by failure to keep joints mobile, failure to appropriately splint the hand, and so forth.

In managing injuries that involve several organ systems, it is necessary to set some priority for repair. For mechanical reasons, if open fixation of bone is required, this should generally be done initially. This provides stability and avoids the possibility of re-injury of other repaired tissues. Vascular repair should follow.

If both arterial and venous injury are present, it is preferable to perform venous repair first. The importance of venous outflow in maintaining arterial flow is demonstrated experimentally in Figure 14-19. In addition, repair of veins before arterial repair lessens blood loss. When as many venous channels have been repaired as is technically feasible, arterial reconstruction is carried out. When arterial flow is re-established, brisk bleeding from injured muscles, subcutaneous tissue and skin can be expected. If a large wound exists, transfusion will almost certainly be required at this point. The timing of nerve repair is controversial. If accurate primary nerve anastomosis can be achieved without adding significantly to the risk to the patient, it is the wrffer’s opinion that this should be done. Magnification is extremely helpful in matching and accurately suturing nerve ends. If definitive primary repair is not done, the nerve ends should be loosely sutured to simplify subsequent reconstruction. Bone, sizable blood vessels and nerves undergo at least surface necrosis if exposed to air. For this reason these structures must be covered with soft tissue to permit continued function. Flaps of muscle, subcutaneous tissue or skin can be utilized for this purpose, with primary or delayed skin grafting of the resulting defect. Skin may be harvested at the original procedure and “banked” for several days before use.

Although minor injuries to the extremities can be appropriately treated in the Emergency Room, injuries involving tendon, nerve, vessel or bone should be repaired in the Operating Room. This long-standing advice may be modified if outpatient surgical facilities that maintain a high standard of contamination surveillance and are adequately equipped with lights, suction, etc. are available. Technical methods involved in treating specific extremity injuries are covered in other sections and will not be repeated here. (See sections related to fractures, hand and arterial injury). It seems appropriate to emphasize the role of buried sutures as foreign bodies and to suggest that their use be limited. The use of sterile adhesive strips for skin closure is well suited to many extremity wounds.

Systemic antibiotics are indicated when the wound is considered to be heavily contaminated, when a prolonged period of time between wounding and repair occurs and when significant foreign body is employed in repair.
Fig. 14-19. Experimental demonstration of the importance of venous occlusion on arterial flow. (From Barcia et al.: Am. Surg., 175:221, 1972)

![Graph showing arterial and venous blood flow over time with vein occlusion and release.]

Essential that adequate blood levels of antibiotic be achieved as close to the time of wounding as possible. Antibiotics given more than 6 hours after repair are not effective in reducing the incidence of wound infection. The selection of antibiotics is based on an estimate of the most likely contaminating organism. The use of topical antibiotics is controversial. The author favors their use but not as a substitute for careful preparation and adequate debridement.

Postoperative management is largely related to the detection and appropriate treatment of infection, and rehabilitative measures. If infection appears, early drainage and appropriate antibiotic therapy are indicated. Efforts to maintain and restore function by splints and physiotherapy are important in achieving maximally good results.

REPLANTATION

Surgical replantation of a totally severed human extremity was first successfully accomplished by Malt and Associates in 1962.9 Within a very short period, other successful replantation procedures were performed and a sizable literature on the subject has accumulated.6,7,10 It is clear that successful replantation after traumatic amputation can be performed and that the results in many instances are gratifying.

Replanting an amputated extremity involves the same surgical techniques and principles which have been enumerated in this section. Replantation has been successful at virtually all levels in the upper extremity and recently has been extended to the fingers. Hand and finger replantation will be considered in a separate section. Although digital replantation requires an operating microscope and expertise in microsurgery, replantation of the extremity at other levels can be performed by any well trained surgical team in any well equipped hospital.

Perhaps the most important consideration in replantation is proper selection of patients. This is not an exact process and will change as experience is recorded and particularly when improvements in managing peripheral nerve injury are forthcoming. It is the author’s opinion that lower extremity replantation should not be attempted except possibly in those rare instances in which both extremities are involved. The reason for this opinion is that the weight-bearing function of the lower extremity can be reasonably well replaced by a prosthetic appliance. An anesthetic, poorly controlled lower extremity is actually a liability to a patient and the prolonged morbidity required to achieve even this end result is not justifiable. Other factors in the selection process include the age of the patient, the nature of the injury, the level of injury, the extent of contamination and the psychological characteristics of the patient.

In general, best results with replantation procedures have been achieved in younger patients. This is probably due to a variety of factors, including better nerve regeneration. The prolonged morbidity and necessity for reconstructive procedures add to the hesitation in performing a limb replantation in an older patient.

The results of replantation improve as the level of amputation moves distally. This is due to the characteristics of nerve regeneration, as the easiest replantation technically is the upper arm where fewer but larger structures are involved.

The type of injury is a factor in selecting patients for replantation. Clean, sharp amputation is obviously the most favorable type of injury. Avulsion with long segments of nerve injury probably is a contraindication to attempting replantation (Fig. 14-20). The extent of contamination is also a factor, since infection in a replantation wound almost certainly spells failure of the attempt.

It should be recalled prior to attempting replantation that the procedure usually commits the patient to several subsequent operative procedures and a very long period of rehabilitation, principally physiotherapy. In instances where these are neither desirable nor possible, the initial attempt should not be made.
Fig. 14-20. A patient shortly after amputation of both arms. The long, avulsed segments of nerve are clearly visible and constitute a contraindication to attempted replantation.

A number of factors related to the individual patient should be weighed and these include the patient's age, occupation and psychological condition. Obviously, individuals whose livelihood depends on extremity function should be more seriously considered for replantation. Evidence of emotional instability should be weighed against attempting replantation, since the procedure and subsequent convalescence are indeed stressful. Unfortunately, questions of disability, compensation and secondary gain have greatly complicated replantation attempts after industrial accidents.

Replantation has been successful when circulation was restored as late as 18 hours after amputation. There is no strictly defined limit, however, and it is possible that extremities that have been cooled could be successfully replanted after longer periods. A practical limit would appear to be 12 hours. Because skeletal muscle is the first tissue in the extremity to be irreversibly damaged after amputation, theoretically the more distal amputation involving a minimum of skeletal muscle should be least affected by time. Improved emergency transportation services will permit patients in most areas of the United States to reach a medical institution capable of performing replantation well within 12 hours.

It is advisable to place the amputated extremity in a clean, preferably sterile, iced container as soon as possible after amputation. When the extremity reaches a medical facility, the circulation should be cleared by cannulating the artery and perfusing with chilled Ringer's lactate solution containing heparin and penicillin or other appropriate antibiotic. This maneuver is also helpful in identifying the ends of veins which can be tagged with fine suture. Perfusion probably has no value after the return solution is clear and should then be discontinued.

If the patient has no significant associated injuries and is considered an appropriate candidate for replantation, x-ray films of the cervical spine should be obtained in order to assess the possibility of neural avulsion.

The steps in replantation do not differ from those described in treating extremity injuries in general. The essential steps are illustrated in Figure 14-21. After copious irrigation of the wound and debridement of hopelessly damaged tissue, fixation of bone is carried out by whatever method is appropriate. Both intramedullary and plating devices have been used satisfactorily. It is essential, in the upper arm, to shorten the humerus by approximately 2 cm in the adult in order to permit suture of the muscles. This is probably true in the forearm as well. After bone stabilization and fixation is completed, the vascular system is reconstructed, beginning with the veins. At least two veins should be repaired for each major arterial trunk. Perfusion of the artery, using Ringer's lactate, is often very helpful in locating the distal vein ends. Failure to obtain satisfactory venous outflow has been the major cause of circulatory failure in attempted replantation. External Silastic venous shunts have been described. Profuse hemorrhage from all wound surfaces is to be expected when circulation is re-established, and blood should be available.
for transfusion. Cardiovascular collapse occurring when revascularization is completed has been mentioned in laboratory studies but has not been documented in humans.\(^5\)

The phenomenon is probably due to blood and fluid loss.\(^12\)

Acidosis has been reported after revascularization in a child.\(^10\) Suture of nerves and muscles and closure of skin complete the replantation procedure. The extremity should be placed in a well padded splint and elevated.

Postoperatively, swelling of the extremity is to be expected and is treated by mild elevation. Anticoagulants are not advised. Antibiotics should be started as soon as possible after injury and continued until it is clear that the risk of infection has subsided.

The initial physiotherapy is directed toward maintaining joint mobility, particularly in the fingers. Electrical stimulation of muscles is perhaps unproved but has been employed widely. Early repair of neural structures, if not performed at the original procedure, is advocated.

It should be emphasized that the functional result in extremity replantation should be compared with the function of prosthetic devices rather than normal extremity function. Using this criterion, more than one half of the reported cases of extremity replantation can be considered successful.

**ANNOTATED BIBLIOGRAPHY**


This was an early paper dealing with experimental aspects of limb replantation.


The original paper describing the first successful human limb replantation.


A careful followup of the largest series of limb replantations in the United States.


An extensive review of the relatively early literature relating to limb replantation.

**REFERENCES**


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**Head and Spinal Cord Injuries**

**Robert R. Smith, M.D.**

—Shouldst thou find that smash which is in his skull like those corrugations which form in molten copper and something therein throbbing and fluttering under thy fingers like the weak place of an infant’s crown before it becomes whole—thou shouldst say “an ailment not to be treated.”—The Edwin Smith Papyrus

Despair concerning severe head injuries, like that recorded above some 5000 years ago, prevailed until the early part of this century when the era of modern surgery began. Progress made in diagnostic skills, anesthesia, aseptic techniques, and surgical prowess has more than compensated for the increasing power and complexity of our tools and weapons. As a result, many more patients with severe head injuries have been able to leave the hospital and to become productive citizens. On the other hand, the reduction of mortality has also resulted in a large number of survivors crippled both mentally and physically.