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PICTORIAL ESSAY

Terrible triad injuries of the elbow

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Abstract
Terrible triad injury of the elbow is a complex injury that is classically defined as elbow dislocation along with fractures of the coronoid process of the ulna and the radial head. The injury is usually associated with typical soft-tissue disruptions (with common involvement of the lateral collateral ligament complex, elbow joint capsule, as well as the common extensor and flexor–pronator tendons) that are best understood in the context of injury mechanism as well as the role and relevance of the various elbow stabilizers. The goals of this article are to review the pertinent anatomy, mechanism of injury, classification and imaging of terrible triad injuries of the elbow with brief descriptions of treatment, and complications of this complex injury.

Keywords Terrible triad injury of the elbow · Elbow fracture-dislocation · Coronoid fracture · Radial head fracture · Complex elbow dislocation

Introduction

The terrible triad of the elbow was a term coined by Hotchkiss in 1966 and is used to describe a complex injury characterized by elbow dislocation (typically posterolateral) as well as coronoid and radial head fractures (the definition has been extended by some authors to include radial neck fractures) [1, 2]. Historically, most of these injuries were treated conservatively, with poor prognosis and high incidence of treatment failures (seen as redislocation, chronic instability, and elbow osteoarthritis) [3, 4]. A change in treatment paradigms to early surgical treatment for the majority of such injuries has resulted in improved functional outcomes [5, 6].

The goals of this article are to review the pertinent anatomy, mechanism of injury, classification and imaging of terrible triad injuries of the elbow with brief descriptions of treatment, and complications of this complex injury.

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Anatomy

The elbow is a complex joint composed of three distinct articulations (the ulnohumeral, radiocapitellar, and proximal radioulnar joints) that are enveloped by a single synovial capsule. The elbow is a trochleogingylomoid joint, demonstrating hinged (ginglymoid) motion in flexion and extension at the ulnohumeral and radiocapitellar joints, and radial (trochoid) motion in supination and pronation at the proximal radioulnar articulation.

Elbow stability is provided by both osseous and soft-tissue structures [5]. The irregular and highly congruent surfaces of the bones forming the elbow joint along with the capsuloligamentous stabilizers provide the static constraints, while dynamic stability is provided by the muscles that cross the elbow joint. The major elbow joint stabilizers are also divided into primary and secondary stabilizers. Primary stabilization is provided by the ulnohumeral joint (the ulnohumeral joint - specifically the coronoid process- provides an important buttress to the elbow joint, resisting varus stress and preventing posterior dislocation), anterior bundle of the medial collateral ligament, and the lateral collateral ligament complex [7]. Secondary restraint to elbow instability is provided by the radial head (the radial head provides a secondary restraint to valgus instability), flexor pronator, and extensor tendon origins and the joint capsule [8]. An elbow with intact primary constraints would be stable, regardless of the status of the secondary stabilizers. The secondary constraints become critical to elbow joint stability only with disruption of one or more of the primary restraints.

The static soft-tissue stabilizers include the joint capsule and the lateral and medial collateral ligament complexes, which are formed at sites of distinct capsular thickenings. The lateral collateral ligament complex is composed of four distinct structures: the annular ligament, radial collateral ligament (RCL), lateral ulnar collateral ligament (LUCL), and the functionally irrelevant accessory collateral ligament (Fig. 1) [9]. The annular ligament wraps around the radial head and neck and inserts on the anterior and posterior margins of the lesser sigmoid notch of the proximal ulna (this ligament has minor relevance in adult elbow stability). The RCL and the LUCL originate from the inferior margin of the lateral epicondyle of the humerus. Distally, the RCL fibers blend with the annular ligament, while the LUCL courses along the posterolateral margin of the radius and inserts on the supinator crest along the lateral aspect of the proximal ulna, distal to the annular ligament [8]. The LUCL is the primary soft-tissue restraint against varus and posterolateral rotational elbow instability [3, 9].

The medial collateral ligament (MCL) is composed of anterior, posterior, and the functionally irrelevant transverse bundles (Fig. 2) [3]. The anterior bundle of the MCL originates from the anteroinferior aspect of the medial epicondyle of the humerus and inserts on the sublime tubercle of the anteromedial facet of the coronoid process [5]. The posterior bundle originates from the inferior aspect of the medial humeral epicondyle and inserts on the posteromedial margin of the trochlear notch, forming the floor of the cubital tunnel. The anterior bundle is the primary restraint to valgus load, while the posterior bundle provides a secondary restraint to valgus stress and resists internal rotation [5].

Mechanism of injury

Terrible triad injury typically results from a fall on an outstretched hand. As an axial load is applied to the arm, the elbow sustains a valgus load and the distal humerus internally rotates against the fixed forearm, with resultant supination of the forearm relative to the

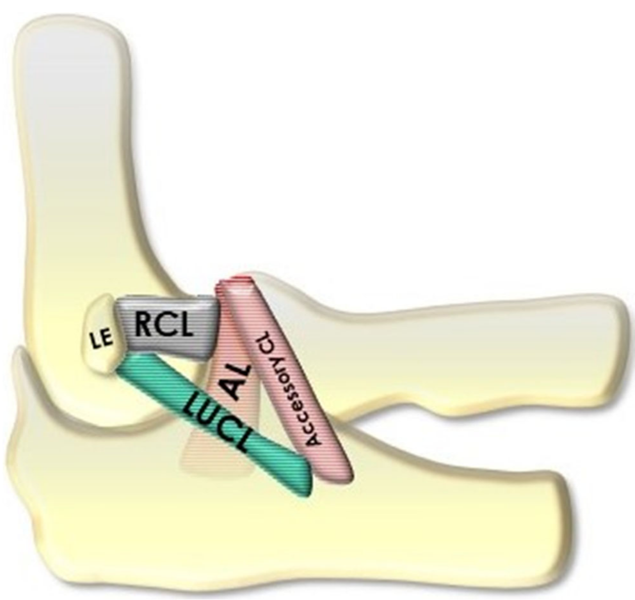

Fig. 1 Lateral collateral ligament complex. Illustration demonstrates the four components of the lateral collateral ligament complex: the annular ligament (AL), radial collateral ligament (RCL), lateral ulnar collateral ligament (LUCL), and the functionally irrelevant accessory collateral ligament (CL). The RCL and the LUCL originate from the inferior margin of the lateral epicondyle (LE) of the humerus. Distally, the RCL fibers blend with the annular ligament, while the LUCL courses along the posterolateral margin of the radius and inserts on the supinator crest along the lateral aspect of the proximal ulna, distal to the annular ligament

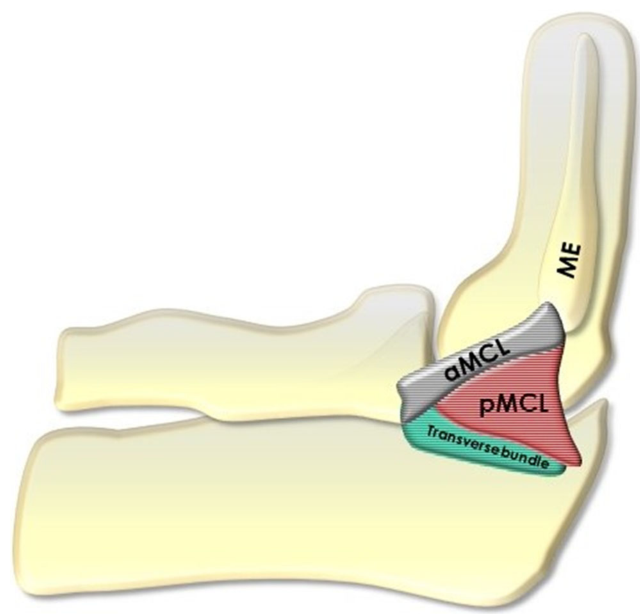

Fig. 2 Medial collateral ligament. Illustration shows the medial collateral ligament components: the anterior (aMCL), posterior (pMCL), and the functionally irrelevant transverse bundles. The anterior bundle of the MCL originates from the anteroinferior aspect of the medial epicondyle (ME) and inserts on the sublime tubercle of the coronoid. The posterior bundle originates from the inferior aspect of the medial humeral epicondyle and inserts on the posteromedial margin of the trochlear notch, forming the floor of the cubital tunnel

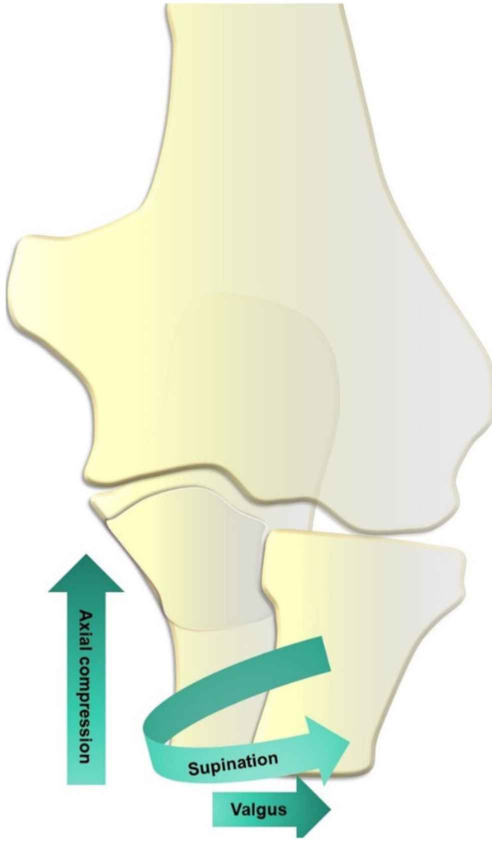

Fig. 3 Mechanism of terrible triad injury. Terrible triad injury typically results from a fall on an outstretched hand. As an axial load is applied to the upper extremity, the elbow sustains a valgus load and the distal humerus internally rotates against the fixed forearm, with resultant supination of the forearm relative to the humerus

humerus (Fig. 3). The coronoid rotates posterolaterally relative to the distal humerus (typically the radius and ulna rotate together as a unit) and with terrible triad injuries there is eventual posterior (typically posterolateral) elbow dislocation, with associated impaction fracture of the radial head and shear fracture of the coronoid process [5]. This injury is commonly associated with capsuloligamentous injuries that typically progress from lateral to medial. Lateral ulnar collateral ligament disruption is sequentially followed by tears of the other components of the LCL complex and the elbow joint capsule and ultimately medial collateral ligament disruption (elbow dislocation can occur without disruption of the MCL) [3]. The common extensor and flexor–pronator tendons are commonly disrupted as well [7].

Classification

Terrible triad injuries are classified based on pattern of coronoid and radial head fractures [5]. Coronoid fractures were classically classified using the Regan–Morrey classification, which is based on the height of coronoid involved with the fracture as delineated on a lateral elbow radiograph. Type I fractures involve the coronoid tip, type II fractures involve < 50% of the coronoid height, and type III fracture encompass > 50% of the coronoid height [10]. Additionally, an "A" or "B" modifier is used for fractures without and with elbow dislocation, respectively.

Currently, coronoid fractures are most commonly stratified using the O'Driscoll classification system (Figs. 4 and 5) [11]. This system stratifies coronoid fractures into three types based on anatomical location (Fig. 4), fracture size, and mechanism of injury. Coronoid tip fractures are coronally oriented fractures that usually occur as a complication of elbow subluxation or dislocation [9]. These fractures are divided into two subtypes based on fracture fragment size: subtype I fractures are ≤ 2 mm and subtype II fractures (Fig. 5a) are > 2 mm and rarely involve > 30% of the coronoid height (coronoid height can be measured on lateral elbow radiographs or 2D or 3D reconstructed CT images, from the trough of the trochlear notch to the coronoid tip).

Anteromedial fractures (Fig. 5b, c) are obliquely oriented fractures that involve the anteromedial facet of the coronoid and are divided into three subtypes: subtype I involves the anteromedial facet without involvement of the sublime tubercle, subtype II extends into the coronoid tip, and a subtype III fracture (Fig. 5b, c) extends into the sublime tubercle, with or without involvement of the coronoid tip. Anteromedial facet fractures are usually varus posteromedial rotatory fracture subluxations.

Basal coronoid fractures have a more direct posterior injury mechanism and involve the coronoid body with at least 50% of the height of the coronoid being fractured. These fractures are divided into two subtypes: subtype I

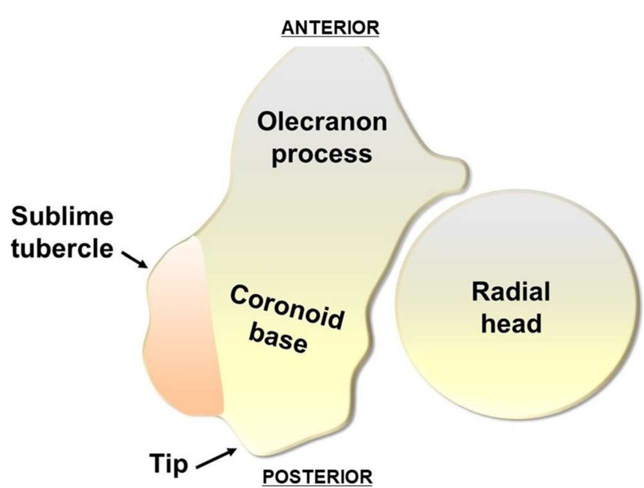

Fig. 4 Pertinent anatomy for classification of coronoid fractures using the O'Driscoll classification system. Orange section represents the anteromedial facet. "Anterior" and "posterior" refer to image orientation

Fig. 5 O'Driscoll classification of coronoid fractures (different patients). **a** Lateral elbow radiograph in a 28-year-old male with terrible triad injury shows posterior elbow dislocation, anteriorly displaced coronoid tip (subtype II) shear fracture fragments (white arrow), and a radial head (black arrows) fracture secondary to impaction against the capitellum. **b**, **c** Anteroposterior radiograph and axial CT image of the elbow in a 33-year-old male shows a comminuted anteromedial subtype III coronoid fracture involving the anteromedial facet (short black arrows) and the sublime tubercle (long black arrow). Coronoid tip (white arrow). **d** Sagittal reconstructed CT image in a 38-year-old male shows a comminuted basal subtype II coronoid fracture with concomitant involvement of the olecranon process (arrows)

involves the coronoid base while subtype II extends into the olecranon process (Fig. 5d). The O'Driscoll classification is useful for predicting associated injuries and elbow instability, as well as planning surgical approach and treatment [11].

The most common types of coronoid fractures seen in terrible triad injuries are coronoid tip and less commonly anteromedial fractures [5]. Although small (≤ 2 mm) coronoid tip fractures may occur in isolation, tip fracture fragments that are larger than 2 mm are almost always a part of a terrible triad injury (Fig. 5a) [5]. Coronoid tip fractures result from shear stress and are not due to avulsion injuries (the anterior elbow joint capsule inserts an average of 6.4 mm distal to the coronoid tip) [4].

Radial head fractures

In adults, radial head fractures are the most common type of elbow injuries and account for approximately 30% of elbow fractures [12]. Radial head fractures are commonly classified using the Mason–Johnston classification [9, 12–14]. Type I fractures (Fig. 6) are nondisplaced or minimally displaced (< 2 mm) fractures. Type II fractures are displaced (> 2 mm) fractures. Type III fractures are comminuted and displaced, whereas type IV fractures (Fig. 5a)

Fig. 6 Radial head fracture. Anteroposterior elbow radiograph in a 41-year-old female shows a minimally displaced, radial head fracture (type I fracture in the Mason–Johnston classification)

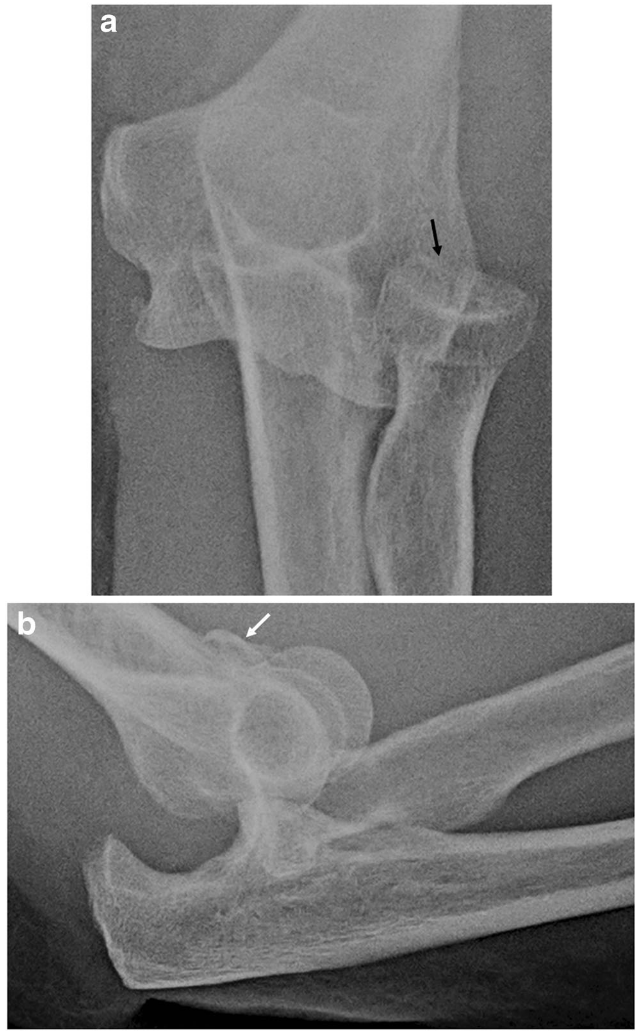

Fig. 7 Terrible triad injury. Anteroposterior (**a**) and lateral (**b**) elbow radiographs in a 70-year-old female show posterolateral elbow dislocation, a mildly comminuted and displaced (up to 2.6 mm) radial head fracture (black arrow), and a displaced (white arrow) coronoid tip fracture (subtype II in the O'Driscoll classification)

are radial head fracture-dislocations (all radial head fractures in terrible triad injures are considered type IV fractures). Although this is the most common classification system used for radial head fractures, the Mason–Johnston classification has low interobserver and intraobserver reliability [9, 12, 15].

Several studies have reported a high incidence of associated elbow ligament and interosseous membrane injuries in radial head fractures [12]. In addition, radial head fractures may be associated with capitellar chondral defects and loose bodies [12]. Therefore, recognition of a radial head fracture should prompt a careful search for associated injuries [9, 12] .

Imaging

Initial imaging of terrible triad injuries consists of standard anteroposterior and lateral elbow radiographs obtained before and after elbow reduction (Figs. 7 and 8). Radiographs of the shoulder, forearm, and wrist are obtained as clinically indicated (ipsilateral upper extremity injuries are seen in 10–20% of patients with complex elbow dislocations) [5]. CT is recommended for detailed characterization of fracture pattern, displacement and comminution, demonstration of intra-articular osseous fragments, and surgical planning (Table 1) [5, 8]. Three-dimensional CT reconstructions have shown to improve interobserver agreement on the classifications of coronoid and radial head fractures [15, 16]. Three-dimensional printing of elbow fractures is useful for surgical planning and physician–patient communication [17]. MRI is not commonly required for evaluation of terrible triad injuries in the acute setting [5].

Treatment

Most terrible triad injuries are treated surgically, with fixation or replacement of the radial head, coronoid fracture fixation, repair of the lateral collateral ligament, and if necessary repair of the medial collateral ligament (Fig. 9) [3, 6]. The goal of surgery is to congruently stabilize the elbow to permit elbow

Fig. 8 Drop sign and evaluation of postreduction joint congruency. Immediate postreduction lateral elbow radiograph in a 41-year-old male with terrible triad injury after closed reduction and splinting. The ulnohumeral joint is incongruent being widened posteriorly and converging anteriorly (indicated by dotted lines). There is widening (5.5 mm) of the ulnohumeral distance (black line), referred to as the "drop sign." Persistent drop sign on follow-up radiographs may be a sign of elbow instability

Fig. 9 Postoperative imaging of terrible triad injury. Anteroposterior radiograph of the elbow in a 16-year-old male shows radial head arthroplasty (patient had a comminuted radial head fracture with significant subchondral bone loss that was unrepairable), coronoid screws, and lateral humeral suture anchors at site of lateral collateral ligament complex repair. Postoperative soft-tissue emphysema is noted

motion. Current surgical paradigms result in satisfactory clinical outcomes in the majority of cases [6].

Complications

Complications of terrible triad injuries include redislocation, residual instability, elbow stiffness, heterotopic ossification (Fig. 10), fracture malunion or nonunion, elbow arthrosis, olecranon bursitis, ulnar or radial nerve palsy (due to the surgical approach or placement of hardware), and hardware-related complications [5, 6].

Table 1 Checklist for radiographic or CT reporting of terrible triad injuries [5, 9, 18, 19]

Element	Comment
Direction of dislocation on prereduction radiographs	Special attention should be paid to the radiocapitellar line: On any radiographic view, a line drawn along the long axis of the diaphysis of the radius should intersect the capitellum. Any deviation is suggestive of subluxation or dislocation of the radial head
Joint congruency on postreduction images	Drop sign (ulnohumeral distance ≥ 4 mm) on routine unstressed postreduction lateral elbow radiographs: Drop sign may be present on immediate postreduction radiographs and usually disappears on follow-up radiographs. Persistent drop sign on follow-up radiographs may be a sign of elbow instability
Joint effusion	Seen as an elevated anterior fat pad and/or a visible posterior fat pad: In the setting of trauma, an occult fracture is likely to be present with elbow joint effusion and a radiographically undetectable fracture. Joint effusion may be absent when elbow fracture or dislocation is associated with a disrupted joint capsule
Characterization and classification of fractures	Radial head fractures may be subtle and only evident on lateral oblique or radial head views
Number and location of intra-articular osseous fragments	

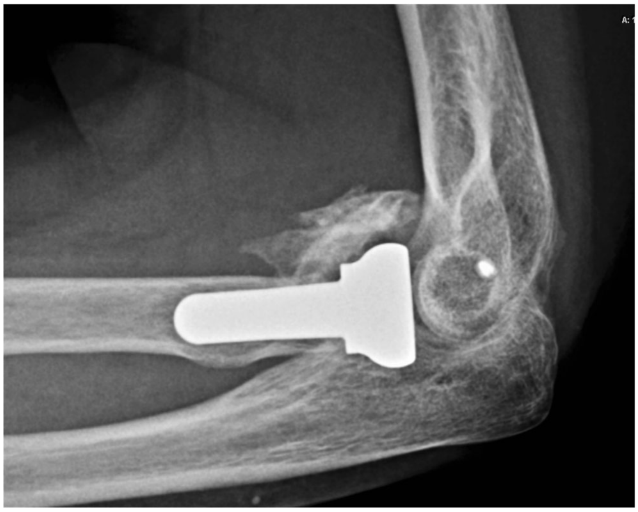

Fig. 10 Heterotopic ossification. Lateral elbow radiograph in a 67-year-old female after surgical treatment for terrible triad injury (observe the radial head arthroplasty and the distal humeral suture anchor at site of lateral collateral ligament complex repair) shows bridging anterior elbow heterotopic ossification

Conclusion

Terrible triad injury of the elbow is a complex elbow fracture-dislocation that is associated with typical disruptions of the elbow soft-tissue stabilizers. Initial imaging consists of standard anteroposterior and lateral elbow radiographs obtained before and after elbow reduction. CT is recommended for detailed characterization of the fracture-dislocation and surgical planning. A change in treatment paradigms from conservative treatment to early surgery for the majority of such injuries has resulted in improved functional outcomes.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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