Review Article

Terrible Triad Injury of the Elbow: Current Concepts

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Abstract

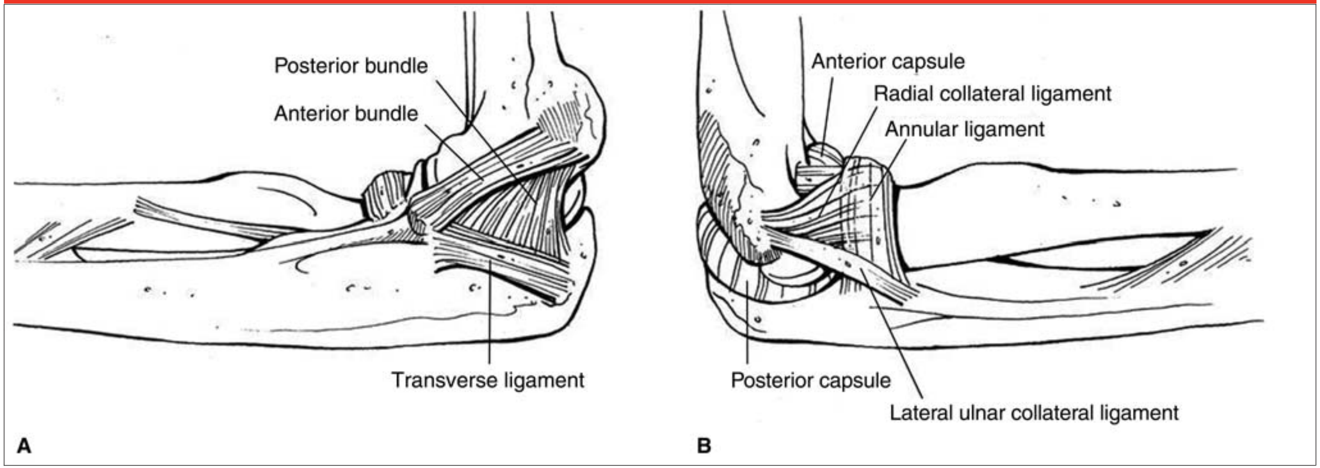
Fracture-dislocations of the elbow remain among the most difficult injuries to manage. Historically, the combination of an elbow dislocation, a radial head fracture, and a coronoid process fracture has had a consistently poor outcome; for this reason, it is called the terrible triad. An elbow dislocation associated with a displaced fracture of the radial head and coronoid process almost always renders the elbow unstable, making surgical fixation necessary. The primary goal of surgical fixation is to stabilize the elbow to permit early motion. Recent literature has improved our understanding of elbow anatomy and biomechanics along with the pathoanatomy of this injury, thereby allowing the development of a systematic approach for treatment and rehabilitation. Advances in knowledge combined with improved implants and surgical techniques have contributed to better outcomes.

Elbow dislocations are categorized as simple or complex. A simple dislocation of the elbow is a capsuloligamentous injury with no fractures; a complex dislocation has associated bony injuries. A complex elbow dislocation with associated radial head and coronoid process fractures was named the terrible triad by Hotchkiss[1] because of historically poor outcomes. Despite the complexities of this injury, an understanding of the relevant anatomy and the factors associated with elbow stability allows the application of a systematic algorithm for treatment. This approach can help ensure that sufficient elbow stability is achieved to allow early motion, thereby leading to improved outcomes in most patients. However, despite the best attempts at reconstruction, even in those experienced with treating these injuries, the final outcome may be fair or poor, according to reporting of several clinical series.[1,2] Further research is required to improve the outcomes of these serious injuries.

Anatomy

The elbow consists of bones, ligaments, tendons, and muscles that interact to allow for a stable, pain-free arc of motion. An understanding of the specific anatomy of these structures is paramount to the successful treatment of terrible triad injuries. The proximal ulna consists of two facets, the greater sigmoid notch and the lesser sigmoid notch (ie, radial notch). The greater sigmoid notch articulates with the trochlea, whereas the lesser forms an articulation with the radial head as the proximal radioulnar joint.[3] The coronoid process provides an important anterior and varus buttress to the elbow joint. It consists of a tip, body, anterolateral facet, and anteromedial facet. At the inferomedial border of the anteromedial facet, the sublime tubercle is the

Figure 1



Anatomy of the medial **(A)** and lateral **(B)** collateral ligaments of the elbow. (Reproduced from Tashjian RZ, Katarincic JA: Complex elbow instability. *J Am Acad Orthop Surg* 2006;14:278-286.)

insertion site for the anterior bundle of the medial collateral ligament (MCL).[3] On the lateral aspect of the proximal ulna, distal to the lesser sigmoid notch, the lateral ulnar collateral ligament (LUCL) inserts on the supinator crest.[4]

The radial head is a slightly elliptical structure that articulates with the capitellum and the lesser sigmoid notch of the proximal ulna. Hyaline cartilage covers both the articular dish and most of the articular margin. With the forearm in neutral rotation, the lateral portion of the articular margin of the radial head is devoid of hyaline cartilage. This lateral portion of the radial head, which is devoid of articular cartilage, does not articulate with the capitellum or the proximal ulna. The radial head provides an important anterior and valgus buttress to the elbow.

In addition to the bony supporting structures, several soft-tissue structures require consideration in the treatment of terrible triad injuries. The lateral collateral ligament (LCL) consists of the radial collateral ligament, the LUCL, and the annular ligament.[5] As noted, the LUCL originates at an isometric point on the lateral epicondyle and attaches to the supinator crest of the proximal ulna. The annular ligament attaches to the anterior and posterior margins of the lesser sigmoid notch. The radial collateral ligament originates from the lateral epicondyle and fans out to attach to the annular ligament (Figure 1). The LCL functions as an important restraint to varus and posterolateral rotatory instability.[6,7]

The MCL consists of an anterior bundle, posterior bundle, and transverse ligament. Of these, the anterior bundle is of prime importance in elbow stability (Figure 1). The anterior bundle originates from the anteroinferior aspect of the medial epicondyle, inferior to the axis of rotation, and inserts on the sublime tubercle at the base of the coronoid process. The MCL functions as an important restraint to valgus and posteromedial rotatory instability.[8,9]

The muscles and joint capsule also provide stability to the elbow. The anterior capsule attaches a few millimeters distal to the tip of the coronoid process and is typically torn in simple dislocations of the elbow.[10] Secondary constraints to elbow stability are provided by the flexor pronator mass, which arises from the medial epicondyle, and the common extensor origin, which arises from the lateral epicondyle. Together, these structures dynamically stabilize the elbow against valgus and varus forces, respectively.[11]

Biomechanics

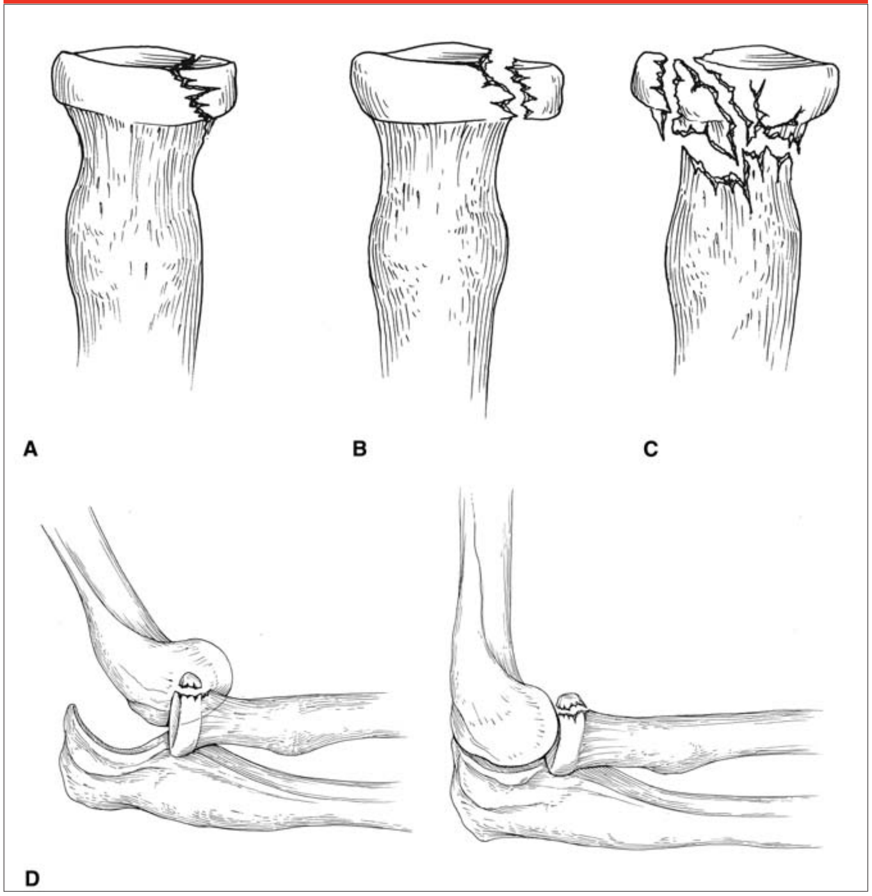
The anatomic features of the elbow that contribute to stability have been examined in various studies and can be divided into two main categories: primary and secondary. The primary stabilizers of the elbow are considered to be the ulnohumeral articulation, the MCL, and the LCL. The secondary stabilizers include the radial head, joint capsule, and the common flexor and extensor origins.[12]

The ulnohumeral articulation is the primary bony supporting structure in the flexion-extension plane. More specifically, beyond 30° of flexion, the coronoid process provides substantial resistance to posterior subluxation or dislocation.[13] Biomechanical studies have shown that the coronoid process is an important elbow stabilizer in response to axial, varus, posteromedial, and posterolateral rotatory forces.[14,15] Larger coronoid fractures have a progressively greater influence on elbow stability. Small fractures involving 10% of the coronoid process have been shown to have little effect on elbow stability in cadaveric biomechanical studies.[15] In the setting of a simulated terrible triad injury, when residual instability was present after LCL repair and radial head repair or arthroplasty, repair of the MCL was more effective than fixation of small coronoid fractures in restoring elbow stability.[15] In clinical series of terrible triad injuries, most coronoid fragments were larger than 10% of the coronoid process, suggesting that surgical fixation of the coronoid process should usually be performed during treatment of terrible triad injuries.

The anterior bundle of the MCL has been shown to be the most important stabilizer of valgus stress to the elbow, while the radial head acts as a secondary stabilizer. However, both the radial head and MCL are required to provide normal elbow stability.[16] In the setting of an incompetent anterior bundle of the MCL, an intact radial head becomes an extremely important secondary elbow stabilizer. The radial head also provides axial support to the forearm and acts as an anterior buttress resisting posterior dislocation or subluxation. In addition, it indirectly provides varus stability by tensioning the LCL. Partial articular fractures of the radial head have also been shown to alter stability in laboratory studies, particularly in the setting of ligamentous injuries.[13,17] Repair of fragments as small as 25% of the radial head should be considered in the setting of terrible triad injuries.

Sectioning of the MCL has been shown to cause gross valgus and internal rotation instability of the elbow.[8,9] Transosseous repair of the MCL restored elbow stability in vitro and should allow for early active and passive motion. Muscle activation and forearm supination stabilize the MCL-deficient elbow with the arm in the dependent position. Valgus loading should be avoided while the MCL is healing.[8,9] The LCL provides varus and posterolateral rotatory stability of the elbow; repair using transosseous sutures is effective. Muscle activation and forearm pronation stabilize the LCL-deficient elbow with the arm in the dependent position. Varus loading, such as occurs with shoulder abduction, should be avoided while LCL injuries are healing.[18]

Figure 2

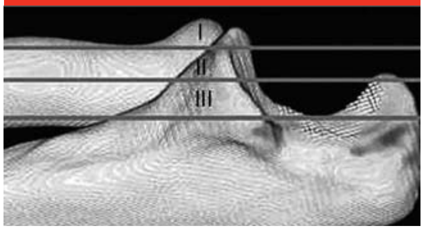


Mason classification of radial head fractures. **A,** Type I, nondisplaced. **B,** Type II, displaced partial articular fracture. **C,** Type III, comminuted fracture. **D,** A type IV injury, described by Johnson[20] in 1962, indicates an associated ipsilateral ulnohumeral dislocation.

Fracture Classification

Fracture classification systems have been developed to address the individual components of the terrible triad. Mason[19] classified radial head fractures into three categories: type I, nondisplaced fracture; type II, displaced partial articular fracture with or without comminution; and type III, comminuted radial head fracture involving the whole head (Figure 2). Hotchkiss[21] later modified Mason's classification based on clinical examination and intraoperative findings so that it could help guide treatment decisions. In the Hotchkiss modifica-

Figure 3



Coronoid fracture classification developed by Regan and Morrey.[22] Type I fracture, avulsion of tip of coronoid process; type II, fracture involving ≤50% of the coronoid process height; type III, fracture involving >50% of the coronoid process height. (Reproduced with permission from Doornberg JN, Ring D: Coronoid fracture patterns. *J Hand Surg [Am]* 2006;31:45-52.)

Figure 4

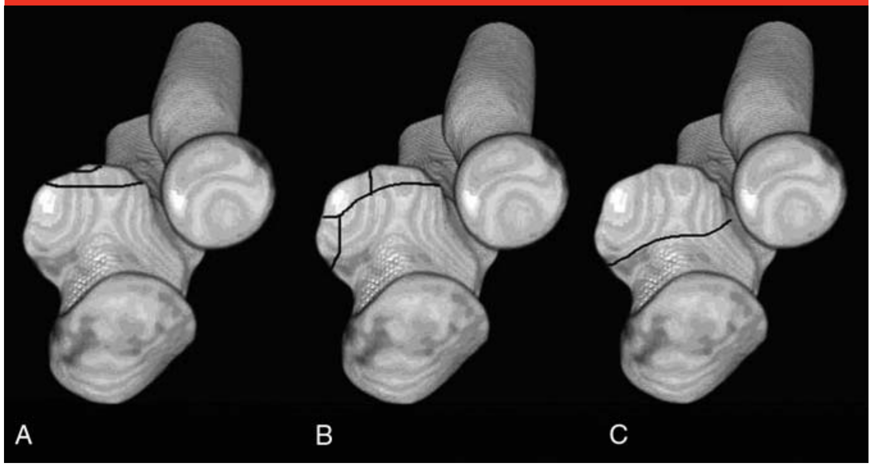


Illustration of the coronoid fracture classification according to O'Driscoll et al.[28] The three types are tip **(A)**, anteromedial facet **(B)**, and basal **(C)** fractures. Tip fractures are subclassified into two groups, either ≤2 mm or >2 mm in size. Anteromedial facet fractures are subclassified into three subtypes (anteromedial rim, rim plus tip, and rim and tip plus the sublime tubercle). Basal fractures are subclassified into two groups (coronoid body and base, and transolecranon basal coronoid fractures). (Reproduced with permission from Doornberg JN, Ring DC: Fracture of the anteromedial facet of the coronoid process. *J Bone Joint Surg Am* 2006;88:2216-2224.)

tion, type I fractures are those displaced <2 mm, with no mechanical block; type II are those with >2 mm of displacement that are repairable and may have a mechanical block to motion; and type III are comminuted fractures that are judged to be not repairable by radiographic or intraoperative findings and that require excision or replacement.

Two classification systems outline the fracture patterns seen in coronoid process injuries. The first, proposed by Regan and Morrey,[22] was based on the height of the coronoid fragment (Figure 3). A type I fracture involved an "avulsion" of the tip of the coronoid process, type II involved a single or comminuted fracture representing ≤50% of the coronoid process, and type III involved a single or comminuted fracture of >50% of the coronoid. These authors further classified these types into A and B, representing associated absence or presence of a dislocation, respectively.

A second classification scheme was recently reported by O'Driscoll et al[23] and is based on the location of the fracture in reference to local anatomy. The classification divides the coronoid process into the tip, the anteromedial facet, and the base (Figure 4). These groups are subcategorized to better define the anatomic site of the fracture. Coronoid tip fractures are divided into fragments that are ≤2 mm or >2 mm. Tip fractures are most frequently seen in association with terrible triad injuries. Tip fractures do not usually extend past the sublime tubercle; therefore, the ulnar attachment site of the MCL is usually intact. Fractures of the anteromedial facet are divided into three subtypes. Anteromedial subtype 1 fractures do not involve the coronoid tip and extend from just medial to the tip to just anterior to the sublime tubercle. Subtype 2 fractures are subtype 1 with involvement of the coronoid tip. Subtype 3 fractures involve the anteromedial rim of the coronoid and the sublime tubercle (Figure 4). Basal coronoid fractures consist of a fracture through the body of the coronoid process and involve at least 50% of the coronoid height. Basal fractures are divided into subtype 1, which involves only the coronoid process, and subtype 2, which consists of a coronoid body fracture in association with an olecranon fracture.

Mechanism of Injury

The terrible triad injury is often caused by a fall on an outstretched hand. A posteriorly directed force results from a fall on an extended elbow, which levers the ulna out of the trochlea.[13] Subsequently, the anterior capsule and collateral ligaments undergo increased tension and eventually fail. O'Driscoll et al[24] described an additional valgus stress and/or posterolateral "roll-out" that occurs with this injury. The authors postulated that, in a fall with the arm extended, the elbow becomes fixed, and the body produces a valgus and posterolateral rotatory moment. Sequentially, the capsuloligamentous structures of the elbow begin to fail from lateral to medial.[24] The anterior bundle of the MCL is postulated to be the last to fail; therefore, an elbow can theoretically dislocate without a complete tear of this structure. As the elbow slides out of joint, fractures of the radial head and coronoid process frequently occur.[25-27]

Anteromedial facet fractures do not occur with the same posterolateral rotatory instability pattern that leads to terrible triad injuries. O'Driscoll et al[24] suggest that an axial force combined with posteromedial rotation, varus force, and elbow flexion causes the medial trochlea to abut onto the anteromedial facet of the coronoid. This results in an anteromedial facet fracture with associated disruption of the LCL due to a varus force.[23] The radial head is usually not fractured in a varus posteromedial instability pattern, and it is therefore by definition not a true terrible triad injury.

Diagnosis and Initial Management

Patient history and physical examination are vital to the diagnosis and management of terrible triad injuries. The history should include the severity and mechanism of injury. High-energy injuries often involve more ligamentous and osseous disruption than do low-energy injuries, which are more commonly seen in elderly, osteoporotic patients. The mechanism of injury is also important because it allows the surgeon to better predict which structures are injured. The examination should note any signs or symptoms of neurovascular injury and skin or soft-tissue compromise. An evaluation of the precipitants of the fall that resulted in the injury is necessary because the patient may have undiagnosed alcohol dependence, cerebrovascular disease, or cardiac arrhythmia. Special attention should be directed toward identifying comorbidities and reversible illness that affect treatment recommendations and perioperative risk.

The physical examination should begin with inspection. Any obvious deformity of the elbow should raise the question of dislocation and/or fracture. Furthermore, areas of ecchymosis may indicate specific sites of injury; for example, ecchymosis at the medial elbow may represent an MCL injury. Abrasions, extensive swelling, and fracture blisters should be identified because their occurrence may influence the timing of surgery. Finally, open wounds should be carefully looked for because their presence constitutes a surgical emergency. When the patient's pain allows, palpation of the elbow for tenderness, assessment of bony alignment, and gentle range of motion (ROM) may also suggest the location of pathology. The joints above and below the elbow, in particular the distal radioulnar joint, should be examined. If the wrist is not examined in the presence of a radial head fracture, then a tear of the interosseous membrane and distal radioulnar joint ligaments, the so-called Essex-Lopresti injury, may be missed. Without treatment, this injury will lead to poor outcomes.[28] A detailed neurologic examination should be performed to evaluate the function of the axillary, musculocutaneous, median, ulnar, and radial nerves.

When, after the history and physical examination, preliminary radiographs reveal an elbow dislocation, initial management begins with a closed reduction under intravenous conscious sedation or general anesthesia. After reduction is achieved, the elbow should be brought through the ROM to test stability in all planes, with the forearm in pronation, neutral, and supination. A closed reduction offers the benefit of lessening pain and soft-tissue swelling, and it allows for more accurate interpretation of radiographs. After the reduction is achieved, a second neurologic and vascular examination is indicated, and any changes should be noted.

Imaging

Pre- and postreduction imaging includes anteroposterior and lateral radiographs, which should be examined carefully for fracture characteristics and concentricity of the ulnohumeral and radiocapitellar joints. A line drawn through the center of the radial neck should intersect the center of the capitellum, regardless of the radiographic projection. The coronoid process should be closely viewed on the anteroposterior and lateral images. Lateral radiographs are also used to determine the height of the coronoid fracture; however, the pattern and extent of the fracture are typically difficult to characterize on plain radiographs.

Computed tomography (CT) is routinely used in patients with terrible triad injuries to identify fracture patterns, comminution, and displacement, which may not be evident on plain radiographs. The advent of three-dimensional CT has further improved our understanding of these injuries. Three-dimensional images can improve the visualization of fracture fragments and their location, as well as fracture line propagation. In addition, digital subtraction of the humerus can isolate areas of the elbow to allow for better characterization of fracture patterns.

Treatment

Nonsurgical

Most patients presenting with a terrible triad injury require surgery[1,2] for stabilization; however, some cases may be managed nonsurgically.

When nonsurgical treatment is to be undertaken, several specific criteria must be met. After reduction of the dislocation, the ulnohumeral and radiocapitellar joints must be concentrically reduced. The elbow must also be sufficiently stable to allow early ROM, such that the elbow should extend to approximately 30° before becoming unstable. The congruency of the elbow can be evaluated fluoroscopically following the initial reduction performed under sedation in the emergency department. Alternatively, the congruency of the elbow during active motion can be evaluated fluoroscopically following initial splint removal within 10 days if the patient's pain allows.

The nonsurgical treatment plan requires that imaging, including a CT scan, show a small nondisplaced or minimally displaced radial head or neck fracture that does not cause a mechanical block to forearm rotation or elbow flexion/extension. The coronoid fracture must also be a small tip fragment as confirmed by CT scans, which are routinely recommended in the evaluation and treatment of these injuries. In these circumstances, the injury may be treated as a "simple" dislocation.

After reduction, an initial period of immobilization at 90° of flexion in a light fiberglass splint is recommended for 7 to 10 days. This allows for a reduction of swelling and a return of muscle tone around the elbow. Patients are also encouraged to work on isometric biceps and triceps muscle contractions. Weekly clinical and radiographic follow-up is required for the first 4 weeks to ensure maintenance of a congruous reduction and to ensure that the associated fractures do not displace.

The optimal nonsurgical management of terrible triad injuries has not been established. After muscle tone returns to the elbow in 7 to 10 days, active motion is initiated with a resting splint at 90°, avoiding terminal elbow extension. After 4 to 6 weeks, static progressive extension splinting is added at night to encourage recovery of elbow extension. Strengthening is initiated after healing of ligament and osseous injuries is assured.

Surgical

Most terrible triad elbow injuries are managed surgically. When the patient is deemed medically fit, surgery is indicated for failure to meet nonsurgical treatment criteria, for open wounds, and/or for neurologic or vascular injury. The steps involved in surgical management are presented as an algorithm in Figure 5.

Several surgical approaches to the elbow have been described, and the decision of which approach to choose is controversial. Factors in selecting an approach include fracture and instability pattern, soft-tissue injury, and surgeon experience.

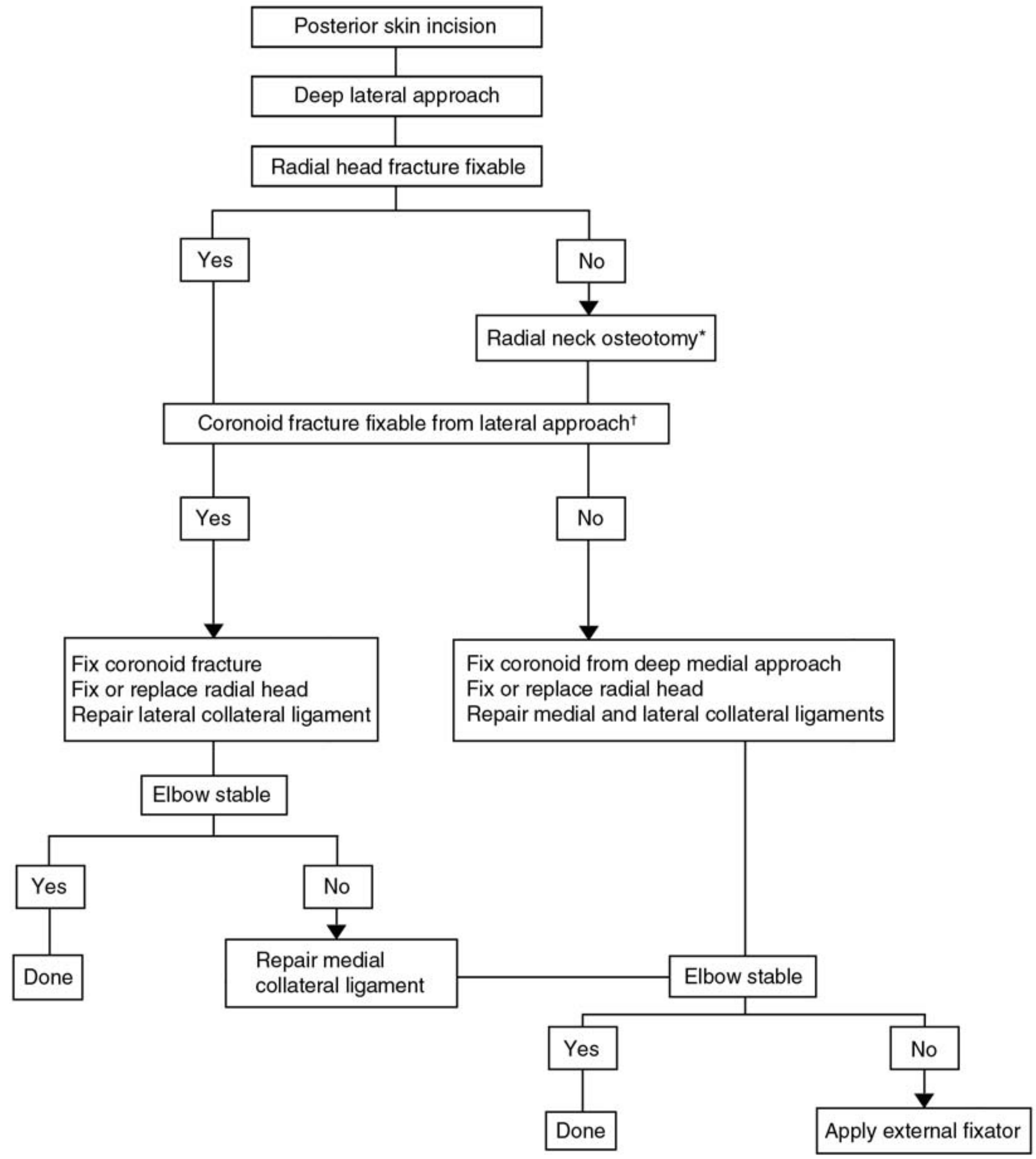
The first decision to be made is the location of the skin incision, which may be medial, lateral, or posterior longitudinal. Historically, a lateral skin incision has been used; however, in the setting of a terrible triad injury, a posterior skin incision has several advantages. It allows access to both the medial and lateral aspects of the elbow, and it precludes the need for a second medial skin incision should a medial deep approach be required. Also, a posterior skin incision has a lower risk of injury to the cutaneous nerves compared with medial and lateral skin incisions.[29] In addition, the posterior skin incision, while longer than the isolated medial and lateral incisions, is more cosmetic and is less easily seen than the lateral incision. A disadvantage of a posterior incision is that the relatively large medial and lateral skin flaps created increase the possibility of seromas and hematomas. Flap necrosis is also a potential complication, although it is rare in the setting of trauma.

Once the posterior skin incision is made, a lateral full-thickness fasciocutaneous flap is raised. In general, a medial fasciocutaneous flap and exposure of the ulnar nerve are not indicated initially because many terrible triad injuries can be completely addressed from the lateral side. For the deep lateral approach, the interval between the extensor carpi ulnaris and anconeus (ie, Kocher interval) is used. Alternatively, the extensor digitorum communis tendon can be split in the midline. Both approaches allow access to the radial head and the almost invariably disrupted LCL. Often, the injury leaves the lateral epicondyle completely devoid of soft-tissue attachments.

A deep medial approach may be required if the coronoid fracture cannot be adequately reduced and fixed from the lateral side, if repair of the MCL is needed to address persistent instability, or if the ulnar nerve is injured. The ulnar nerve may require anterior subcutaneous transposition if it is symptomatic or in the rare circumstance in which it is entrapped within the joint. If the flexor pronator mass is not disrupted, it can be reflected or split to allow access to the coronoid fracture and the underlying MCL.

Hotchkiss[30] described the "medial over-the-top" approach for elbow contracture releases, an exposure that also allows good visualization of the coronoid process. In this approach, the flexor pronator mass is split, and the anterior half is detached and elevated with the brachialis and the anterior joint capsule off the anterior humerus to allow exposure of the coronoid fracture. For larger coronoid fragments, the whole flexor pronator mass can be divided and elevated off the medial epicondyle and MCL to allow exposure of the entire coronoid process and medial ulna, a procedure similar to

Figure 5



Algorithm for the surgical management of terrible triad injury.
*Neck osteotomy in preparation for radial head replacement. If fragment size is <25% of the radial head, fragment excision may be considered.
†Type I coronoid fractures may not require repair.[15]
(Adapted with permission from Spencer EE, King JC: A simple technique for coronoid fixation. *Tech Shoulder Elbow Surg* 2003;4:1-3.)

a submuscular ulnar nerve transposition described by Taylor and Scham.[31]

In the setting of radial head fractures necessitating repair or replacement, the coronoid process can usually be fixed through the radial head defect from the lateral surgical approach. In this case, a targeting guide can be used to precisely position two drill holes entering the base of the coronoid fracture from the subcutaneous border of the ulna (Figure 6). Alternatively, these drill holes can be done freehand, with a fingertip placed on the fractured surface of the coronoid process for triangulation. A nonabsorbable suture is used to grasp a portion of the anterior capsule while encircling small coronoid fragments or being passed through drill holes in larger fragments. Gaining exposure is

Figure 6

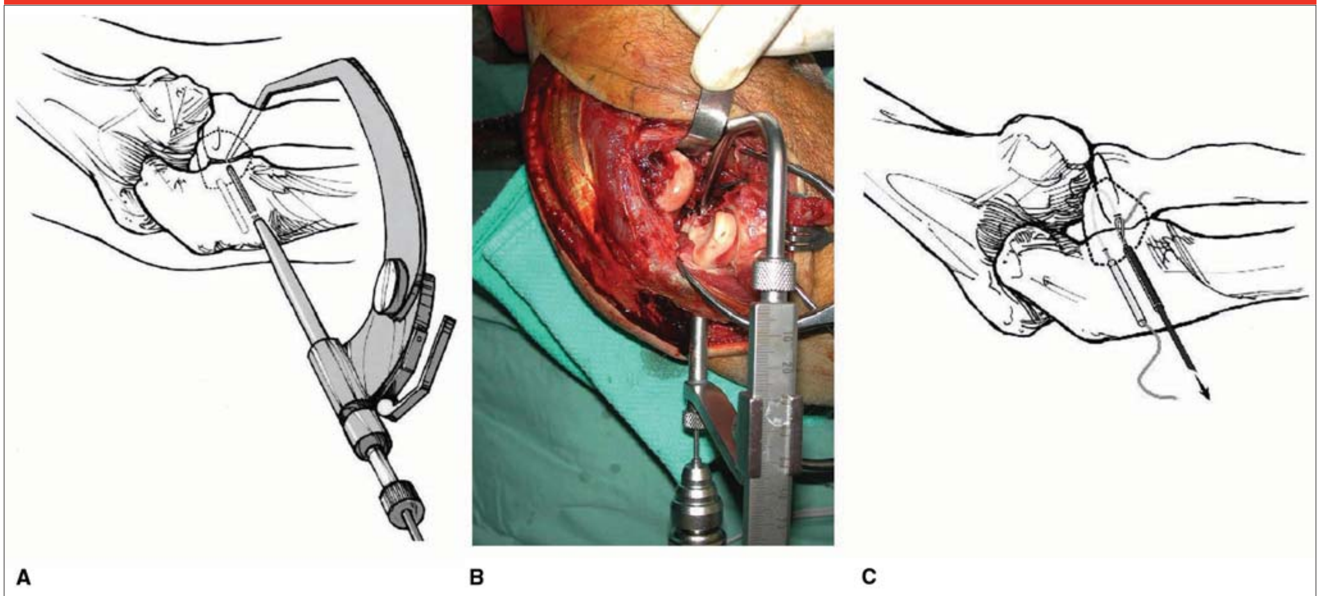


Illustration **(A)** and photograph **(B)** of a targeting device used to assist in drill-hole placement for retrograde screws or suture fixation of the coronoid fracture. **C,** Suturing of the coronoid fragment is most frequently done through the lateral arthrotomy, after which the sutures are drawn through drill holes (arrow) exiting the subcutaneous border of the ulna.

important in this technique, and release of the common wrist extensors from the lateral condyle may be needed to improve visualization.

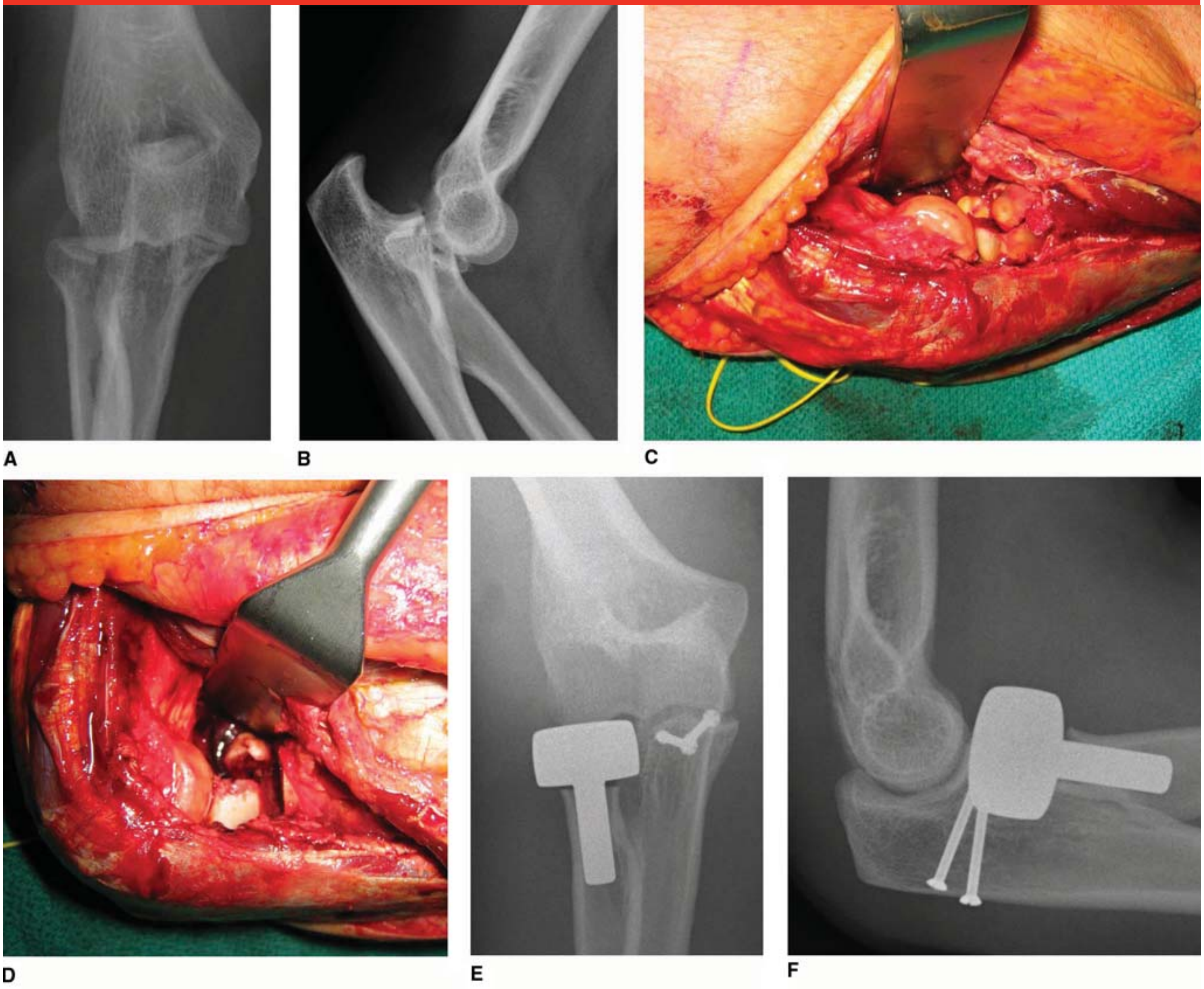
The anterior capsular attachment to the coronoid fragment or fragments should not be released because protecting the attachment enhances stability. A suture-passing device can be used to retrieve sutures through separate drill holes. The sutures are then tied with the elbow held reduced.[32] If the coronoid fracture fragment is larger, then small-diameter cannulated screws may be used for fixation in a retrograde fashion from posterior to anterior[32,33] (Figure 7). Basal coronoid fractures, which are rarely seen in terrible triad injuries, can be fixed by means of a plate placed anteromedially or directly medially on the proximal ulna.

Available options in managing the associated radial head fractures are fragment excision, open reduction and internal fixation, and radial head arthroplasty. When <25% of the head is damaged, when the fragments are too small or osteoporotic to fix, and when the fragments do not articulate with the proximal radioulnar joint, they may be excised if stability of the elbow can be achieved by secure repair of the coronoid and collateral ligaments.[34,35] The stability of the elbow should be assessed following fragment excision; if residual instability is present, radial head replacement is recommended.

If a radial head fracture is deemed repairable, the hardware used for osteosynthesis may include countersunk traditional screws (Figure 8), headless compression screws (Figure 9), or plates. Fixation is typically performed with 1.5-, 2.0-, or 2.4-mm countersunk screws after an anatomic reduction and provisional stabilization with Kirschner wires. Noncomminuted radial neck fractures can be reduced with the use of two or three oblique screws to secure the head to the neck.[36] Cannulated 3.0-mm screws are helpful in these circumstances because guidewires prevent the screws from glancing off the inner cortical bone of the medullary canal.

If the radial neck is comminuted, a radial neck plate should be considered (Figure 10). Plates must be placed in the "safe zone," which is the region that does not articulate with the proximal radioulnar joint.[37] This is easily identified at surgery by placing the forearm in neutral rotation and applying the plate directly lateral. In fractures involving the radial neck, the posterior interosseous nerve is at risk during the approach; therefore, great care must be taken as dissection is performed distally. Pronation of the forearm moves the nerve away from the surgical dissection. The use of plates requires dissection along the radial neck and interferes with the gliding of the annular ligament; therefore, postoperative loss of forearm rotation due to scarring is not uncommon. Additional surgery may be required in these circumstances for plate removal and release of adhesions after fracture healing. Following plate fix-

Figure 7



Anteroposterior **(A)** and lateral **(B)** injury radiographs of a 38-year-old woman with a right terrible triad injury. **C,** An intraoperative view through the Kocher interval demonstrates the comminuted, unrepairable radial head fracture. **D,** Because the fracture was deemed to be unrepairable, an arthoplasty was selected, and a radial neck cut was performed. Once the radial head was excised, visualization of the type II coronoid fracture improved. Postoperative anteroposterior **(E)** and lateral **(F)** radiographs demonstrating open reduction and internal fixation of the coronoid fracture with two 3.0-mm cannulated screws and a metallic modular radial head arthroplasty.

ation of the radial neck, repair of the annular ligament should be performed to restore elbow stability.

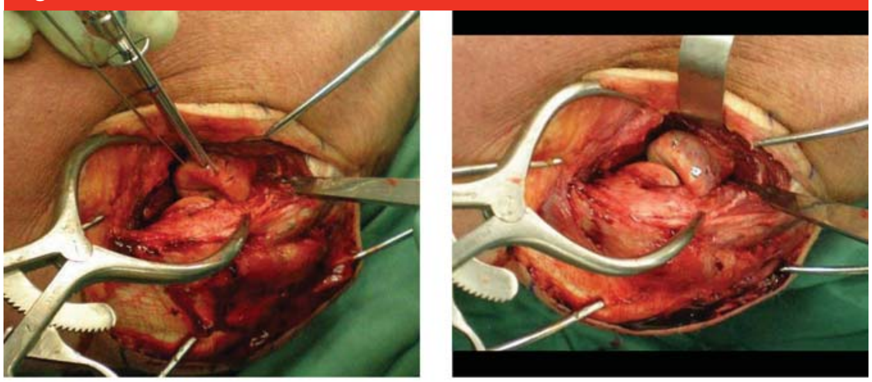
If there is extensive radial head comminution, neck comminution, or poor bone quality, replacement arthroplasty should be considered. The implants available are numerous; however, the use of a modular prosthesis is preferable because it allows the surgeon the latitude to independently modify head and stem diameters and heights to ensure an optimal fit.[34,35] The radial head prosthesis sizing is based on the fragments excised from the elbow. The height of the implant should correspond to the height of the excised fragments so that placement of a radial head prosthesis that is too thick is avoided. The implant should articulate at the level of the proximal aspect of the proximal radioulnar joint, approximately 2 mm distal to the tip of the coronoid process.

For terrible triad injuries, we think that excision of the radial head without replacement is contraindicated. It is well documented that the radial head is critical to valgus stability when the MCL is injured, that the radial head resists posterior displacement of the elbow when the coronoid process is deficient, and that the head tensions the repaired LCL to resist varus and posterolateral rotatory instability. Several authors have reported a high incidence of complications with radial head excision in terrible triad injuries.[17,26,34,35,38,39]

Once the bony structures have been repaired, the ligamentous structures should be evaluated. The LCL is usually avulsed from its origin on the lateral epicondyle. Midsubstance tears and avulsion of the LCL from its insertion on the ulna are uncommon.[40] The LCL can be reattached to the lateral epicondyle with suture anchors or transosseous sutures (Figure 11). The most important step in achieving a successful isometric repair is placing the sutures at the center of rotation of the elbow, which is located at the center of the capitellar curvature on the lateral epicondyle.[35] We prefer the transosseous technique because it allows strong fixation and tensioning with running locking sutures in the LCL and common extensor origin. If the MCL is intact, the LCL is repaired with the forearm in pronation; however, if the MCL is injured, LCL repair is performed with the forearm in supination to avoid gapping open the medial side of the elbow by overtightening the lateral repair. Because the LCL is isometric, repairs are performed with the elbow at 90°, the most convenient position during surgery.

After repair of the coronoid process, radial head, and LCL, the elbow should be fluoroscopically examined for stability, while it is flexed and extended with the forearm in supination, neutral position, and pronation. In the authors' experience, if the elbow remains congruous from approximately 30° to full flexion in one or more positions of forearm rotation, repair of the MCL is not necessary. Thirty degrees should be considered a guideline; further clinical and biomechanical studies are needed to determine the indications for MCL repair in terrible triad injuries. If instability is still an issue, the MCL should be repaired with the use of suture anchors or transosseous sutures, with drill tunnels placed through the medial epicondyle and special care taken to protect the ulnar nerve.[8]

Figure 8



A B

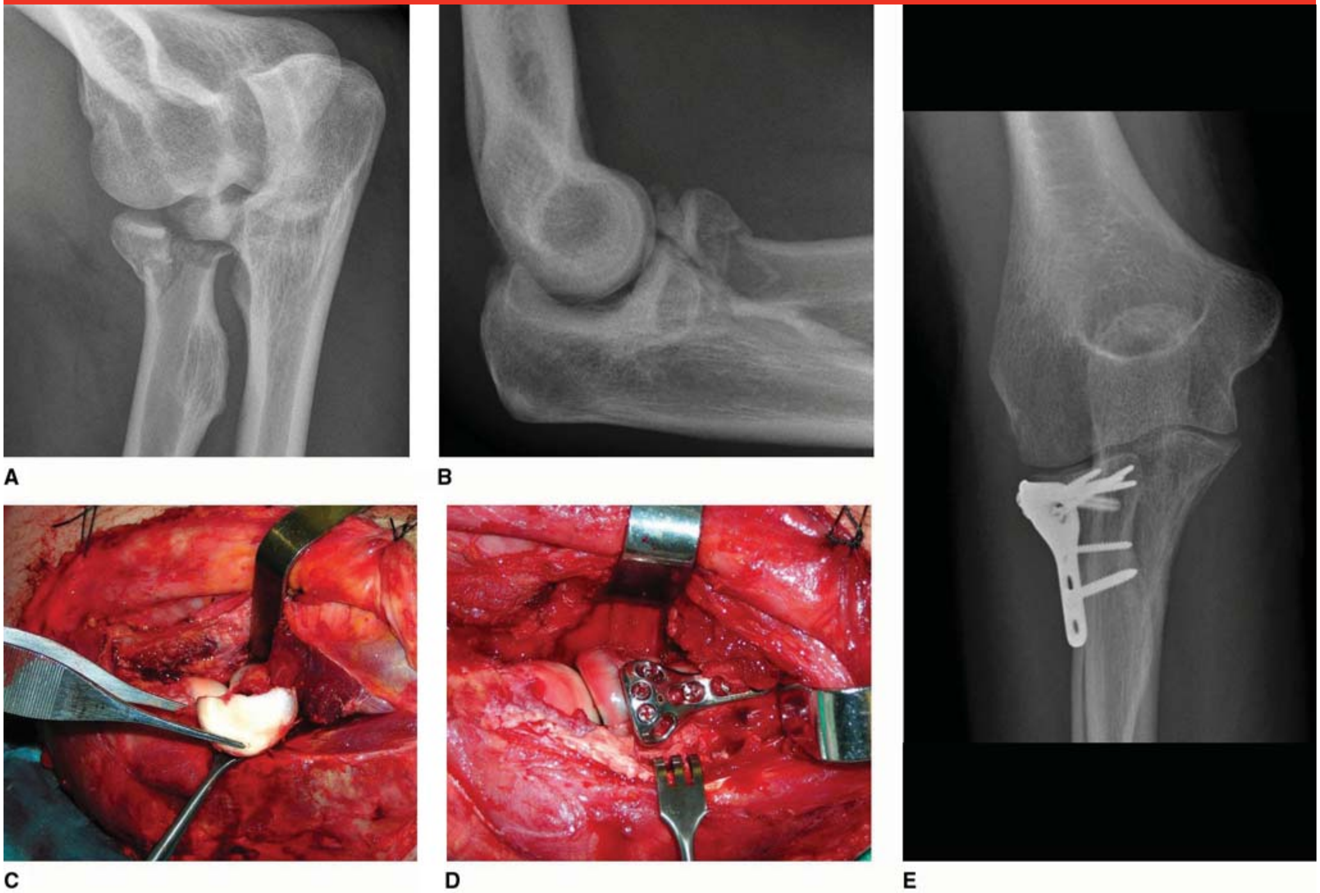
A, Fixation of a radial head fracture with temporary Kirschner wires and cannulated screw guides. **B,** Definitive fixation with cannulated countersunk screws.

Figure 9

A B C D

Preoperative anteroposterior **(A)** and lateral **(B)** radiographs of radial head and coronoid fractures. Postoperative anteroposterior **(C)** and lateral **(D)** radiographs demonstrating fixation of the radial head fracture with multiple headless compression screws and fixation of a coronoid fracture with a cannulated screw.

Figure 10



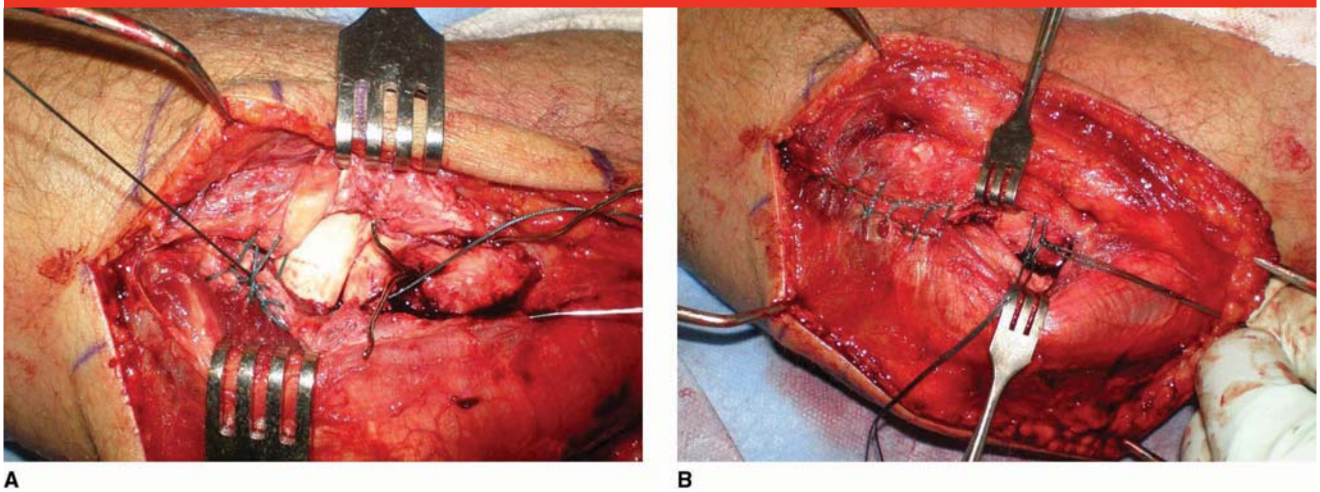
Preoperative anteroposterior **(A)** and lateral **(B)** radiographs demonstrating a fracture of the radial head and neck with a Regan-Morrey type II coronoid process fracture following closed reduction of an elbow dislocation. **C** and **D,** Through the Kocher interval (anconeus to extensor carpi ulnaris), the radial head was reconstructed with an anatomic radial neck plate placed in the safe zone, and the coronoid fracture underwent suture fixation. **E,** Postoperative anteroposterior radiograph, after lateral ligament repair.

In the rare circumstance that the elbow remains unstable following repair or replacement of the radial head and repair of the coronoid process, MCL, or LCL, a static or hinged external fixator should be applied to maintain a concentric reduction of the elbow.[41] While a dynamic external fixator is preferred, the use of a static fixator for up to 3 weeks is also acceptable. In some acute cases, the use of a dynamic fixator may be considered to protect tenuous fixation of comminuted coronoid fractures. The dynamic fixator is most commonly employed for delayed treatment to maintain stability of the elbow in the setting of suboptimal soft-tissue and bony repair. When an external fixator is unavailable, the placement of a transarticular Steinmann pin to stabilize the ulnohumeral joint can be employed. If used, the pins should be removed early, within 3 weeks, because of their tendency to break and the potential for pin-site infection leading to septic arthritis.

Rehabilitation

The final step before leaving the operating room is to perform a careful fluoroscopic examination of the elbow to assess any residual instability and to determine the best position for immobilization as well as the safe arc of motion for rehabilitation. If the MCL is intact, the elbow is immobilized in a well-padded fiberglass splint at 90° of flexion, with the forearm in full pronation to avoid posterolateral instability and to protect the LCL repair. If both the MCL and LCL have been repaired, the arm should be splinted in neutral rotation. If the LCL has been securely fixed and the MCL has not, immobilization at 90° of flexion and in full supination should be considered. Although the period of initial immobilization will vary with injury, supervised motion should generally begin within 2 to 5 days after surgery. Patients

Figure 11



A, The lateral collateral ligament is repaired through drill tunnels to the isometric point on the lateral epicondyle. Note the bare lateral epicondyle, resulting from tearing of the lateral collateral ligament and common extensor origin following an elbow dislocation. Two wires, functioning as suture passers, have been placed through the bone tunnels. **B,** The extensor origin is repaired as a second superficial layer.

should begin active flexion and extension, avoiding terminal extension, depending on the intraoperative evaluation of stability. Full active forearm rotation is permitted with the elbow in 90° of flexion to protect the collateral ligament repairs.

If residual instability is a concern, the use of an overhead rehabilitation protocol is helpful, with the patient lying supine and the humerus/arm positioned vertically. This position uses gravity to maintain joint compression; it also decreases patient apprehension. A resting splint with the elbow at 90° and the forearm in the appropriate position of rotation is used between exercises for 6 weeks. A gradual increase in terminal extension is permitted as healing progresses. It is the practice of the authors to prescribe a static progressive extension splint employed at night. This is begun at the 6-week mark to ensure that sufficient healing of the bony and ligament repairs has occurred. Strengthening is initiated at 8 weeks once osseous and ligament healing is secure. The postoperative rehabilitation protocol will vary depending on the injury pattern; however, the primary goal is to begin early elbow motion while maintaining a concentric joint reduction and protecting bony and soft-tissue repairs.[26,34,35] When a static external fixator is used, it is typically removed within 3 weeks to avoid stiffness. A gentle manipulation may be required at the time of fixator removal to facilitate regaining motion; however, great care must be taken because there is a risk of fracture as well as of heterotopic bone formation. With an articulated external fixator, early motion is started as soon as the soft tissues allow, and the fixator generally is removed between 3 and 8 weeks postoperatively as ligament and bone healing progress.

The optimal rehabilitation of terrible triad injuries is unknown. Based on biomechanical studies[7-9] and the authors' clinical experience, the described rehabilitation protocols have been useful in allowing early motion while maintaining stability, particularly in the setting of tenuous fracture fixation or ligament repairs.

Outcomes

Relatively few studies have documented the outcomes of terrible triad injuries of the elbow. Pugh and McKee[27] reported a mean arc of flexion of between 20° and 135° and mean rotation of 135°. A delay in treatment or revision surgery resulted in a 20% greater loss of motion compared with acutely treated injuries. Up to 25% of the patients needed revision surgery for residual instability, stiffness, or removal of hardware.

In a multicenter series, 36 patients underwent fixation or replacement of the radial head, repair of the coronoid when possible, and fixation of ligamentous and capsular injuries.[34] At a mean follow-up of 34 months, the authors reported a flexion-extension arc averaging 112° ± 11°, with forearm rotation averaging 136° ± 16°. At follow-up, 15 patients were rated as excellent, 13 as good, 7 as fair, and 1 as poor by the Mayo Elbow Performance Score. Patient complications were noted in this study; two patients required revision surgery for synostosis, one for recurrent instability, four for contracture release and implant removal, and one for a wound infection. The authors concluded that the outcomes were directly related to the period of immobilization; patients who had prolonged immobilization did not do as well.

Similar findings were reported by Broberg and Morrey,[42] who noted that immobilization for more than 4 weeks led to consistently poor results. It should be noted, however, that a surgeon often has to decide between stability and mobilization. In the end, the outcome of managing a stiff congruent elbow is usually better than that of treating a mobile elbow with residual instability and incongruency.[23]

Forthman et al[43] reviewed 34 patients, of whom 30 could be classified as having terrible triad injuries. At a mean follow-up of 32 months, the average ulnohumeral arc of motion was 117° (range, 75° to 145°) and forearm rotation was 137° (range, 0° to 180°). Good to excellent results were reported in 77% of patients using the system of Broberg and Morrey.[42]

Complications

Complications are frequently encountered following treatment for terrible triad injuries. The frequency of complications is related to the severity of the injury. Common complications are instability, malunion, nonunion, stiffness, heterotopic ossification, infection, and ulnar neuropathy.[25-27,34,43]

It was initially thought that instability was more prevalent with Regan and Morrey type III coronoid process fractures;[22] however, instability seems to be more common following type I or II coronoid fractures. This is theorized to occur because of the frequency of associated ligamentous injuries around the elbow and the technically challenging aspects of obtaining stable internal fixation of these smaller fractures. Terada et al[44] and Josefsson et al[45] also reported that chronic elbow instability was more common in patients with smaller fractures of the coronoid process, particularly when associated with a radial head fracture. They suggested that even small coronoid fractures usually have the anterior capsule attached and, if they are repaired, joint stability may increase. However, a recent biomechanical study suggests that fixation of small type I coronoid tip fractures contributes little to stability in spite of this anterior capsular attachment. Repair of the collateral ligaments was found to be more beneficial than suture fixation of the coronoid process in the treatment of small type I coronoid fractures.[15] However, because in most patients with terrible triad injuries the coronoid fractures are larger than 10%, excision or nonrepair of coronoid fractures is rarely indicated.

Failure of internal fixation is common following repair of radial neck fractures, likely because of poor vascularity leading to osteonecrosis and nonunions.[46] Hardware migration can occur, particularly when smooth Kirschner wires are used. Loosening or failure of radial head implants has been reported, although newer designs offer much more modularity, thereby allowing for more accurate implant sizing, which may lead to improved results.[47]

Posttraumatic stiffness is a common complication after treatment of terrible triad injuries of the elbow. The best treatment is prevention, such that at the time of index surgery, the elbow should be rendered sufficiently stable to allow early ROM. Should stiffness occur, the first line of treatment is nonsurgical, with passive stretching and static progressive splinting. Turnbuckle splinting should also be considered if stiffness persists despite therapy and standard splints. Stiffness that is recalcitrant to nonsurgical treatment may be treated surgically with open or arthroscopic capsular release.

Heterotopic ossification that limits motion typically requires an open approach. Ring et al[48] reported good results with open capsular excision in 46 patients with posttraumatic stiffness. At a mean follow-up of 48 months, there was restoration of a functional arc of motion of nearly 100°. Heterotopic ossification that becomes clinically significant is relatively uncommon. In a series of 24 patients with fracture-dislocations of the elbow, only 1 patient developed this condition, and treatment in this patient had been delayed by 8 days.[42] The use of prophylactic measures for heterotopic ossification is controversial. Some authors recommend prophylactic measures only for those patients with a concomitant head injury or those who have failed initial surgical treatment.[27] When prophylaxis is decided upon, we employ indomethacin 100 mg rectally twice a day for 24 hours, followed by 25 mg orally three times a day for 3 weeks. Nonsteroidal anti-inflammatory drugs should be avoided in patients with peptic ulcers, asthma, kidney disease, and cardiac disease as well as in the elderly.

Posttraumatic arthritis can occur because of chondral damage at the time of injury as well as because of residual elbow instability or articular incongruity.[41,49] Treatment options include débridement, radial head excision, radial head arthroplasty, and total elbow arthroplasty.

As with any surgical procedure, infection remains a potential complication after surgical fixation of elbow injuries. Surgical site infections around the elbow should be treated in the same way as any infection that occurs around a joint. If the infection is thought to be superficial, oral or intravenous antibiotics may be used. If the superficial infection is slow to respond or when there is any indication of a deep infection, serial surgical débridement with intravenous organism-specific antibiotics should be done.

Summary

Terrible triad injuries remain difficult to treat. The surgeon must carefully examine and view images of the injured arm to determine the extent of bony and ligamentous injury. Most authors agree that prompt surgical attention with a systematic approach to restore anatomy and provide sufficient stability to allow early motion are the key factors for a successful outcome. Stiffness, a common complication after terrible triad injuries, is generally avoided by stable repair and early mobilization. The long-term outcome of terrible triad injuries remains unknown.

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