Management of Terrible Triads

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Background

The term "terrible triad of the elbow" was coined by Hotchkiss to describe the constellation of a traumatic elbow dislocation, radial head fracture, and associated coronoid fracture [1]. This dislocation pattern and its associated bony fractures earned this nickname due to their historically poor outcomes and the propensity for early recurrent instability, chronic instability, and posttraumatic arthritis [2–6]. In a description of the historical treatment of patients with elbow dislocations associated with radial head and coronoid fractures treated without a consistent surgical algorithm, 64 % of patients had a "poor" outcome [7]. In a report of the Arbeitsgemeinschaft fur Osteosynthesefragen (AO) experience, Heim and coworkers found that 73 % of patients developed premature arthrosis with residual instability [8]. Recent clinical and biomechanical studies have better defined surgical indications and protocols that have led to improved patient outcomes [9]. Good functional outcome can be achieved if stable, anatomic fixation of all osseous structures that contribute to elbow stability is performed [2, 4, 6, 10, 11]. This allows early motion of the joint at the same time allowing healing of the capsuloligamentous structures. Despite an improved understanding of the pathoanatomy and advances in surgical technique, complications are still frequent and include stiffness, residual instability, and posttraumatic arthrosis [12].

This chapter focuses on the evaluation, treatment options, published outcomes, and complications of terrible triad injuries of the elbow. A systematic approach to the management of this injury complex is provided, with an emphasis on the understanding of the pathoanatomy and current surgical treatments.

Evaluation

Fracture-dislocations of the elbow are typically acute and traumatic, and thus the patient presentation and history are typically straightforward. The patient presents with a history of trauma, often related to a fall on the outstretched hand. In addition, these injuries may occur due to high-energy trauma and thus a thorough work-up to rule out concomitant musculoskeletal and visceral injuries must be performed. Careful inspection of the soft tissue envelope for open wounds and abrasions should be performed to rule out occult open fractures. In addition to a careful evaluation of the involved elbow, the ipsilateral shoulder and wrist shoulder also be inspected for any signs or symptoms of injury. Other associated

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injuries have been reported in 10–15 % of cases, such as distal radius fracture, perilunate dislocations, and shoulder injuries [13]. The distal radioulnar joint and forearm should be specifically evaluated for tenderness or instability as a longitudinal injury of the forearm needs to be ruled out if there is a concomitant radial head fracture.

The documentation of peripheral nerve function and vascular status in the injured extremity, both before and after any attempted closed reduction is critical. Due to pain and swelling from the acute injury, extensive examination of the elbow is often poorly tolerated. It is unusual for a patient to tolerate varus and valgus stress testing to investigate collateral ligament rupture in the acute setting. Nevertheless, the clinician should maintain a high index of suspicion for collateral ligament injury.

Plain radiographs in orthogonal anterior–posterior and true lateral planes should be obtained of the elbow (Fig. 5.1). X-rays should be performed prior to attempted closed reduction. If patients present in clinic from an emergency department or are transferred from an outside facility, cast or splint material can often obscure bony detail. In certain circumstances it may be unclear on X-ray if the fracture fragments come from the radial head or coronoid process. The coronoid fracture is typically distinguished as a triangular fragment anterior to the trochlea in the dislocated elbow and proximally, within the coronoid fossa, after concentric reduction. Frequently computed tomography (CT) scans with reformatted images and three-dimensional reconstructions are needed for better understanding of the fracture patterns and amount of displacement. These images are also useful for preoperative surgical planning (Fig. 5.2).

The individual components of the terrible triad can be individually classified to aid in the evaluation of this injury:

Fractures of the Radial Head

The radial head is an important secondary stabilizer of the elbow to valgus stress and the radiocapitellar joint accounts for 60 % of load transfer through the elbow joint [14]. Several classification systems exist for fractures of the radial head. The most common cited classification system is that described by Mason [15] and later modified by Johnston [16]. The classification system is purely radiographic and in many cases has proven insufficient to guide clinical treatment. Mason type 1 fractures are nondisplaced fractures of the radial head. Type II fractures are displaced more than 2 mm and involve greater than 30 % of the surface of the head. Type III fractures are described as comminuted fractures often

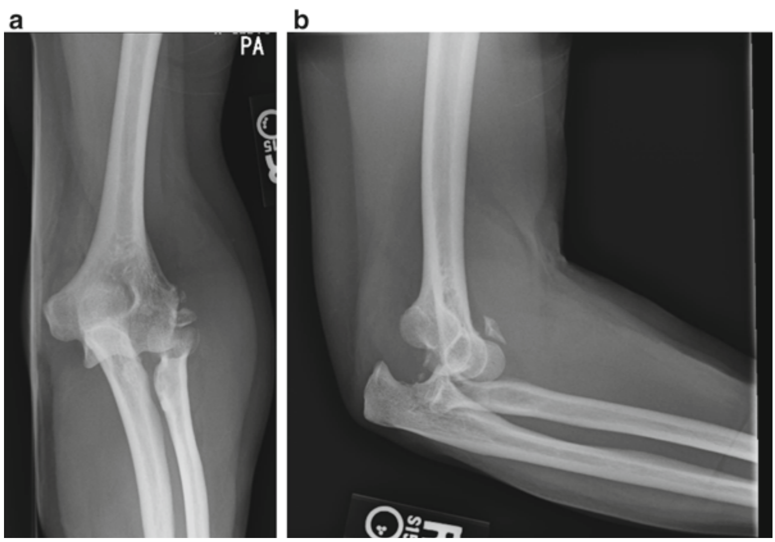

Fig. 5.1 (**a**) AP and (**b**) Lateral radiographs of a right elbow demonstrating the three components of the terrible triad: posterior dislocation, radial head fracture, and coronoid process fracture

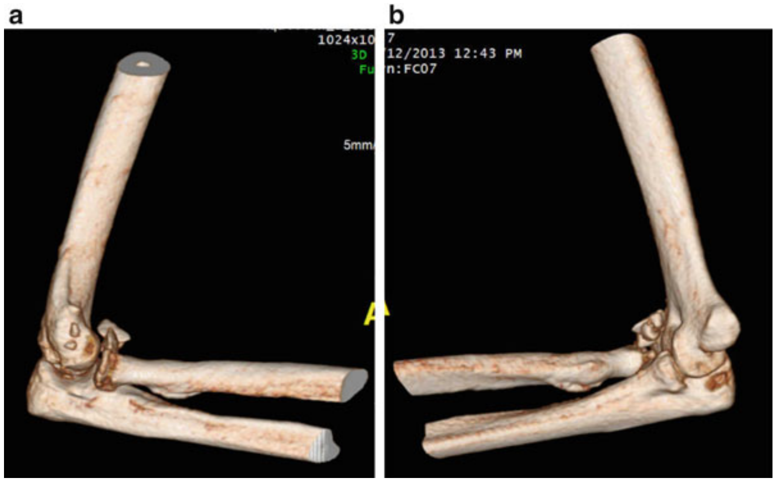

Fig. 5.2 3-Dimensional reconstruction CT scan of a right elbow with a terrible triad injury, as viewed (**a**) laterally and (**b**) medially

involving the entire head. Johnston later added the type IV fracture category, which is characterized by a radial head fracture with concurrent ulnohumeral dislocation (Fig. 5.3). This system does not account for associated injuries, which include tears of the interosseous membrane or mechanical blocks to range of motion from osteochondral shear injuries, which often influence both treatment and outcome. The Hotchkiss modification includes clinical examination and provides guidelines for the treatment (Fig. 5.4). In spite of the limitations as a comprehensive classification system, the Mason classification endures as one of the most popular and often cited systems used to describe radial head fractures.

Fractures of the Coronoid Process

The coronoid process of the ulna serves as a bony anterior buttress, which prevents the posterior displacement of the forearm relative to the humerus. The triceps, brachialis, and biceps muscles have a net resultant posteriorly directed force. Thus when a coronoid fracture reaches a critical threshold and becomes large enough that it no longer acts as a restraint against this posterior force, the elbow will remain subluxed or dislocated, despite an initial reduction of the joint. Coronoid fractures were first classified by Regan

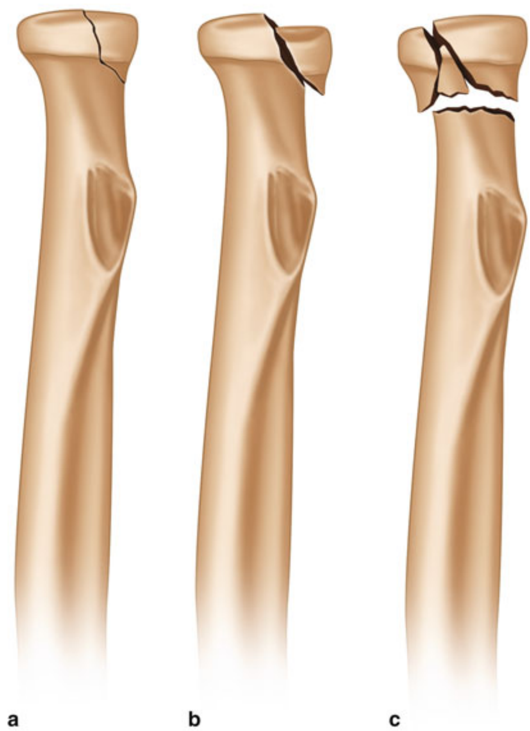

Fig. 5.3 Mason classification of radial head fractures. (**a**) Type I—Fissures or marginal fractures without displacement; (**b**) Type II—marginal sector fracture with displacement (Segment of the lateral border of the radial head is separated from the other quadrants, is impacted and depressed, or is tilted out of line) (**c**) Type III—Comminuted fractures involving the whole head of the radius

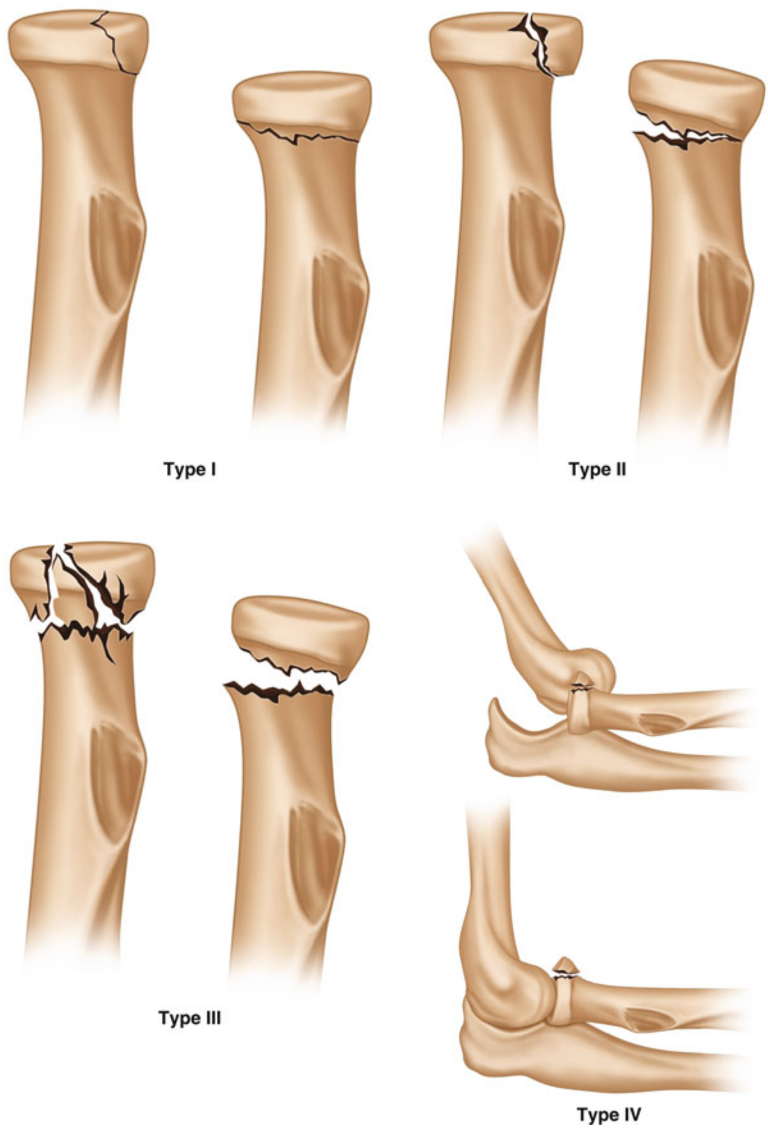

Fig. 5.4 Hotchkiss modification. Type I—nondisplaced or minimally displaced (<2 mm) fractures of the radial head or neck with no mechanical block, Type II—displaced fractures (>2 mm) that are reparable and may have a mechanical block to motion, Type III—comminuted fractures that are not reparable that require excision or replacement, Type IV—radial head fracture with ipsilateral ulnohumeral dislocation

and Morrey into three categories based on the size of the fragment as seen on a perfect lateral radiograph of the elbow [17, 18]. Type I fractures involve only the tip of the coronoid process, which does not have any soft tissue attachments and thus often does not require fixation. Type II fractures involve less than 50 % of the height of the coronoid process. The brachialis and anterior capsule have attachments attach to this portion of the coronoid [19–21]. Type III fractures involve more than half of the coronoid and render the elbow unstable. Because the anterior band of the ulnar collateral ligament inserts at the base of the coronoid, these fractures cause instability both posteriorly and to valgus stress [22]. A modification of the system later added a "B" to represent the presence and an "A" to indicate the absence of an associated elbow dislocation (Fig. 5.5). This classification system has prognostic implications, as larger fractures were associated with worse outcomes due to greater instability of the elbow joint [17]. This classification system predates the routine use of advanced imaging and does not provide information about the mechanism of injury or the

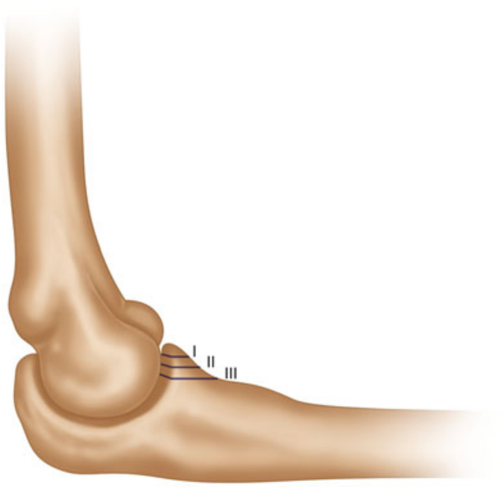

Fig. 5.5 Regan and Morrey classification of coronoid fractures. Type 1—avulsion of the tip, Type II—fracture involving <50 % of the coronoid process height, Type III—fracture involving >50 % of the coronoid process height

obliquity of the fracture. However due to its simplicity and prognostic utility it remains a useful and popular classification in the management of coronoid fractures.

The availability of CT scans has advanced our ability to accurately delineate the morphology of coronoid fractures. In 2003 a new classification system was proposed by O'Driscoll in order to improve the description of coronoid fracture patterns [23]. This system accounts for the mechanism of injury, provides information regarding associated osseous and soft tissue injuries and ultimately guides treatment. The classification is comprised of three main types: type I is a transverse fracture of the tip of the coronoid process, type II is a fracture of the anteromedial facet and type III is a fracture of the base of the coronoid. These three types are further subdivided based on the severity of involvement (Fig. 5.6).

In the O'Driscoll classification, type I fractures involve the tip of the coronoid process but do not extend medially into the sublime tubercle, anteromedial facet, or distally into the coronoid body. They are transverse in orientation and usually include the insertion of the anterior capsule [24]. These fractures occur due to a shearing mechanism as the coronoid is driven against the distal humerus during an elbow dislocation. Type I fractures are further sub-classified into two types, based on the size of the fractured tip: subtype 1 involve less than 2 mm of bone and subtype 2 fractures involve more than 2 mm of the coronoid tip. Tip fractures are the most commonly encountered pattern in a classic terrible triad injury.

Type II fractures involve the anteromedial aspect of the coronoid process (anteromedial facet) and are associated with a varus and posteromedial mechanism of injury. These fractures are often associated with disruption of the lateral collateral ligament (LCL) and can result in persistent elbow instability leading to rapid posttraumatic arthritis if not recognized and appropriately treated. Not all fractures require surgical repair but identification of this injury pattern is necessary as indications for surgery differ compared to tip fractures. In addition to LCL disruption the medial collateral ligament (MCL) can also be involved in the injury pattern. Anteromedial subtype 1 fractures are located between the tip of the coronoid and the sublime tubercle, with the fracture line exiting medially at the cortex in the anterior half of the sublime tubercle. Laterally, the fracture line exits just medial to the tip of the coronoid. In sub-type 2 fractures the fracture line extends laterally to include the tip of the coronoid process. Sub-type 3 fractures are characterized by having the entire sublime tubercle involved. Type II subtype 3 fractures, by definition, involve the insertion of the anterior bundle of the MCL. Anteromedial facet fractures are most commonly associated with posteromedial rotatory instability of the elbow, not posterolateral rotatory instability seen in terrible triad injuries. In general, these fractures do not typically occur in a classic terrible triad injury although very rarely can be seen.

Basal coronoid fractures (type III) involve the body of the coronoid, indicated by the fracture involving at least 50 % of the height of the coronoid. These fractures are often associated with a less severe soft-tissue injury compared with the tip and anteromedial fracture patterns. The differentiation between basal subtype 1 and subtype 2 fractures is made based on an associated olecranon fracture. Additionally, subtype 1 fractures

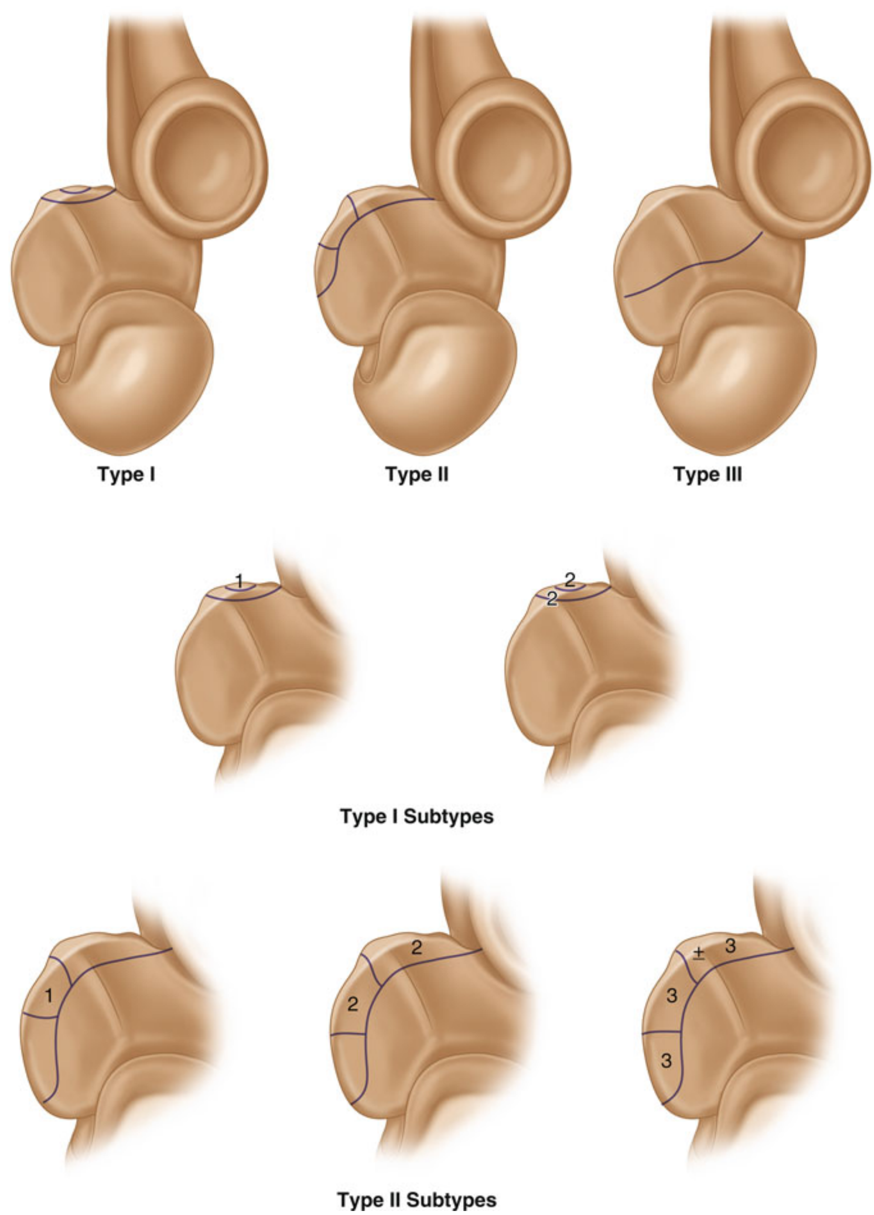

Fig. 5.6 O'Driscoll classification of coronoid fractures (Type 1 tip fractures: subtype 1— <2 mm, subtype 2— >2 mm; Type 2 anteromedial facet fractures: subtype 1—amteromedial rim, subtype 2—anteromedial rim and tip, subtype 3—anteromedial rim and sublime tubercle ± tip; Type 3 basal fractures—subtype 1—coronoid body and base, subtype 2—transolecranon basal coronoid fracture)

are typically fragmented, extend into the proximal radioulnar articulation and are often associated with a radial head injury as well. Basal injuries can rarely be seen in terrible triad injuries but more commonly in fracture dislocation patterns involving a fracture of the olecranon process (posterior Monteggia fracture-dislocation).

Injury to the Lateral Collateral Ligaments

In addition to bony fractures, terrible triad injuries also compromise the lateral ligamentous stabilizers of the elbow. The lateral ligamentous stabilizers include the lateral ulnar collateral (LUCL), the radial collateral (RCL), and the annular ligaments. In 2003 McKee and his coworkers described the pattern of lateral soft-tissue injury in a series of patients with elbow dislocations and fracture dislocations requiring open operative repair [25]. Six injury patterns to the lateral stabilizers were described: (1) proximal avulsion of the lateral ligaments, (2) bony avulsion fracture of the lateral epicondyle, (3) mid-substance rupture of the lateral ligaments, (4) ulnar avulsion of the LUCL at its insertion, (5) ulnar bony avulsion of the LUCL at the supinator crest (cristae supinatoris) and (6) a combination of 2 or more of the described patterns. The most common pattern in their series was proximal avulsion of the lateral ligaments, which was encountered in 52 % of patients (32 of 62 patients). In 41 cases (66 % of patients) a concomitant rupture of the common extensor origin was also discovered [25].

Treatment Algorithm

Following closed reduction of a complex elbow dislocation, the joint often remains unstable and incongruent. Prolonged immobilization is fraught with complications and can lead to either long-term stiffness or continued instability. Thus most terrible triad injuries are most appropriately managed with surgical fixation except a very isolated group that can be considered for nonoperative management.

A step-wise approach aids in addressing all the critical components of this injury complex if surgical repair is performed. This includes fixation or replacement of the radial head, fixation of the coronoid fragment and repair of the lateral collateral ligament. Once this has been completed, the elbow is assessed for stability to determine the need for adjunctive treatment such repair of the medial collateral ligament or placement of an external fixator.

Nonoperative Strategies/Therapy Protocols

Initial treatment involves closed reduction and splinting with radiographs to confirm concentric elbow joint reduction. If reduction cannot be obtained or maintained, repeated attempts at closed reduction should not be attempted. Repeated reduction maneuvers are postulated to contribute to the formation of heterotopic ossification about the elbow. Because this injury complex is particularly prone to instability, patients can knowingly or unknowingly dislocate while immobilized in a long arm cast. Even if cast immobilization is successful at maintaining a concentric reduction over time, it precludes early range of motion and leads to contracture. In general, several criteria are required for patients being considered for nonoperative treatment. These include: (1) obtaining and maintaining a concentric reduction of the ulnohumeral and radiocapitellar joints, (2) the reduction must remain stable through a functional arc of motion (within 30° of full extension) and thus allow for early active motion, (3) patients should have small (type I or type II) minimally displaced coronoid fractures, and (4) pronation/supination should be tested to insure the radial head fracture does not cause a mechanical block to motion. Patients should be able to perform supine overhead passive flexion and extension exercises without crepitation or the sensation of instability. Regular weekly surveillance radiographs are required for the first 3–4 weeks to ensure maintenance of a concentric elbow joint.

A recent study reviewed a small series of select patients with terrible triad injuries of the elbow treated nonsurgically utilizing the previously described criteria. The authors reported mean MEPI score of 94 and demonstrated acceptable post injury range of motion (mean flexion 134°, extension 6°, pronation 87° and supination 82°) and strength (strength as mean percentage of the contralateral unaffected elbow: flexion 100 %, extension 89 %, pronation 79 %, and supination 89 %) [26]. 36 % of patients went on to have some radiographic evidence of arthritis and two patients required surgery, one for early recurrent instability and a second for arthroscopic debridement of heterotopic ossification. Overall, these are comparable results to surgically repaired injuries although strict criteria must be used to attempt nonoperative treatment for it to be successful. While a very select group of these injuries can be treated without surgery it is rare and operative fixation is indicated in most cases.

Surgical Management/Technique-Based/Surgical Pearls

A systematic approach helps to address the critical components of this injury and has been shown to improve clinical outcomes [9]. Traditionally this includes fixation or replacement of the radial head, fixation of the coronoid fragment and repair of the LCL. Once this is completed the elbow is reassessed for stability, to determine the need for repair of the medial collateral ligament and whether an external fixator is required.

Patient Set-Up and Surgical Approach

Surgery can be performed under regional or general anesthesia. The patient is typically positioned supine using a arm board or “lazy” lateral with the arm brought over the chest. A nonsterile tourniquet can be applied under the final drapes or a sterile tourniquet can be placed depending on the size of the patient’s arm. Preoperative imaging and fluoroscopy should be available for use intraoperatively. Two types of incisions may be used, either an extensile posterior skin incision or a lateral skin incision. With the posterior incision full-thickness fasciocutaneous flaps are raised starting on the lateral side. The medial flap is only developed if medial exposure is required for medial collateral ligament repair or ulnar nerve release.

The injury is initially exposed via a lateral arthrotomy. The injured structures are identified from superficial to deep. The deep lateral approach is performed either through Kocher’s (Fig. 5.7) or Kaplan’s interval or a combination of both. Typically the lateral collateral ligament complex with the common extensor is avulsed off the lateral epicondyle and either the Kaplan or Kocher interval or both can be developed distally to gain access to the radial head and coronoid [25, 27]. Although usually not necessary, releasing a portion of the extensor origin from the lateral supracondylar ride of the humerus can improve lateral exposure. Distally, the annular ligament is incised and later repaired. Deep to the common extensor tendon, the origin of the lateral ligament complex is assessed. Often, the common extensor and the lateral ligament complex are detached as a unit and do not need separation but rather are repaired en mass. Commonly a bare lateral epicondyle is encountered, consistent with a complete proximal avulsion of the LUCL [25]. Next the radial head is assessed. The decision to proceed with either radial head fracture fixation or replacement with arthroplasty is made based on the age of the patient, the degree of comminution and bone quality. If the radial head fracture is deemed repairable attention is turned to fixation of the coronoid process. However, if arthroplasty is planned then a radial neck osteotomy is performed in preparation for the prosthetic implant. The radial neck osteotomy and removal of the remaining head fragments have the benefit of dramatically improving exposure of the fracture bed of the coronoid process from the lateral side.

When the radial head is amenable to fixation, visualization of the coronoid injury can be challenging. Several maneuvers can assist with visualization and exposure from the lateral arthrotomy. The fragments of the radial head, if loose, can be temporarily removed from the wound. Alternatively, the fragments can sometimes be hinged distally on their intact soft tissue attachments. If additional exposure is still required the elbow joint can be subluxed posterolaterally to deliver the coronoid into the field of view. In some cases, a separate medial approach will be needed for adequate exposure and internal fixation of the coronoid fracture. This is more common in cases where the radial head fracture fragments are small and reparable precluding good coronoid exposure and/or the coronoid fracture is large, comminuted, or preferentially involves the anteromedial facet.

Coronoid Fracture Fixation

Surgical repair and stabilization are carried out from deep to superficial, and the coronoid injury is addressed first. Fixation of the coronoid fracture depends on its size and degree of comminution [21, 22, 24]. Small O’Driscoll type 1

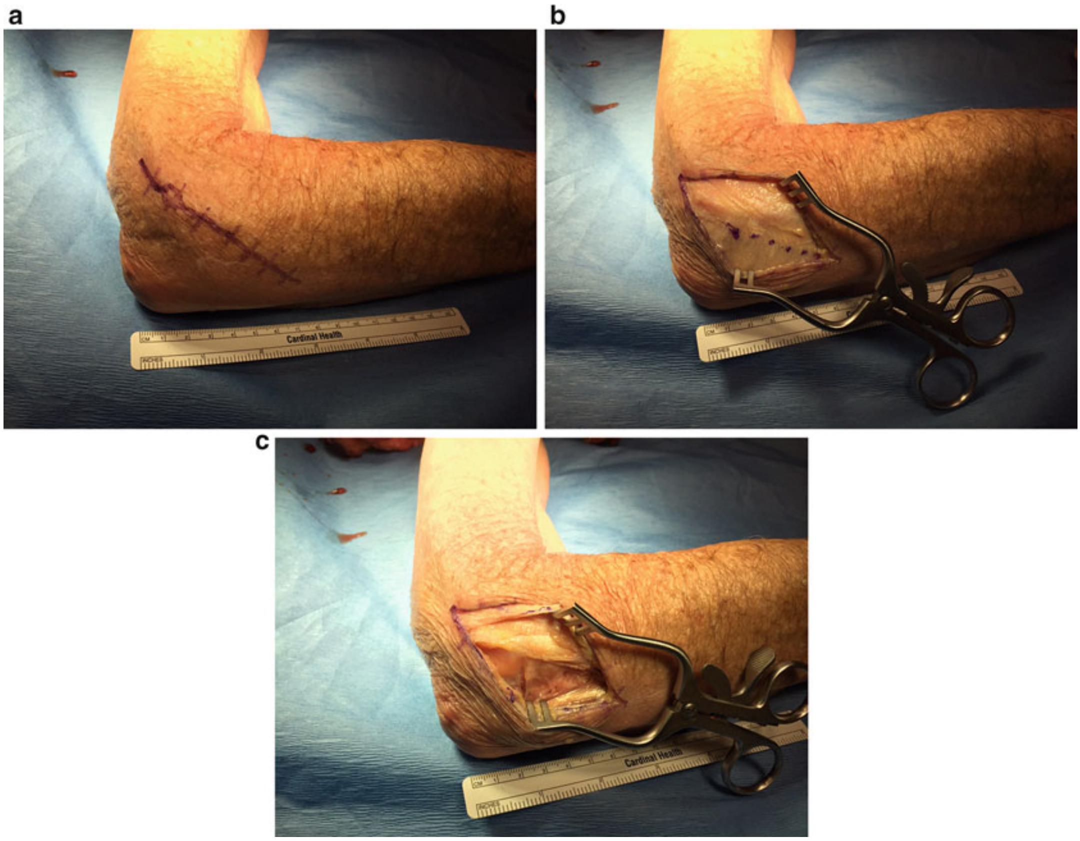

Fig. 5.7 Posteriolateral approach to the elbow (Kocher) (**a**) Skin incision begins proximal to the lateral epidondyle and is carried distally and obliquely to a point 5 cm from the tip of the olecranon on the ulna. (**b**) In line with its fibers, the interval between the Anconeus (*target sign*) and the Extensor Carpi Ulnaris (*open circle*). (**c**) the Anconeus (*target sign*) is retracted dorsally and the Extensor Carpi Ulnaris (*open circle*) is retracted volarly to reveal the underlying deep structures

fractures can often be ignored as there is minimal bony compromise and the benefits of anterior capsular repair are minimal. If fixation is needed for stability this can be accomplished with sutures passed through drill holes from the dorsal aspect of the proximal ulna into the fracture bed and can be facilitated by utilizing a targeting guide (Fig. 5.8). This device can typically be found in any anterior cruciate ligament (ACL) reconstruction tray. In Type 1 fractures with only a small osseous fragment, sutures provide more reliable fixation than screws.

The requirement for fixation of small coronoid tip fractures remains controversial. Recent research has called into question the need for coronoid fracture fixation [28]. Terada et al. [29] and Josefsson et al. [30] both reported that chronic elbow instability was more common in patients with smaller fractures of the coronoid process. The authors suggested that even small coronoid fractures should be repaired to reconstruct the anterior buttress provided by the anterior capsule. 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 [31]. Repair of the collateral ligaments was found to be more critical than suture fixation of the coronoid process in the treatment of small type I coronoid fractures [31]. However, because the overwhelming majority of published protocols still support coronoid or anterior capsule fixation, repair of even small coronoid fractures is currently the standard [6, 12, 21, 32].

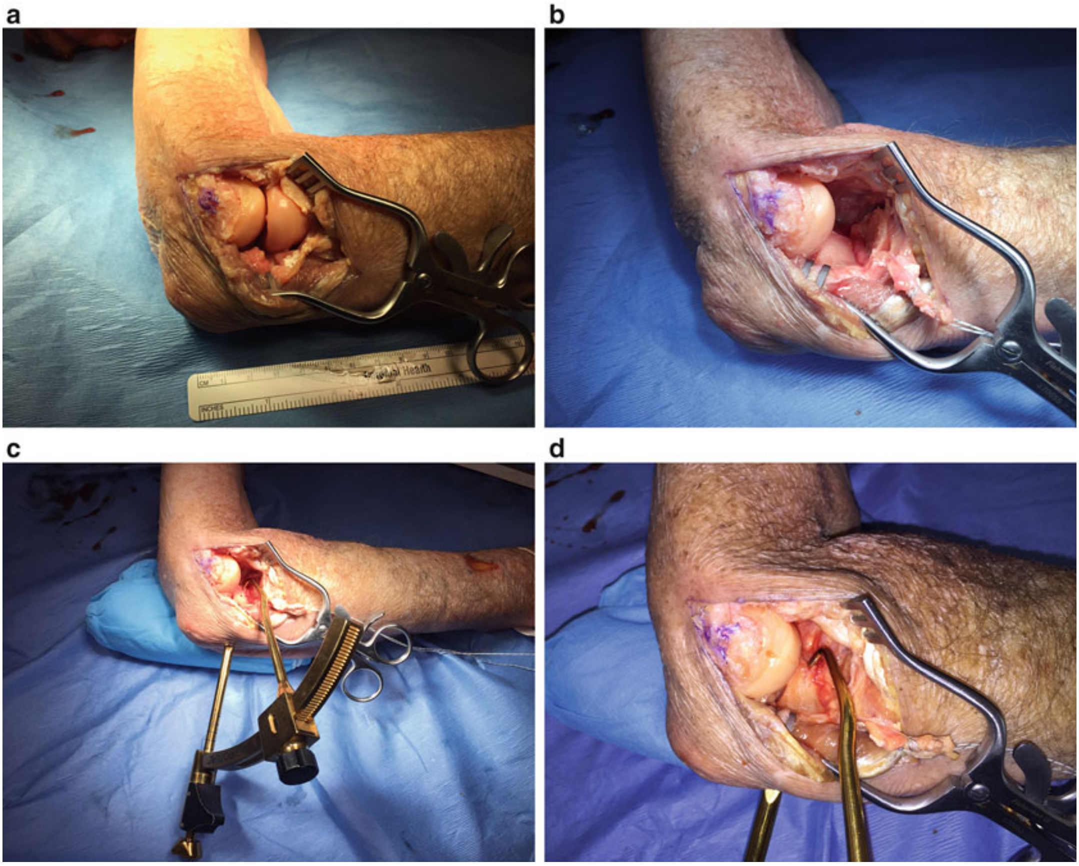

Fig. 5.8 Coronoid fracture fixed with targeting guide. (**a**) lateral joint exposure (**b**) radial head resection (**c**) targeting guide into the coronoid fracture bed (**d**) drilling transosseous tunnels in the proximal ulna

For larger transverse fragments the suture is passed through drill holes in the fragment and is also passed through the capsule. With larger osseous fragments screw fixation can be performed with a large pointed reduction forceps to hold the fracture reduced while an ACL drill guide is utilized to pass a guide wire from the proximal posterior ulna into the coronoid fragment. A partially threaded cannulated screw can then be advanced over the guide wire and the fracture is compressed. If the size of the coronoid fragment allows, a second screw is placed in the same manner. Anatomic reduction of the fracture is often challenging and is likely unnecessary as long as the anterior buttress and capsular attachments are securely restored [21].

A medial approach offers excellent visualization of the entire coronoid, including the base. Fixation from the medial side can also be achieved with targeted screws into the coronoid through the dorsal surface of the ulna. Larger fracture fragments or fractures with medial comminution can be repaired using fracture specific plates or mini-fragment plates molded to the contour of the medial coronoid. Various medial approaches are available including a split of the flexor pronator, a flexor carpi ulnaris splitting approach through the bed of the ulnar nerve or the Taylor-Scham approach between the ulnar shaft and the ulnar head of the flexor carpi ulnaris. Each of the these approaches has been previously described in Chap. 3.

Radial Head Fractures

The goals of treatment for the fracture of the radial head are to have a stable construct allowing the radial head to function both as an elbow stabilizer and also permitting early protected mobilization. In general, aggressive operative treatment of radial head injuries restoring the load bearing capacity of the lateral column is preferred in patients with terrible triad injuries. Because the radial head is an important secondary stabilizer, excision in the setting of complex elbow instability is contraindicated acutely [33]. The radial head resists valgus load when the MCL is injured and acts as a buttress to posterior instability with a deficient coronoid [34, 35]. Additionally, it restores the lateral column of the elbow, acting to tension the repaired lateral ligaments resisting varus and posterolateral rotatory instability. Previous studies have demonstrated elbow instability and posttraumatic arthrosis following resection of the radial head in complex elbow dislocations [7]. Therefore, the preferred surgical treatment options in the setting of terrible triad injuries include open reduction and internal fixation (ORIF) or radial head arthroplasty.

The decision between performing open reduction and internal fixation is based upon several factors including fracture location, number of fragments, and comminution. Previous studies have demonstrated inferior outcomes in radial head fractures with greater than three articular fragments treated with open reduction and internal fixation [30]. In a series of 56 radial head fractures treated with ORIF, 13 of the 14 Mason Type III fractures with more than three fragments had unsatisfactory results in contrast to all 15 Mason type II fractures which had satisfactory results [36]. A recent study compared radial head fractures treated with ORIF versus radial head arthroplasty in patients with terrible triad injuries [31]. All patients were managed with a standard algorithm consisting of either repair or replacement of the radial head, repair of the lateral ligaments and repair of the coronoid fracture. The decision to replace or repair the radial head was based on the number of articular fragments; patients with three or less fragments underwent internal fixation. With a minimum of 18 months of follow-up no differences were found in DASH score, Broberg-Morrey index, or in overall range of motion. All patients that underwent arthroplasty at the index procedure had a stable elbow at final follow-up where as 3 or 9 patients in the ORIF group were found to have residual instability. However, 37 % of the patients in the arthroplasty group demonstrated radiographic signs of arthritis compared to none in the ORIF group [37]. Based upon this data, open reduction internal fixation will likely reduce the long-term chance of developing arthritis but should only be considered in patients in whom stable fixation can be achieved with good bone, no comminution, and a limited number of fragments. Otherwise, arthroplasty provides a more reliable outcome in terms of restoring stability.

Radial Head Fracture Open Reduction and Internal Fixation

Open reduction and internal fixation is reserved for radial head fractures with three or fewer fragments, good bone quality, minimal comminution, and ideally when there is not complete disruption at the radial neck. Advances in contemporary techniques have improved surgical outcomes using internal fixation [36]. Variable pitch headless screws, 1.5 or 2.0 mm cortical mini-fragment screws, pre-contoured radial rim and neck plates, T-plates, mini-condylar plates, and absorbable pins have all been described for the restoration of the fractured radial head and neck.

The articular surface should be reduced under direct visualization using a dental pick or small point-to-point reduction forceps, and should be confirmed with fluoroscopic imaging. Provisional fixation is obtained with small diameter Kirschner wires. Hardware is then placed with the goal of achieving enough stability to allow postoperative functional mobilization (Fig. 5.9). Headless or countersunk screws are utilized to avoid radiocapitellar chondrolysis. Additionally, careful attention to screw lengths will avoid radioulnar joint penetration and avoid painful rotation, diminished range of motion and osteoarthritis. If the fracture pattern involves extension into the radial neck, then operative fixation usually requires the addition of a plate. The nonarticulating portion of the radial head is referred to as the "safe zone" [38–40] which is the preferred region of plate placement. The safe zone corresponds to an approximately 90–110° arc of radial head sur-

Fig. 5.9 X-rays of ORIF of the radial head (**a**) Anterior–posterior (**b**) Lateral

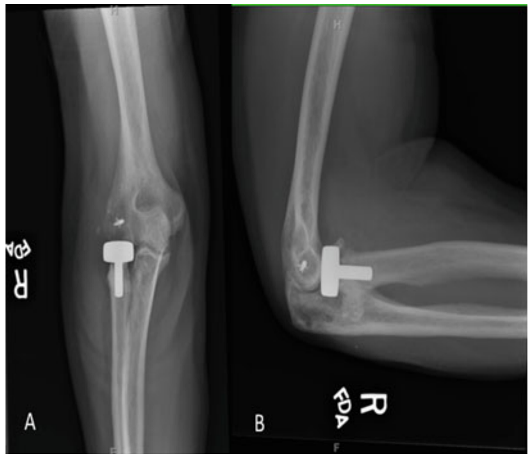

Fig. 5.10 X-rays of a radial head arthroplasty (**a**) Anterior–posterior (**b**) Lateral

face and is defined as the lateral portion of the radial head/neck that lies between perpendicular axes through the radial styloid and Lister's tubercle [40]. Application of the plate to the radial side of the neck with the forearm in neutral rotation ensures placement in the "safe zone". Care should be taken to avoid plating distally past the bicipital tuberosity as distal dissection places the posterior interosseous nerve at risk for injury.

Radial Head Arthroplasty

As a result of non-unions and loss of fixation seen with more complex fracture patterns treated with open reduction and internal fixation [36, 41], radial head arthroplasty has become the preferred treatment for acute comminuted fractures (Fig. 5.10). This is particularly relevant in terrible triad injuries where elbow stability is augmented by immediate restoration of lateral column load bearing. The residual head should be resected at the metaphyseal flare to preserve the function of the annular ligament. To provide a stable rim for the prosthesis and aid in accuracy of implant sizing, the maximum amount of radial neck should be preserved.

Optimal sizing of the implant is important in achieving a successful result [42, 43]. Sizing relates to recreation of the normal radial head diameter and radial length. The ideal sized implant should be chosen by comparing the aggregate of the excised fragments of the radial implants to the various radial head size options. In general, downsizing the head diameter slightly is recommended over placing a larger diameter head. If the diameter is too large it will cause undue loading of the margins of the sigmoid notch and potential loss of forearm motion. Reestablishing radial length is critical to normalizing elbow kinematics and stability. That being said an overstuffed radial head will result in pain, diminished range of motion, and capitellar erosion. Under sizing will prevent proper restoration of lateral column loading needed to minimize the risk of persistent instability. Most modern arthroplasty systems are modular allowing for variable head and neck sizing combinations. A trial implant should be inserted to test for stability and motion. To ensure joint congruity and the absence of impingement, the elbow range of motion, both flexion-extension and pronation-supination should be evaluated and documented. To avoid overstuffing, the articular surface of the radial head should lie flush with the proximal aspect of the radioulnar joint at the lesser sigmoid notch just distal to the articular surface of the base of the coronoid. The lateral ulnohumeral joint should be directly visualized to judge for any gapping, as this is the most sensitive intraoperative test for oversizing [42, 43]. Fluoroscopic imaging is then obtained to ensure concentric reduction and appropriate sizing.

Repair of the Lateral Ligament Complex

In most terrible triad injuries, the lateral ligament complex (LUCL and RCL) and common extensor origin are avulsed from the lateral epicondyle. Multiple successful repair techniques including transosseous tunnels and suture anchors have been described [27]. Typically a running locking suture is passed through the lateral ligaments and the posterolateral joint capsule. The isometric point on the lateral epicondyle is then identified at the center of the arc of the capitellum [44]. The sutures are fixed at the isometric point either through a bone tunnel or anchor. The sutures are tensioned with the elbow concentrically reduced in 90° of flexion and full forearm pronation (Fig. 5.11). After the lateral ligament complex is repaired the common extensor layer is repaired in a side-to-side fashion closing Kocher's and/or Kapan's intervals (Fig. 5.12). Reconstruction of the lateral ligaments is rarely needed in the acute setting although it should be considered when these injuries present in a delayed fashion, beyond 6 or 8 weeks, where the elbow has been subluxated and the tissue quality is compromised.

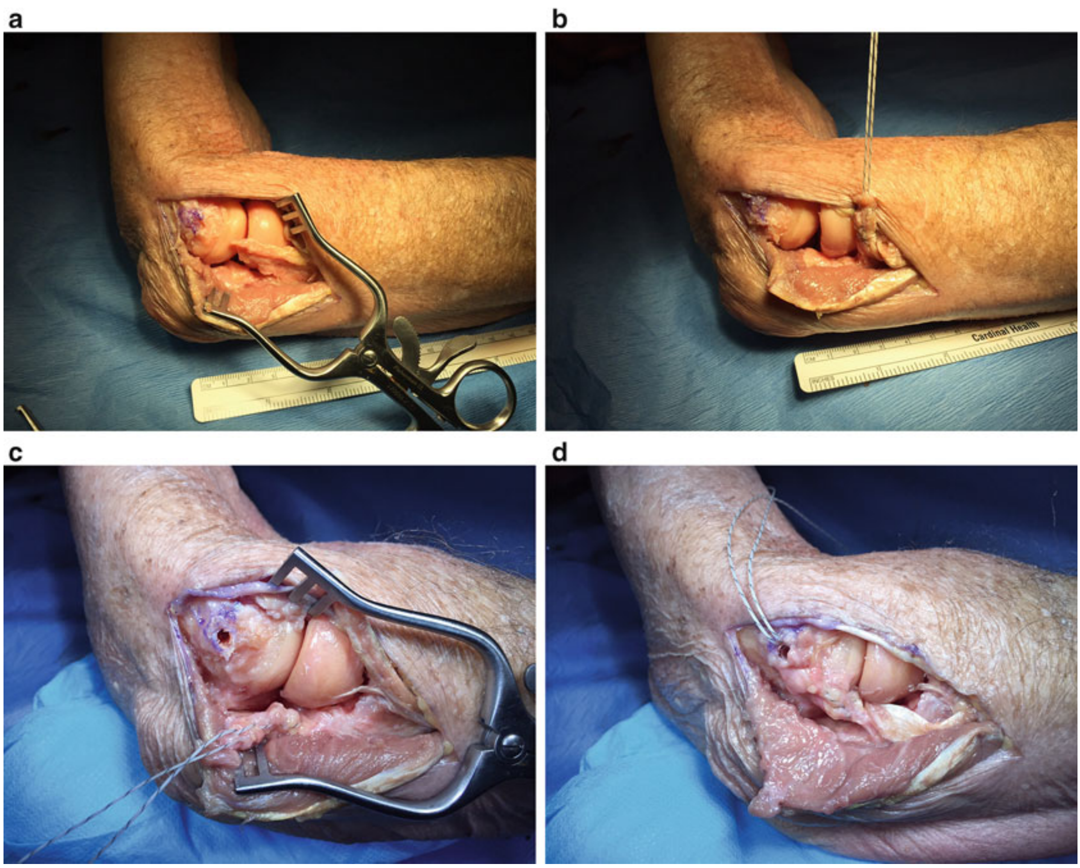

Fig. 5.11 Lateral collateral ligament repair. (**a**) Demonstrates a lateral ulnar collateral ligament (*black arrow*) avulsed off its origin at the lateral epicondyle (*star*). (**b**) The lateral ulnar collateral ligament (*black arrow*) is prepared using an #2 ultrastrong nonabsorbable suture placed using a running locking technique (Krachow). (**c**) A drill hole is placed for a suture anchor at the isometric point on the lateral epicondyle (*arrow*). (**d**) The lateral collateral ligament tensioned and repaired (*solid black lines*) using an anchor while the elbow is held in approximately 90° of flexion

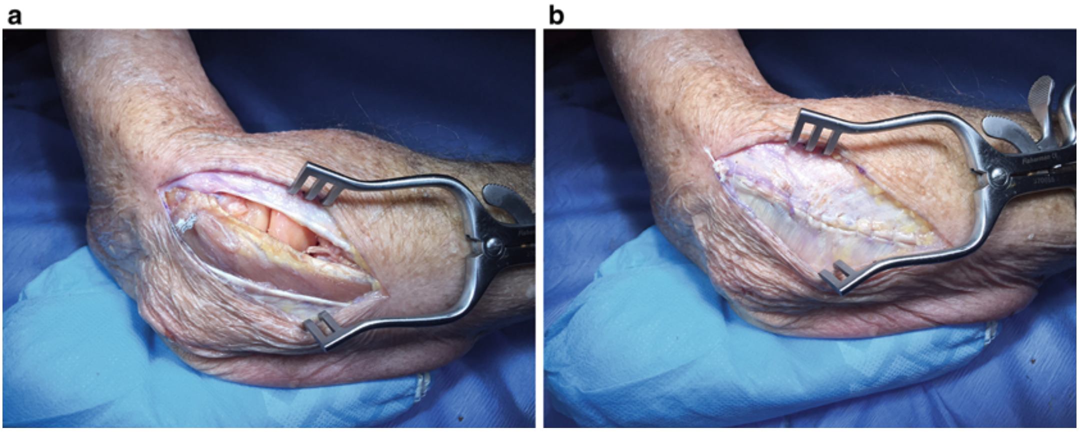

Fig. 5.12 Repair of the common extensor tendons and fascial closure. (**a**) The anconeus (*target sign*) and common extensor tendon are incorporated into the repair, (**b**) The overlying fascia is repaired

Persistent Instability

After repair of the coronoid, fixation or replacement of the radial head and repair of the lateral ligaments joint stability should be assessed throughout flexion extension of the elbow in neutral rotation. Ideally the ulnohumeral joint should demonstrate no asymmetric gapping or subluxation out to 30° shy of terminal extension with the forearm in neutral rotation or pronation. On occasion persistent instability that would limit early postoperative range of motion is encountered. In this circumstance further surgical efforts are required to obtain joint stability. If the lateral incision has been utilized, repair of the MCL through a separate medial incision is indicated. If a posterior incision has been utilized the MCL can be repaired by elevating a full-thickness medial flap and performing a deep approach to the MCL just anterior to the ulnar nerve. The ulnar nerve at risk during this approach and it is imperative that the nerve be identified and protected during the MCL repair. If the elbow remains unstable after repair of the MCL then application of a hinged external fixator is the final option to salvage early postoperative range of motion [45–48]. Alternatively placing a static external fixator can be performed to maintain a concentric reduction of the joint for 3–4 weeks and then removed to allow graduated range of motion.

Application of the hinged fixator begins with the insertion of a center axis guide pin through the center of elbow rotation aided by fluoroscopic guidance. This pin can be placed either from the lateral or medial side of the joint. After verifying on orthogonal views that the pin is through the center of rotation, the elbow is held reduced while the frame is assembled around it. Two pins are inserted into the humerus above the elbow through small open incision to ensure the radial nerve and its branches are protected. Two pins are placed into the ulna at its subcutaneous border. The pins are affixed to the hinge and the construct is tightened. The guide pin is then removed. Next the elbow is taken through a functional range of motion from 30 to 130° to confirm that the joint remains reduced.

Alternative Surgical Protocols

Other operative treatments include “internal” hinged fixation, and static external fixators for persistent instability of complex fracture dislocations. Although effective in select situations these methods all have drawbacks. Orbay et al. published results on the use of an internal stabilizer fashioned from a Steinmann pin to manage complex fracture-dislocations of the elbow [49]. Their technique utilizes a bent Steinmann pin introduced through the axis of ulnohumeral

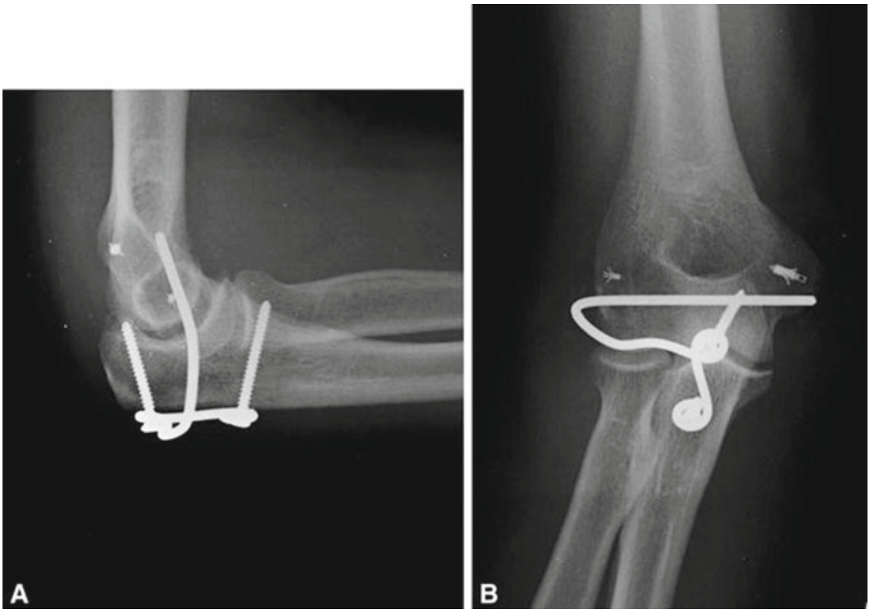

Fig. 5.13 Internal elbow hinge (**a**) Anterior–posterior (**b**) Lateral (Courtesy of Jorge Orbay, MD Miami Hand & Upper Extremity Institute)

rotation and fixed to the proximal ulnar shaft (Fig. 5.13). They reported on a series of ten patients treated with their device, which acts as an internal hinged fixator. Mean range of motion at latest follow-up was flexion 134°, extension −19°, pronation 75°, and supination 64°. All elbows were clinically and radiographically stable. Complications resulting in additional procedures occurred in four patients. They concluded that their device allowed early postoperative range of motion of the elbow in patients that demonstrated persistent elbow instability without out the need to place a device that requires transcutaneous pins [49].

In some patients the ligamentous and bony disruption of the elbow does not allow application of a hinged external fixation device, in these cases static external fixation may be utilized to obtain and maintain joint stability. Range of motion may be started after removal of the static fixator. Eventual secondary procedures such as capsular releases may be necessary to reach maximum range of motion. Both static and hinged external fixators neutralize forces across the injured segment until the joint has healed enough to accept those forces.

Although not widely utilized, several centers have successfully treated terrible triad elbow injuries with a protocol that involves placing a single 4.5 mm large fragment cortical transarticular screw from the medial proximal ulna into the lateral distal humerus for persistent instability (Fig. 5.14). This screw is placed utilizing fluoroscopic guidance in the operating room and the patient is placed into a long arm cast for complete joint immobilization. After 3–4 weeks, the patient is taken back to the operating room where the transarticular screw is removed and the joint is check for stability. If the elbow remains concentrically reduced through a functional arc of motion then a hinged elbow brace is applied and a range of motion protocol is begun. If any concerns for instability remain, the patient is placed back into a long arm cast and followed up in clinic in 2–3 weeks at which point the motion protocol is begun. Caution should be utilized when incorporating these alternative surgical techniques into the operative treatment of terrible triad injuries as future research is still required to guide the surgical indications for their use and to elucidate the appropriate patient or injury characteristics that may require them.

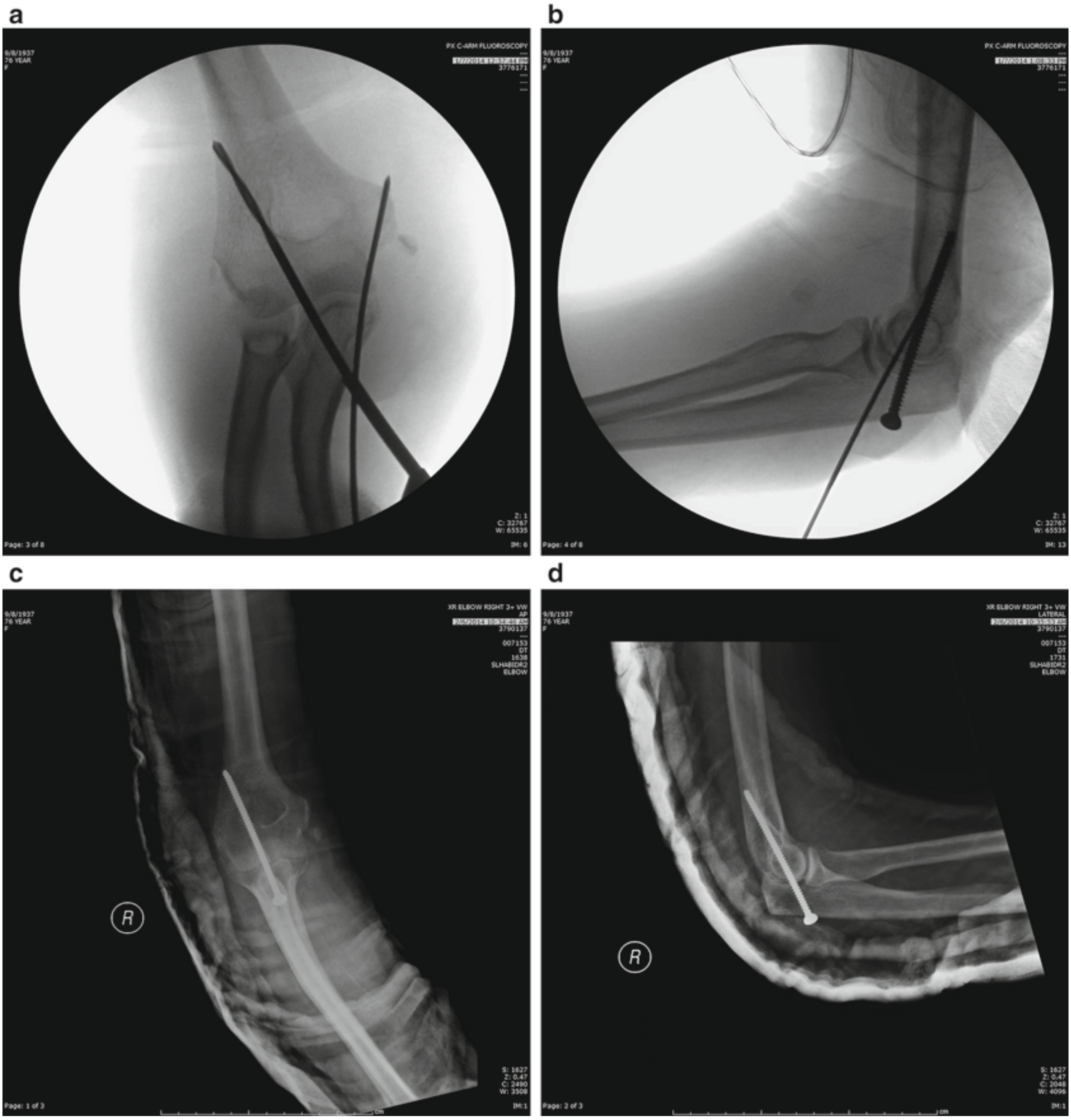

Fig. 5.14 Trans-articular screw (**a**) Fluoroscopic intraoperative anterior–posterior (**b**) Fluoroscopic intraoperative lateral (**c**) Postoperative anterior–posterior radiograph (**d**) Postoperative lateral radiograph

Published Outcomes/Complications

Outcomes

A retrospective review of 36 consecutive patients with an elbow dislocation and an associated fracture of both the radial head and the coronoid documented the outcomes of a standardized surgical protocol utilizing current surgical techniques [9, 50]. The authors surgical protocol included fixation or replacement of the radial head, fixation of the coronoid fracture if possible, repair of associated capsular and lateral ligamentous injuries, and in selected cases repair of the medial collateral ligament and/or adjuvant-hinged external fixation. Patients were evaluated both radiographically and with a clinical examination at the time of the latest follow-up. At a mean of 34 months postoperatively, the flexion-extension arc of the elbow averaged 112° ± 11° and forearm rotation averaged 136° ± 16°. The mean Mayo Elbow Performance Score was 88 points (range, 45–100 points) and corresponded to 15 excellent results, 13 good results, seven fair results, and one poor result. Concentric stability was restored to 34 elbows. Eight patients had complications requiring a reoperation: two developed a synostosis; one developed recurrent instability; four required hardware removal and elbow release; and one developed a wound infection. They concluded that a standardized systematic surgical protocol for terrible triad fracture-dislocations of the elbow restored sufficient elbow stability to allow early motion postoperatively and reasonable functional outcomes.

Another retrospective study reported on the results of all patients aged 18 years or older whom underwent surgical treatment for "terrible triad" elbow fracture dislocation at one institution over a 7 year period [10]. Surgical treatment involved fixation or replacement of the radial head, repair of the anterior capsule or coronoid fracture in most cases, and repair of the lateral collateral ligament. Outcomes included grip strength, range of motion, Disabilities of the Arm, Shoulder, and Hand (DASH) questionnaire score, and a visual analog score for pain as well as radiographic assessment. Eleven patients were presented; seven patients had suture fixation of the coronoid fragment and anterior capsule, two had screw fixation of the coronoid, and two had no repair of the coronoid. The radial head was replaced in nine patients and repaired in one, and a fracture fragment was excised in another. The average follow-up for the cohort was 38 months. The average arc of motion of the injured elbow was 112° and that of the contralateral elbow was 142°. The average DASH score was 19.7 (scale, 0–100), with the mean visual analog pain score being 2.2 (scale, 0–10). No patients had recurrent elbow instability. Three patients underwent further surgical procedures, all for loss of motion. The authors concluded that a systematic approach to the fixation of "terrible triad" elbow fracture dislocations provides predictable elbow stability and functional range of motion in the medium term.

In a retrospective series over a 5 year period, a single surgeon reported on 22 patients with the terrible triad injury complex of the elbow [52]. Operative treatment consisted of open reduction internal fixation (ORIF) or prosthetic replacement of all fractures of the radial head and coronoid and reattachment of the origin of the lateral collateral ligament (LCL) complex to the lateral epicondyle. The MCL was not repaired in any of the 22 patients. Postoperatively one patient had instability that was attributed to noncompliance and required revision surgery. At an average of 32 months after injury, patients had an average of 117° ulnohumeral motion and 137° forearm rotation, and 17 of 22 patients (77 %) had good or excellent results. This author concluded that MCL repair is unnecessary in the treatment of dislocation of the elbow with associated intra-articular fractures provided that the articular fractures and the LCL are repaired or reconstructed.

In a multicenter study of patients with terrible triad injuries, Pierrart et al. reported on a series of 18 patients treated operatively [11]. At an average follow up of 31.5 months postoperatively, the mean MEPS score value was 78 (25–100) and corresponded to three excellent results, ten good results, three fair results, and two poor results. Five early and three late complications were reported. The authors recommended that the goals of surgery should be: to restore stability by preserving the radial head whenever possible through repair or replacing it with a prosthesis, by repairing the lateral collateral ligament and performing fixation of the coronoid fracture. If the elbow remains persistently unstable, options include repair of the medial collateral ligament or application of a hinged fixator.

Finally, recent research has challenged the concept that coronoid process fractures in the setting of the terrible triad injury require operative fixation [28]. In a small series of 14 patients that were treated for acute terrible triad injuries (two Regan-Morrey type I and 12 Regan-Morrey type II coronoid fractures) with a surgical protocol that included radial head repair or prosthetic replacement and repair of the LCL only. No coronoid fracture fixation was performed if intraoperative fluoroscopy confirmed stability throughout a full arc of motion after radial head repair or replacement and LCL repair. Repair of the medial collateral ligament or application of external fixation was not performed in any case. At a minimum follow-up of 2 years the mean arc of ulnohumeral motion at final follow-up was 123° (range, 75–140°) and mean forearm rotation was 145° (range, 70–170°). The mean Broberg and Morrey score was 90 and the average DASH score was 14. Radiographs revealed mild arthritic changes in one patient. One patient developed radiographically apparent but asymptomatic HO and none of the patients demonstrated instability postoperatively [28]. These results should be interpreted with caution. Future research is required to corroborate their findings, which demonstrate that terrible triad injuries with type I and II coronoid process fractures could be treated without fixation of coronoid fractures when repair or replacement of the radial head fracture and repair of the LUCL complex sufficiently restores intraoperative stability of the elbow through a functional range of motion underflouroscopy.

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/subluxation, malunion, nonunion, stiffness, heterotopic ossification, infection, and ulnar neuropathy [9, 24, 51–53].

In rare circumstances instability persists following repair of the osseous and ligamentous structures in a terrible triad injury. In two recent series of elbows treated with a modern surgical algorithm for terrible triad persistent postoperative instability ranged from 0 to 15 % [10, 54]. Persistent instability is likely due to unrecognized/unaddressed medial collateral ligament injury, unreconstructable coronoid fracures, chronic dislocations, or failure of repair. In patients in whom the distal humerus is subluxated over the coronoid base, there may be impaction or attritional bone loss, making simple repair of the coronoid insufficient. In these cases, coronoid reconstruction with bone bone graft can be considered; both radial head and olecranon autografts have been described [55, 56].

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 [57, 58]. The major issue with radial head arthroplasty is overstuffing the radiocapitellar joint [42, 43]. This can lead to abnormal radiocapitellar joint pressures causing pain, loss of flexion, capitellar erosion, and subluxation of the ulnohumeral joint. The native radial head should be used as a template whenever possible. If the native radial head falls between sizes, the implant with the smaller diameter or length should be selected. Intraoperatively the proximal portion of the radial head implant should be flush with the proximal aspect of the lesser sigmoid notch.

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. Stiffness that is recalcitrant to nonoperative treatment may be treated surgically with open or arthroscopic capsular release. If heterotopic ossification is associated with stiffness, an open surgical approach is commonly required. Ring et al. [59] 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 and the use of prophylactic measures for heterotopic ossification is controversial. Some authors recommend prophylactic measures only for those patients with a concomitant head injury, burns, or those who have failed initial surgical treatment.

Posttraumatic arthritis can occur because of chondral damage at the time of injury as well as because of residual elbow instability or articular incongruity [7, 45]. The primary rationale for operative treatment is to restore stability to the elbow because early subluxation of the joint will usually lead to rapid posttraumatic arthrosis of the ulnohumeral joint. Treatment options include debridement, radial head excision, radial head arthroplasty, and total elbow arthroplasty depending on the severity of the joint destruction.

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. In deep infections serial surgical débridement with a course intravenous organism specific antibiotics are indicated.

A systematic review of 16 studies, involving 312 patients with terrible triad fracture dislocations treated with surgery demonstrated Mayo elbow performance scores ranging from 78 to 95. Mean DASH scores ranged from 9 to 31. The proportion of patients who required reoperation due to complications ranged from 0 to 54.5 % (overall70/312 [22.4 %]). Most of these complications were related to hardware fixation problems, joint stiffness, joint instability, and ulnar neuropathy. The two most common complications that did not require reoperation were heterotopic ossification (39/312 [12.5 %] patients) and arthrosis (35/312 [11.2 %] patients).

Conclusions

Terrible triad injuries of the elbow remain challenging to treat and require careful examination of the injured limb and accurate assessment of the imaging to determine the extent of the bony and ligamentous injury. In most cases prompt surgical attention with a systematic approach to restore or replace bony anatomy and provide joint stability is indicated. Restoration of elbow stability that allows for early range of motion is felt to be a key factor in successful outcome.

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