Acute trauma to the upper extremity: what to do and when to do it

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The management of acute trauma to the upper extremity includes the urgent treatment of injuries and the timing and choice of surgical stabilization and reconstruction. To evaluate and treat severe upper extremity trauma, the orthopedic surgeon should understand the principles of the emergency department and operating theater management of commonly seen traumatic injuries to the distal humerus, elbow, forearm, wrist, and hand. A review of the principles for treating these complex injuries, including principles of soft tissue coverage, will aid surgeons in achieving the goal of providing optimal treatment for their patients.

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Introduction

The management of any trauma patient begins with the standard trauma survey [ABODE: airway, breathing, and circulation, followed by evaluation of the disability (assessed using the Glasgow Coma Scale) and exposure for adequate examination while prevention of hypothermia is maintained]. The purpose of the primary survey is the control and stabilization of life-threatening injuries [1]. The secondary trauma survey, consisting of a detailed examination of each body region for possible injury, is then conducted. Standard recommendations for identification of orthopedic injuries include plain radiographs of the injured region and the joints proximal and distal to it.

Debridement coupled with intravenous antibiotics and administration of tetanus toxoid is the most important initial treatment of severe open injuries. Debridement includes copious irrigation and removal of skin, subcutaneous tissue, muscle, fascia, and bone. It should be completed with careful inspection of the entire wound and the medullary canals and an evaluation of muscle viability. In severe situations, such as forearm and wrist amputations, skeletal shortening may facilitate revascularization or replantation.

Acute trauma to the humerus and elbow

Humeral shaft fractures

Fractures of the humeral shaft account for 1–3% of all fractures [2]. Indications for surgical treatment of such fractures include polytrauma, vascular injuries requiring surgery, open or segmental fractures, bilateral humeral fractures, floating elbow injuries, and most pathological fractures. Methods of fixation include plate osteosynthesis, intramedullary nailing, and external fixation. The management of open fractures of the humeral shaft is similar to that of open fractures of other long bones. Prompt surgical debridement, irrigation, intravenous antibiotics, and stabilization are the mainstay. There is controversy about the ideal form of fixation, with advocates of plate fixation and of intramedullary nailing [3–6].

Open reduction and internal fixation is the most acceptable form of surgical treatment. The surgical approach can be anterior, posterior, lateral, or medial. The anterior approach to the humerus is useful for the treatment of fractures of the proximal third of the humeral shaft, as well as for polytraumatized patients, because it is extensile and allows supine patient positioning for concurrent procedures with good access to the airway. The disadvantages of the anterior approach include limited access to the radial nerve if microscopic repair is required and difficult access to the distal part of the humerus. The posterior approach described by Gerwin *et al.* [7] allows good access to the middle and distal parts of the humerus with nearly full exposure of the radial nerve (Fig. 1). The limitations include the need for the lateral decubitus position and limited access to the humeral head and neck. In general, open reduction and internal fixation should be performed with a broad 4.5-mm dynamic compression plate with engagement of a minimum of six cortices, and ideally eight cortices, both proximal and distal to the fracture site.

Intramedullary nail fixation is also a viable option for treating acute humeral shaft fractures. The nail can be inserted antegrade through the proximal part of the humerus or retrograde through the apex of the olecranon fossa. Indications include burns, soft tissue compromise, highly comminuted fractures, obesity, and pathological fractures. The complication rate associated with intramedullary nails is slightly higher than that associated with plate osteosynthesis. These complications include nonunion, shoulder pain (after antegrade insertion), radial nerve injury, elbow stiffness (after retrograde insertion), and heterotopic ossification.

External fixation is not generally recommended as definitive treatment and is usually reserved for severely contaminated wounds or wounds with excessive soft tissue loss [8,9]. External fixation may be used to stabilize a humeral fracture rapidly, if required for vascular repair. The insertion of distal half pins should be carried out through a mini-open approach to protect the radial nerve against injury.

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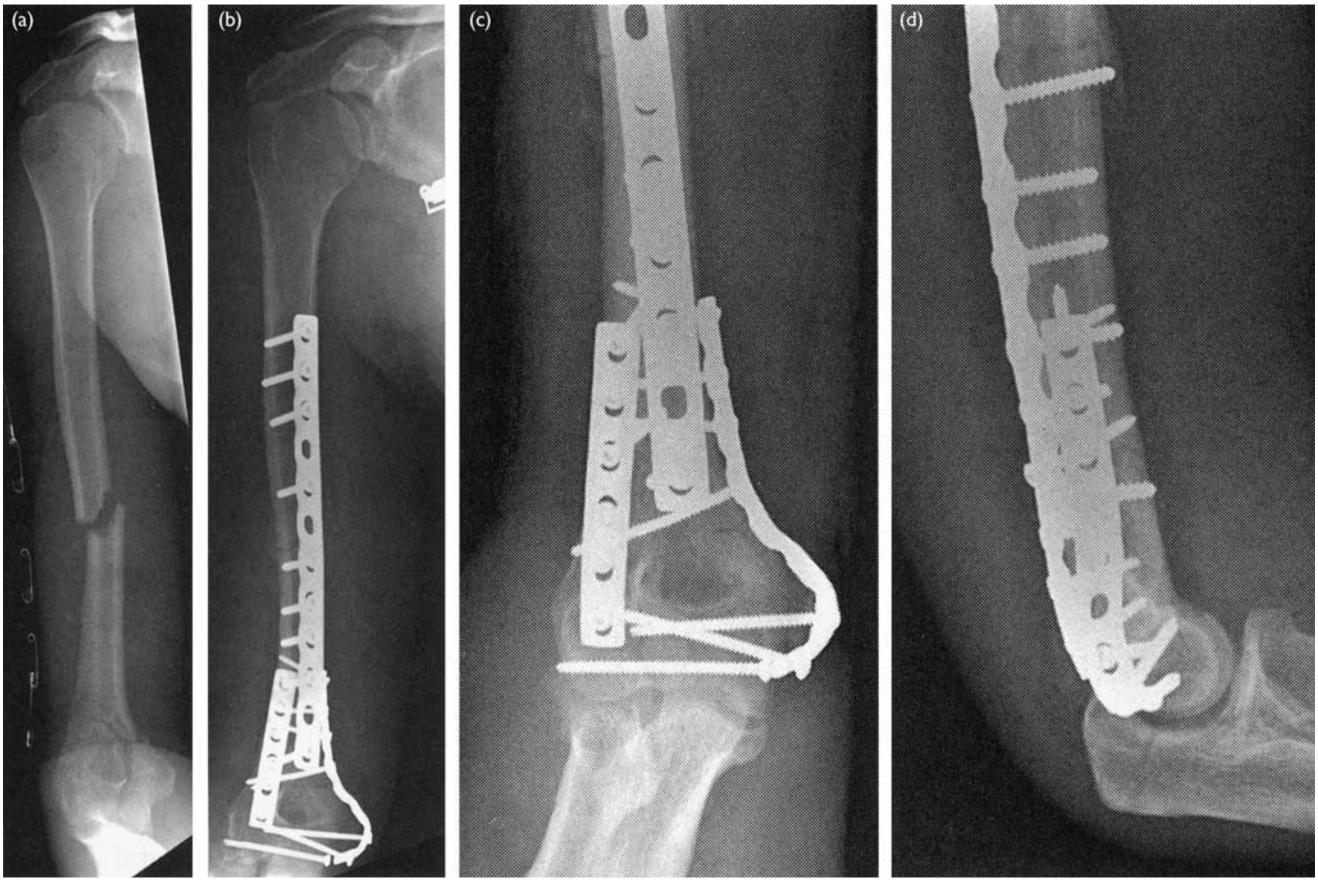
Figure 1



(a) An anteroposterior radiograph of a 45-year-old man who fell off a ladder and sustained a midshaft humeral fracture in association with a distal humeral intra-articular fracture. (b–d) A paratricipital approach extended to a posterior Gerwin approach allowed fixation of the distal humeral fracture with orthogonal 3.5-mm limited-contact dynamic compression plates and fixation of the humeral shaft with a 4.5-mm plate.

Concurrent injury to the radial nerve is frequently associated with humeral shaft fractures. The reported prevalence ranges between 2 and 17%, and management is controversial [2,10–14]. In general, when there is no indication for surgical intervention, the patient can be observed, with an expectation that more than 70% of radial nerve injuries will resolve. When there is an indication for surgical fixation of the humeral fracture, nerve exploration should be carried out in association with open reduction and internal fixation. When a patient can tolerate a lateral decubitus position, the posterior approach to the humerus and radial nerve, as described by Gerwin *et al.* [7], should be used. When there is a high risk of a nerve transection, such as in a patient with penetrating injuries or severe soft tissue loss, early nerve exploration is recommended. If the nerve is transected, a primary microscopic repair should be performed. When there is loss of a nerve segment, the humerus can be shortened for primary nerve repair. If the nerve is deemed irreparable, the ends should be tagged so that they can be found if nerve grafting is performed later.

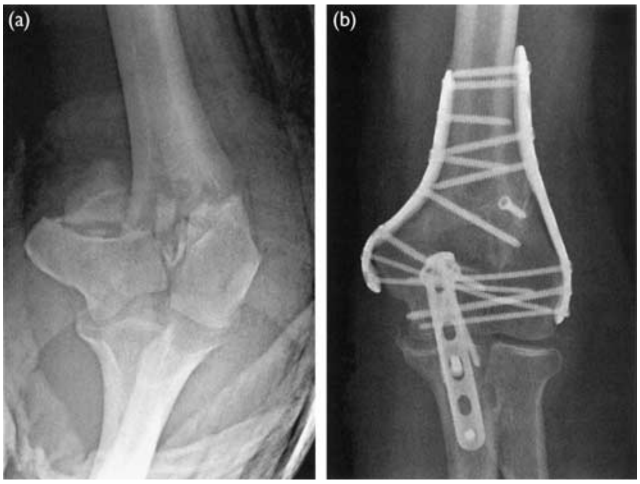
Distal humeral fractures

Distal humeral fractures remain one of the most challenging injuries to manage because they are commonly multifragmented, occur in osteopenic bones, and have a complex anatomy with limited options for internal fixation. In younger adults, these fractures are usually caused by higher-energy mechanisms. Although standard radiographs of the elbow are usually sufficient for diagnosis, a computed tomography (CT) with three-dimensional reconstructions improves the identification and visualization of fracture fragments.

Several surgical approaches have been described for exposure and fixation of distal humeral fractures. The available types of posterior approaches include olecranon osteotomy [15–17] and the paratricipital (triceps-on), triceps-splitting, triceps-reflecting, and triceps-dividing approaches [18–23]. The selection of the approach depends on how much articular visualization is required, the bone quality, the demand level of the patient, associated injuries such as triceps laceration, and whether the intraoperative decision is to proceed with arthroplasty as opposed to fixation.

Anatomical reduction and rigid internal fixation of displaced intra-articular distal humeral fractures provides stability for early range of motion. Patients who are medically fit and whose soft tissues are healthy may have surgery within 48–72 h after the injury [24]. A closed

Figure 2



Parallel plate fixation of an intra-articular distal humeral fracture through an olecranon osteotomy. Preoperative (a) and postoperative (b) radiographs.

distal humeral fracture in a multiply injured patient is splinted and treated after primary stabilization. Most surgeons prefer to perform definitive fixation within 2 or 3 weeks, but there are no data supporting this recommendation. When open reduction and internal fixation cannot be performed for several weeks, external fixation is recommended to stabilize the extremity to improve pain control and facilitate transfers, hygiene, and wound care. External fixator pins should be placed as far as possible from the planned internal fixation site to decrease the likelihood of infection.

Rigid fixation is obtained with orthogonal, parallel, or triple plates (Fig. 2) [25–28]. Under usual circumstances, devascularized bone is debrided, but large segments that include articular cartilage are not necessarily removed. The risk of infection associated with retention of the fragments must be weighed against the risk of post-traumatic arthritis, and all attempts should be made to preserve the articular cartilage.

Rigid fixation of the distal humeral fracture may not be possible in elderly patients with osteopenia, comminution, and/or articular fragmentation or in patients with a pre-existing elbow disorder such as rheumatoid arthritis. In these situations, total elbow arthroplasty is a viable treatment option [29–33].

Fracture-dislocations of the elbow

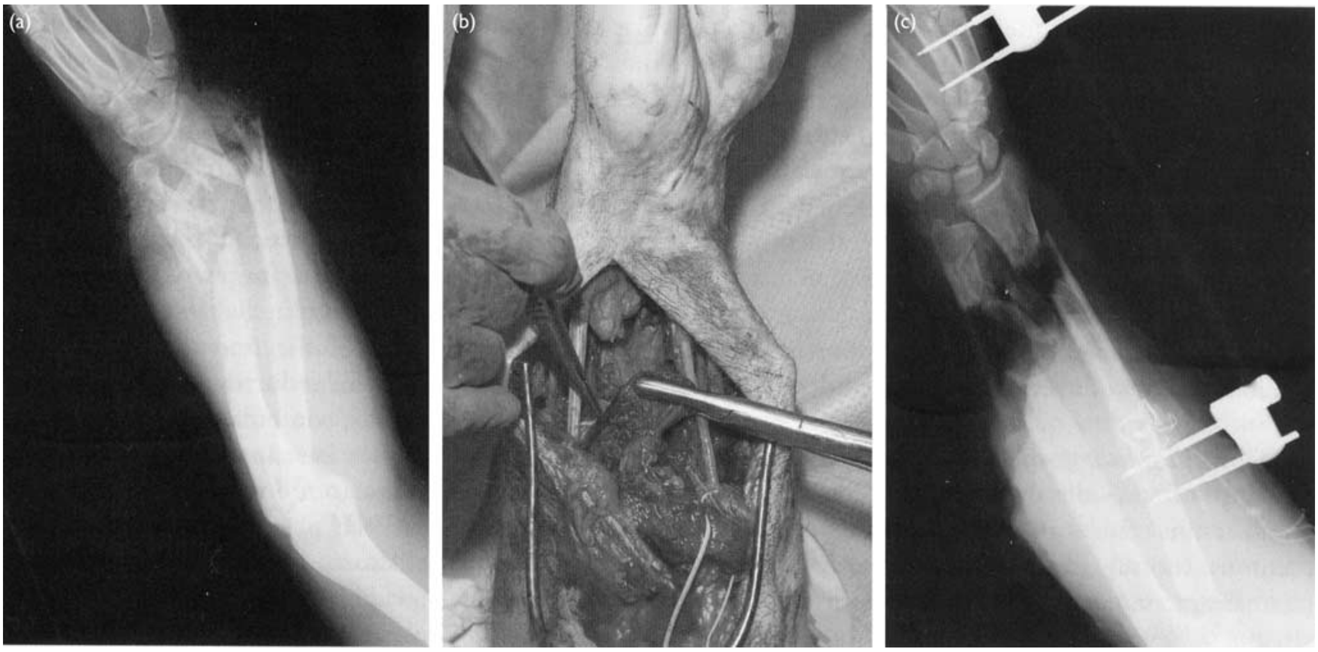
Fracture-dislocations of the elbow remain one of the most difficult and technically complex injuries to manage. These are loosely classified into three broad categories: terrible triad, Monteggia, and varus posteromedial injuries. The primary goal in managing these injuries is to stabilize the elbow to allow early motion. Failure to recognize complex elbow instability or to adequately stabilize the elbow leads to chronic instability, accelerated post-traumatic arthritis, or stiffness [34–41]. The ulnohumeral joint, the anterior bundle of the medial collateral ligament, and the lateral ulnar collateral ligament are the primary stabilizers of the elbow. The secondary stabilizers include the radial head, the joint capsule, and the common flexor and extensor origins. Imaging should include anteroposterior and lateral radiographs with CT to better identify fracture patterns, comminution, and displacement. The initial management of an elbow fracture-dislocation is closed reduction; this reduces pain and soft tissue swelling and allows more accurate radiographical interpretation. After the reduction, a repeat neurological and vascular examination is documented. The management of open elbow fracture-dislocations is similar to that of open distal humeral fractures. The definitive surgical management of terrible triad, Monteggia, and varus posteromedial injuries varies. Most elbow fracture-dislocations require surgical management. When a patient has multiple traumatic injuries that include a closed elbow fracture-dislocation, the elbow fracture-dislocation should be reduced provisionally, followed serially to ensure continued alignment, and treated after the patient's condition has stabilized. When definitive stabilization will be delayed for several weeks, static external fixation is recommended if the elbow displays instability.

Surgical management of an elbow dislocation with associated fractures of the radial head and coronoid, the so-called terrible triad, requires fixation of the osseous structures and repair of the ligaments. Fractures of the radial head should be internally fixed or the head should be replaced, depending on the specific characteristics of the fragments. All coronoid fractures, other than small tip fragments, require open reduction and internal fixation or suture fixation if they are comminuted. After osseous stability is achieved, the lateral ulnar collateral ligament is repaired, and the elbow is examined for stability. If the elbow remains unstable, the anterior bundle of the medial collateral ligament is repaired. In the exceedingly rare circumstance that the elbow remains unstable after anatomical open reduction and internal fixation and ligament repair, a temporary dynamic or static external fixator may be used.

The ulnar fracture of the Monteggia injury is treated with rigid open reduction and internal fixation, which usually stabilizes the radiocapitellar joint. When there is a fracture of the radial head, it is treated with open reduction and internal fixation, radial head arthroplasty, or partial excision, depending on the characteristics of the fracture. If there is a coronoid fracture, anatomical and rigid fixation is required to recreate the anterior buttress of the ulnohumeral joint.

Varus posteromedial instability is caused by a coronoid fracture with an avulsion of the lateral collateral ligament. Repair of these injuries usually requires both a medial and a lateral approach to the elbow: a posterior skin incision can be used to achieve both medial and lateral exposure. The medial approach is used to repair a fracture that involves the anteromedial aspect of the coronoid, and the lateral approach is used to repair the lateral collateral ligament.

Figure 3



(a) A radiograph of open radial and ulnar fractures with ischemia and severe soft tissue injury. (b) Debridement of the injury. (c) Provisional external fixation to allow revascularization.

Acute trauma to the forearm, distal part of the radius, and distal radioulnar joint

Adult forearm fractures

Adult forearm fractures include a fracture of the radius or ulna alone or a fracture of both these bones. The accepted treatment of fracture-dislocations such as a Monteggia fracture-dislocation (fracture of the ulna and dislocation of the radial head) and a Galeazzi fracture-dislocation (fracture of the radius and dislocation of the distal radioulnar joint) is open reduction and internal fixation [42–46]. Nonsurgical treatment is rare, but it can be used for a closed, minimally displaced (middle-to-distal) ulnar shaft fracture [47,48].

As is the case for all fractures, treatment of forearm fractures includes management of the soft tissue injury and restoration of skeletal alignment. If there is an open wound after debridement, open reduction and internal fixation of the radius and ulna is performed either through the traumatic wound or through a separate incision. A separate exposure for each bone is recommended to minimize the risk of radioulnar synostosis [49,50]. External fixation should be considered when the wound is contaminated or the soft tissue injury is extensive (Fig. 3). When there is an arterial injury with ischemia, stabilization (ideally definitive fixation) should be performed quickly, with temporary arterial shunting used to perfuse the distal part of the limb if necessary.

The volar (Henry) approach is used to expose the flat surface of the radius [51]. The dorsal Thompson approach allows exposure but is associated with a risk of injury to the posterior interosseous nerve [52]. The ulna is exposed through the interval between the extensor carpi ulnaris and the flexor carpi ulnaris. Attention to the radial length and radial bow (which should be $\sim 12^\circ$) and the proximal ulnar varus bow (which should be $\sim 9^\circ$) and ulnar variance is key [53]. Rotational malalignment is avoided by reduction and provisional fixation, followed by an examination of the forearm rotation [53–55]. Open reduction and internal fixation with a 3.5-mm limited-contact dynamic compression plate provides balanced fixation with compression across the fracture with three bicortical screws on either side of the fracture. Locking plate fixation is recommended for osteoporotic bones, periarticular fractures, and fractures with segmental bone loss. Malleable reconstruction plates and partial tubular plates should not be used for diaphyseal forearm fractures because they routinely fail and break. The bones with the more easily reduced fractures should be reduced and fixed first. This makes the complex fracture easier to reduce. Radiographs of the contralateral extremity may provide a helpful 'intact' template for reference when one is dealing with severely comminuted fractures.

When a patient has a distal radial or ulnar shaft fracture, stable fixation of the smaller periarticular fragments may be obtained with the use of locking plates, nonlocked minifragment (2.7-mm) plates, or combination plates. Segmental fractures and comminution may be managed with bridge plate or locking plate techniques. Segmental fractures may be treated with two plates placed at 90° to one another, ideally with the plates overlapping by a minimum of two screw holes, with interdigitating screws.

When an incision is not prudent, particularly at the distal diaphyseal (or metaphyseal–diaphyseal) area of the ulna, percutaneous intramedullary fixation is considered to provide stability with minimal dissection of the soft tissues [56]. Finally, external fixation may be used temporarily, or definitively, when needed for a severely contaminated wound [57,58].

Bone defects may be treated using a cancellous or corticocancellous iliac crest bone graft alone if they are less than 6 cm in length and are located within a vascularized and clean wound [17,59]. Larger defects should be filled with autogenous or allogenic cancellous bone grafts. When the soft tissues are compromised, as a result of trauma, prior irradiation, or infection, a vascularized cortical graft is preferred [60]. Acute bone grafting of simple or comminuted fractures remains controversial because it has not been shown to increase the rate of union [44,61]. Delayed grafting is preferable if the soft tissues are compromised. Space for a subsequent graft may be maintained by using antibiotic-impregnated bone cement [62]. Synostosis is a risk after the bone graft is used, and the graft needs to be kept away from the interosseous membrane to reduce this risk. When the injury is severe because of ischemia or crush, particularly with a segmental injury about the wrist, forearm, or elbow, amputation should be considered. Replantation or revascularization can often be performed but may not be appropriate if there is poor myotendinous function, joint contractures, or an insensate extremity. When a forearm-level amputation is necessary, every attempt should be made to preserve the elbow joint and sufficient forearm length and tissue to facilitate the use of prosthesis.

Distal radioulnar joint

Stability of the distal radioulnar joint results from osseous, ligamentous (dorsal and volar radioulnar ligaments), and capsular constraints [63–69]. When the patient has a fracture with an associated distal radioulnar joint injury, the radius and/or ulna are stabilized first, then the distal radioulnar joint is evaluated [46,70]. When the distal radioulnar joint is reduced and stable, it is treated with a splint, with the forearm in either neutral rotation or in supination. When the distal radioulnar joint is unstable, several types of treatments have been recommended [46,71–73]. These include fixation with two 0.062-inch (0.16-cm) Kirschner wires placed just proximal to the distal radioulnar joint across all four cortices (to facilitate removal if they break), external fixation cross-bridging the radius and ulna, or suture repair of the foveal insertion of the distal radioulnar ligaments [74].

Ulnar styloid fixation and foveal repair may be completed at the same time through an ulnar incision using a Kirschner wire and tension band, cannulated screws, or a simple suture technique. In general, ulnar styloid fractures do not require fixation unless the distal radioulnar joint is unstable [75,76]. When the distal radioulnar joint is unstable in the setting of an intra-articular distal radial fracture, the volar and dorsal lunate facet fragments must be reduced because they are attached to the radioulnar ligaments. The most common reason why the distal radioulnar joint cannot be reduced (provided that the radial fracture is reduced) is entrapment of the extensor carpi ulnaris, the triangular fibrocartilage complex, the extensor tendons, and the ulnar styloid [77–81].

High-energy distal radial fractures

High-energy distal radial fractures include extra-articular and intra-articular fractures caused by impaction, shearing, or bending loads. Although, in the past, shortening of up to 5 mm and articular displacement of up to 2 mm have been accepted in the alignment of distal radial fractures, Ruch [82] recommended a more anatomical goal for young, active adults, with an articular step-off of less than 2 mm, radial shortening of less than 2–3 mm, and neutral tilt. CT imaging of intra-articular fractures provides a better understanding of fragment size and position to aid in treatment decisions.

There are several options for stabilizing these fractures, but there are insufficient data to indicate that one type of fixation is superior. Combined external fixation and percutaneous pin fixation has advantages, but its precise role is not clear. Associated complications include pin site infection, complex regional pain syndrome, stiffness, and malunion [83–89]. The best anatomical results are possible with open reduction and internal fixation, and an early return to function may follow [90]. The current trend of volar plate fixation (with distal locking screws or pegs) is supported by numerous reports of good outcomes, but most studies have not substantiated if the overall long-term function is improved [91–95]. Complications include flexor and extensor tendon ruptures and subchondral screw penetration [91,95]. Dorsal plates are quite stable but their use is associated with many complications [96]. Fragment-specific fixation with the use of separate pin–plate constructs for the volar, radial, and dorsal aspects of the fracture are powerful tools for reduction and stabilization. Finally, combinations of these techniques based on the fracture type and comminution may be required. Volar plates take advantage of an anatomical recess at the pronator quadratus fossa for plate placement, minimizing the approach to the area of comminution dorsally [92,93]. During the reduction of these displaced fractures, the brachioradialis tendon may be released through the flexor carpi radialis approach [94], which removes a deforming force and thus improves the reduction. Reduction of intra-articular fractures proceeds with reduction of the volar ulnar cortex, and then the dorsal lunate facet and the radial styloid. Subchondral Kirschner wires may be placed through Kirschner wire holes in the plate to maintain the reduction. They are later replaced with locking pegs to secure the articular reduction. Limitations of this approach include an inability to visualize the interosseous ligament injuries and articular surfaces. Distal and ulnar fracture fragments are also difficult to stabilize because the plate and peg construct does not support or penetrate these small fragments. The volar marginal fracture occurs at the volar ulnar aspect of the distal part of the radius. It is important to identify and treat this intra-articular fracture because the radiocarpal ligaments are attached to the fragment, and the lunate will subluxate or dislocate volarly if the fracture is displaced [97]. Fragment-specific fixation works well for these relatively small fragments, as do Kirschner wire fixation and tension band techniques [98,99]. Severely comminuted fractures or those with volar and dorsal comminution may require adjunctive external fixation.

When an unstable distal ulnar fracture accompanies a distal radial fracture and remains unstable after fixation of the distal part of the radius, the ulnar fracture should be stabilized with a condylar blade plate or a locking plate [17,100]. For severely comminuted and unstable distal radial fractures (especially those associated with multiple trauma), a 3.5-mm distraction plate may be used as an 'internal external fixator' to stabilize the wrist with a temporary 'wrist fusion'; this plate, spanning from the radius to the long finger metacarpal, is used to distract the severely injured and comminuted metaphyseal–diaphyseal area of the radius [101]. The plate is removed after fracture healing, or at ∼12–16 weeks.

Distal radial fractures and soft tissue injuries may be so severe that acute salvage with a wrist arthrodesis or arthroplasty may be the best treatment [102]. Kafury *et al*. [103] and Richards and Roth [104] recommended that proximal row carpectomy, with provision of bone graft, decompression of the ulnocarpal joint, and shortening, be used to facilitate fusion in patients with severe injuries, such as those involving tendon, nerve, or arterial injury.

Acute trauma to the wrist and hand perilunate dislocations and acute carpal tunnel syndrome

Perilunate fracture-dislocations are generally caused by a high-energy injury [105]. However, there is a subset of these injuries that involves primarily ligamentous disruption, which is often missed without a high index of suspicion [106]. Perilunate dislocations usually involve a combination of osseous and soft tissue injuries, with subtypes rated using the Mayfield classification [107]. Perilunate injury follows a predictable pattern, beginning on the radial side of the wrist with either the scaphoid or the scapholunate ligament, proceeding in an ulnar direction through either the carpal bones or the intercarpal ligaments, and culminating with Mayfield stage IV (complete volar dislocation of the lunate).

A perilunate fracture-dislocation requires urgent reduction, either open or closed, because of the risk of acute carpal tunnel syndrome. Reduction of the dislocation relieves pain and allows a more accurate radiographical assessment. Reduction is usually obtained in the emergency department with the use of finger traps, with 10 Ib (4.5 kg) of traction applied for 10–15 min. The authors of this chapter recommend this type of reduction even for an open injury, unless the patient can be taken to the operating room urgently. The wrist is gently dorsiflexed while the physician's thumb maintains pressure on the lunate. Volar flexion should then allow the capitate to be reduced onto the lunate, and a palpable clunk should be felt with reduction. If the lunate is dislocated, it must first be reduced back onto the radius before the intercarpal reduction is performed [107].

Acute carpal tunnel syndrome is a substantial risk, particularly in a patient with a volar dislocated lunate type of perilunate injury in whom carpal tunnel compression is caused by direct pressure on the nerve. Fractures of the distal part of the radius are the most common cause of acute carpal tunnel syndrome, and differentiating median nerve contusion from acute carpal tunnel syndrome is critical when deciding whether acute carpal tunnel release in a patient with a traumatic injury to the wrist is necessary. A patient with a median nerve contusion generally develops nonprogressive sensory changes immediately after the injury, whereas the sensory changes in a patient with acute carpal tunnel syndrome develop later and are associated with worsening pain [108,109]. Although Semmes–Weinstein monofilament tests and measurements of intracarpal canal pressure can be used to diagnose acute carpal tunnel syndrome, the diagnosis is usually based on the history. When an acute carpal tunnel syndrome is diagnosed, immediate surgical release of the transverse carpal ligament is indicated, with an extensile volar incision crossing the wrist crease, allowing full visualization of the nerve during decompression [108].

If a perilunate fracture-dislocation is associated with acute carpal tunnel syndrome, decompression of the carpal canal is the first surgical priority and should be performed urgently. Definitive stabilization of the perilunate injury can be performed at the same time, or provisional pinning can be performed with surgery planned later (optimally within 3–5 days) for definitive stabilization. Definitive surgery for a perilunate injury includes fixation of the scaphoid and other carpal bones if necessary, fixation of the radial styloid if indicated, and ligament repair. Some advocate a single dorsal approach for definitive treatment, with repair of the scapholunate ligament, the lunotriquetral ligament, and the torn dorsal capsular ligaments [110,111]. Others recommend a combined dorsal and volar approach to directly repair the stout volar ligaments [106,112–114]. Perilunate injuries represent substantial trauma to the articular cartilage of the carpus and wrist, and sequelae of stiffness and subsequent arthritic changes are not uncommon [112,115].

Radiocarpal dislocation

Another type of high-energy injury is dislocation of the radiocarpal joint, which is mainly a ligamentous injury. Commonly, this is a dorsal dislocation, usually with avulsion of the cortical margin of the distal part of the radius [116–118]. Moneim *et al*. [119] classified these injuries on the basis of the presence or absence of intercarpal instability, whereas Dumontier and associates [117] subdivided radiocarpal dislocations on the basis of the size of the associated radial styloid fracture.

Initially, these injuries can be treated with closed reduction and splinting. Six of the 12 patients in the study by Mudgal *et al.* [118] had sensory impairment at presentation, and these resolved after reduction. Radiocarpal dislocations are often open and require acute stabilization but even a closed injury should be stabilized within 7 days. The radial styloid fracture is reduced and fixed. Mudgal *et al.* [118] treated their patients with an elevation of the articular rim fragments, a bone graft to fill any defect, a buttress plate fixation in some cases, repair of the ulnar styloid, suture repair of the palmar radiocarpal capsule, and scapholunate repair, as needed.

High-energy axial carpal, carpometacarpal, and metacarpophalangeal joint fracture-dislocations

Severe traumatic injuries to the carpus and hand involve both soft tissue and bone. One of the most dramatic of these injuries is axial carpal dislocation, which is caused by a force of injury transmitted through the hand, splitting it into the radial and ulnar columns [120]. Treatment of this type of 'exploded hand' often requires several surgeries, with initial debridement of open wounds and provisional pinning of the carpus and metacarpals. An external fixator placed across the wrist can be used if needed to obtain stability. This is followed by repair of the fractures; reconstruction of the intercarpal and intermetacarpal ligaments, with supportive pinning, and soft tissue reconstruction [121].

Injuries of the carpometacarpal joints are divided into two groups: those of the thumb carpometacarpal joint and those of the other carpometacarpal joints. An isolated thumb carpometacarpal joint dislocation without a fracture is rare and generally is caused by a high-energy injury or occurs in an individual with hyperlaxity. When this injury is acute, it can be reduced and then temporarily held in a splint, but it often requires the reconstruction of the anterior oblique ligament as described by Eaton and Littler to achieve definitive stability [122,123]. A Bennett-type fracture-dislocation of the thumb carpometacarpal joint is more common and can be treated with closed methods, if it is minimally displaced, percutaneous Kirschner wire pinning, or miniscrews to fix the metacarpal shaft to the volar ulnar fragment [124].

Injuries to the other carpometacarpal joints of the hand are most common at the bases of the fourth and fifth metacarpals as these joints are less intrinsically stable compared with the second and third carpometacarpal joints. Dislocations are usually dorsal and are sometimes associated with fractures of the articular base of the metacarpal. These dislocations are easily missed on standard radiographs, especially when there is a small amount of subluxation. A pronated oblique radiograph of the hand should be obtained if an ulnar-sided hand injury is suspected. When acute, these injuries can be reduced and splinted and then treated within 7–10 days with percutaneous Kirschner wire fixation or application of small screws and plates as needed [125,126].

Metacarpophalangeal joint dislocations are seen after high-energy injuries and often occur in the index finger. A single attempt at a closed reduction is recommended, but these injuries are often irreducible and generally require open reduction. Closed manipulation is performed with the wrist flexed to relax the flexor tendons. The metacarpophalangeal joint is then flexed, whereas the proximal phalanx is pushed dorsally. Metacarpophalangeal joint dislocations are frequently irreducible because of interposition of the volar plate between the proximal phalanx and the metacarpal head, and open reduction is performed through a dorsal incision, with incision of the extensor hood and capsule to expose the volar plate tented over the metacarpal head. The volar plate is released, and the joint is then reduced. The fractures are fixed as needed. Approximately 50% of these injuries are associated with an osteoarticular fracture fragment [127].

Management of soft tissue injuries of the upper extremity

The spectrum of traumatic soft tissue injuries of the upper extremity is vast, ranging from closed soft tissue injuries (such as compartment syndrome) to composite soft tissue and bone loss (amputations and segmental defects) to soft tissue loss alone (degloving and avulsion-type injuries). Discussion of the management of every type of soft tissue injury of the upper extremity is nearly impossible because of the tremendous variations in the types of injuries, the varying degrees of energy imparted to the injured arm, and the numerous mechanisms of injury. However, a key understanding of the principles of treatment of soft tissue injuries can guide a surgeon in choosing the optimal treatment of such injuries of the upper extremity. An outline of the eight basic principles of soft tissue reconstruction that can be applied to upper extremity injuries follows.

Principle 1: prevent further injury

Further injury to the upper extremity must be prevented. After determining the mechanism of injury, it is necessary to ascertain whether compartment syndrome may be an issue or whether a chemical burn must be neutralized [128]. Treating burns or frostbite injuries may be necessary.

Principle 2: achieve adequate debridement

An aggressive tumor-like debridement of all necrotic and nonviable tissue, including bone, is essential [129]. This is often considered the most important single step in the management of soft tissue injuries related to trauma. Appropriate cultures of contaminated tissue should be performed to guide the antibiotic treatment. Reconstructive plans should not impede an adequate soft tissue debridement. Repeat debridements should be performed every 24–48 h, as dictated by the wound and the patient's medical status.

Principle 3: stabilize bone

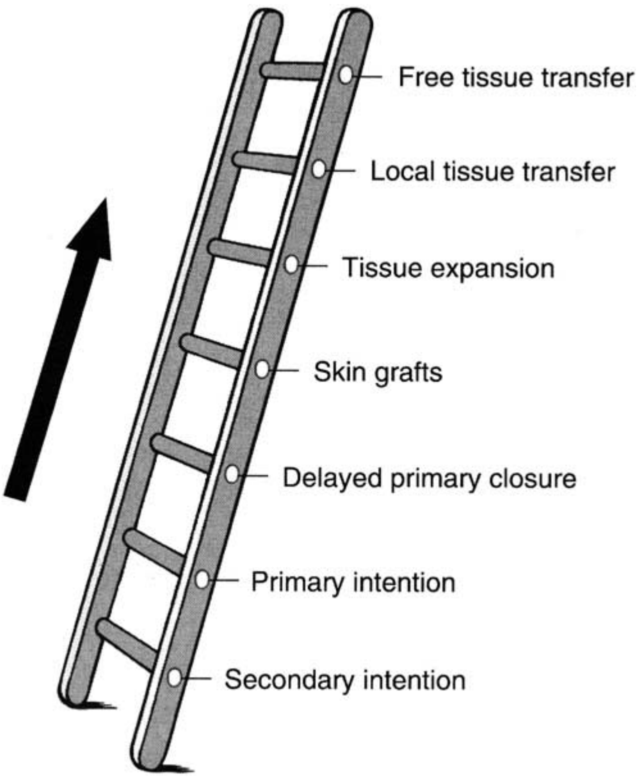
Once adequate debridement of soft tissue and bone has been accomplished, bone stability should be achieved.

This can be performed using external fixation or internal fixation, or both. External fixation is often preferred for highly contaminated wounds or wounds that have poor soft tissue coverage. Internal fixation can be used for adequately debrided wounds that have good soft tissue coverage of bone.

Principle 4: achieve soft tissue coverage

When soft tissue coverage is needed, acute coverage should be considered. Levin's reconstructive ladder identifies the simplest type of soft tissue reconstruction procedure needed to cover a wound, with the procedures increasing in complexity as needed [130,131]. At the lowest level of the reconstructive ladder is healing by secondary intention, whereas free tissue transfer is at the highest level (Fig. 4). When the wound is evaluated to determine the possible options for coverage, it is imperative to consider patient factors; the genesis of the defect; the location, size, and depth of the defect; the exposed structures; the structures needing reconstruction; the degree of contamination; and the quality of the surrounding tissues. All of these factors play a role in the decision.

Figure 4



An illustration showing the reconstructive ladder.

Godina [129] popularized the concept of covering wounds within 72 h. However, with advances in wound management with vacuum-assisted closure devices and antibiotic bead pouches, wound coverage can be performed more than 72 h after the injury without untoward complications [132].

Principle 5: determine possible secondary reconstructive procedures

It is necessary to determine what secondary reconstructions will be needed before the time of the soft tissue coverage and the initial reconstructive procedure. If nerve grafts will be needed, the vascular pedicle of the free flap should be placed as far away from the nerve graft sites as possible. If bone grafting (vascularized or conventional) or tendon procedures are to be performed, it must be decided how these will be accomplished so that the pedicle is properly placed.

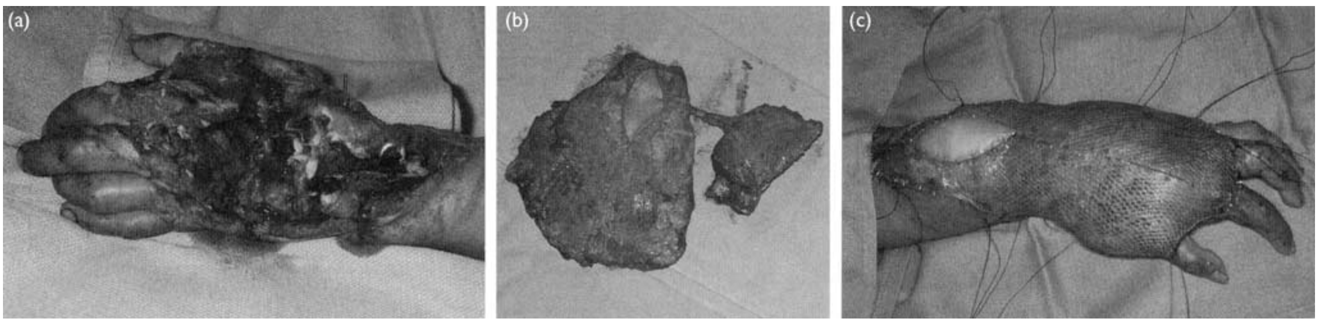
Principle 6: consider composite soft tissue reconstruction

Composite soft tissue reconstruction should be considered when there is soft tissue loss (Fig. 5). A toe-to-thumb transfer is one such composite flap.

Principle 7: evaluate amputation versus limb salvage

An amputation may be better than limb salvage. This is especially true in patients requiring a high amputation in whom replantation is potentially associated with myoglobinuria, reperfusion injury, and systemic sequelae, all of which can place the patient at great risk. Although technically feasible, heroic efforts to reconstruct parts can lead to long recovery times with a prolonged loss of

Figure 5



A composite flap reconstruction of the dorsal part of the hand with a combination of the latissimus dorsi, the serratus anterior, and two ribs on a combined thoracodorsal pedicle. (a) The soft tissue and bone defect; (b) the free composite flap; (c) placement of the flap.

gainful employment and manifestation of psychological problems.

Principle 8: seek advice

One should not hesitate to get assistance and advice. This is the most humbling of the principles but can be one of the most important. Collaboration with other surgeons may be extremely helpful in difficult cases.

Summary

The treatment of severe upper extremity injuries begins with standard trauma algorithms and debridement of devitalized soft tissue. The timing of osseous stabilization varies and is dependent on the quality and integrity of the soft tissue envelope. A collaborative approach often represents the best care for the traumatized patient.

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Conflicts of interest

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