Management of Terrible Triad Injuries of the Elbow
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ABSTRACT
The term ‘Terrible Triad’ was initially coined by Hotchkiss et al to describe fracture-dislocations of the elbow involving three specific injuries: a postero-lateral dislocation, coronoid fracture and radial head fracture.1 Fracture-dislocations of this type are notoriously unstable secondary to loss of the anterior buttress support from the coronoid, valgus support from the radial head, and the posterolateral stabilization of the lateral ulnar collateral ligament (LUCL).2,3 Furthermore, these injury patterns are particularly difficult to treat and have resulted in poor functional outcomes including the need for multiple reoperations.4-6 Herein, the pathoanatomy, classification, diagnosis and management of these challenging injuries will be discussed.

Keywords: Terrible triad elbow, Collateral ligaments, Dislocations, Fractures, Elbow, Elbow joint, Radius, Radius fractures, Coronoid, Coronoid fractures.


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ANATOMY
The osseous anatomy of the elbow is complex and comprised of three bony articulations. The ulnohumeral and radiocapitellar articulation function as hinge or ginglymus joints, and the proximal radioulnar articulation functions as a pivot joint or trochoid. Capsuloligamentous components and musculotendinous components provide additional stability.

Primary Stabilizers
The highly constrained ulnohumeral joint is the primary contributor to elbow stability; however, the medial collateral ligament (MCL) complex and the lateral collateral ligament (LCL) complex also play an important role.2,7 The reciprocal relationship between the anteriorly sloped distal humerus and the posteriorly sloped semilunar notch increases the prominence of the coronoid and defines its role as an essential stabilizer of the ulnohumeral joint.7 Acting as a buttress against posterior subluxation of the ulna, the coronoid provides as much as 50% of overall elbow stability.9-11

The MCL and LCL are the primary capsuloligamentous stabilizers of the elbow.7 The MCL is comprised of anterior, posterior and transverse bundles, originating on the distal portion of the medial epicondyle and inserting on the sublime tubercle of the ulna.12 The MCL complex resists valgus and internal rotational stresses throughout the arc of motion, primarily through the anterior bundle.8 Importantly, the MCL requires an intact coronoid to function properly as the anterior band of the complex inserts at its base.7 The LCL is comprised of the radial collateral, annular and lateral ulnar collateral ligaments (LUCL).12 The LCL complex originates at the isometric point on the distal portion of the lateral epicondyle, surrounds and supports the radial head like a hammock, and inserts on the supinator crest of the proximal ulna, playing a principal role in varus and posterolateral rotary stability.7,8

Secondary Stabilizers
The radial head, anterior joint capsule, and common flexor and extensor origins function as secondary stabilizers of the elbow.8 In an elbow with intact osseous and ligamentous components, the radial head provides resistance against posterior subluxation of the ulna, and contributes, to a lesser extent, to valgus stability.7,9 However, when an MCL or coronoid injury occurs, the radial head becomes critical for valgus and rotary stability.7,11,13 The anterior joint capsule, through its attachment to the coronoid, contributes varus and valgus stability when the elbow is in greater than 90° of extension.8 Unlike the bony and ligamentous structures of the elbow that provide static stability, the muscles crossing the elbow joint improve dynamic stability by maintaining articulations during active contraction.7,8

MECHANISM OF TERRIBLE TRIAD INJURIES
Fracture-dislocations of the elbow occur in a bimodal distribution with spikes in incidence in children and the elderly.14 The most common mechanism of elbow dislocations is a fall on an outstretched hand. During a fall, the elbow is first axially loaded then yields with flexion as
the body internally rotates about the hand. As the body approaches the ground, the elbow is then subjected to an external rotary force and valgus moment. Anatomically, this causes the joint capsule and collateral ligaments to stretch as a posteriorly directed force on the ulna levers it out of the trochlea. The elbow ultimately dislocates once the LUCL fails with fractures of the radial head and coronoid occurring as a result of shear forces secondary to axial loading.

**Progression of Ligamentous Injury and Instability**

During elbow dislocation, capsuloligamentous injury progresses in a circle from lateral to medial in three stages. This progression of injury has been coined ‘The Circle of Horii’. The stages correlate with clinical instability of the elbow and involve disruption of the following structures: stage 1—LUCL, stage 2—remaining lateral ligamentous structures and anterior and posterior joint capsule, stage 3a—partial disruption of the posterior MCL only, stage 3b—complete disruption of MCL.

**FRACTURE CLASSIFICATION**

**Coronoid Fractures**

The Regan and Morrey classification system is widely accepted and defines coronoid fractures based on fragment size. Type I fractures are characterized by coronoid tip avulsion and type II and III fractures are characterized by a fragment size less than 50% and greater than 50% of the coronoid process respectively. O’Driscoll et al described another classification system for coronoid fractures based upon the anatomic site of the fracture: tip, anteromedial facet or base of the coronoid process. Transverse tip fractures are associated with an intact MCL and usually do not extend beyond the sublime tubercle. Base fractures involve at least 50% of the coronoid height. The vast majority of terrible triad injuries involve type II coronoid fractures.

**Radial Head Fracture**

The modified Mason classification system classifies radial head fractures into four types: Type I fractures are displaced less than 2 mm. Type II fractures are displaced more than 2 mm or angulated, but without severe comminution. Type III fractures are severely comminuted, not reconstructable, and usually require excision for movement. Type IV fractures are radial head fractures with an associated dislocation. By definition, all fractures in terrible triad injuries are type IV in the modified Mason classification.

**ACUTE CLINICAL EVALUATION**

Many fracture-dislocations of the elbow are the result of high-energy injury with patients presenting with significant swelling, pain and deformity. Although terrible triad injuries often present with dislocation or obvious elbow instability, spontaneous relocation can occur. According to the initial evaluation of radial head fracture with or without a coronoid fracture should necessitate a thorough physical examination and three or more radiographic views of the elbow.

The initial evaluation of a patient with a terrible triad injury should be conducted with a high-level of suspicion for concomitant fractures, dislocations and injuries in the ipsilateral extremity. A thorough neurovascular exam should be performed immediately before and after any manipulation or imaging of the joint. The ulnar nerve is at the greatest risk for traction injury due to its medial position, but damage to the median and radial nerve has been reported. Soft tissues should be monitored carefully due to the risk of compartment syndrome.

**Radiographic Evaluation and Reduction**

After initial assessment, standard anteroposterior (AP) and lateral plain films should be obtained (Figs 1A to C). These films are useful for determining injury severity and guiding reduction. Initial radiographic evaluation should also include ipsilateral films of the hand, wrist and shoulder to rule out concomitant injuries.

Immediate reduction can reduce pressure on the skin and soft tissues, and decrease the chance of compartment syndrome or neurovascular damage. Reduction should be attempted with the forearm held in supination. This allows for the movement of the coronoid under the trochlea while minimizing trauma to intact medial soft tissues. Reduction of an unstable elbow can be maintained using a double sugar-tong splint with the forearm in neutral position.

The complexity of terrible triad injuries often warrants more advanced imaging modalities (Figs 2A to F). Plain films are typically inadequate for determining the subtle or complex fracture patterns of the coronoid, radial head or olecranon (Fig. 3). A postreduction computed tomography (CT) scan can provide useful diagnostic information and aid in preoperative planning. Lastly, fluoroscopic examination under anesthesia can be used to assess instability and define limits of motion for therapy.

**NONOPERATIVE TREATMENT**

Most patients with a terrible triad injury require surgical management to achieve normal anatomy and function of the elbow. The literature suggests that nonsurgical
Figs 1A to C: Preoperative anteroposterior (A), lateral (B) and anteroposterior oblique internal rotation (C) radiographs of a terrible triad injury in a 33-year-old male. Posterior subluxation of the radius with fractures of the radius and ulna can be appreciated.

Figs 2A to F: Sagittal slices from preoperative CT scan of the elbow progressing from medial (A) to lateral (F). A displaced fracture of the coronoid and anteromedially displaced fracture fragments of the radial head can be appreciated.
management is a reasonable treatment option in only 5% of cases.\textsuperscript{19} Indications for nonoperative treatment include significant medical comorbidities that preclude anesthesia, patient noncompliance, a joint stable through functional range of motion, and minimally or non-displaced fracture fragments.\textsuperscript{19}

In 2009, Mathew et al proposed specific criteria for the nonoperative treatment of terrible triad injury patterns.\textsuperscript{20} In addition to being minimally or nondisplaced, radial head or neck fractures must not cause a mechanical block to flexion/extension or rotation and coronoid fractures should be small tip fractures.\textsuperscript{20} Furthermore, the ulnohumeral and radiocapitellar joints must be concentrically reduced with a stable arc of motion to a minimum of 30° of extension to allow active motion within the first 10 days postinjury.\textsuperscript{20}

In cases of elbow dislocation without identified radial head and coronoid fractures, postrelocation examination can be performed to determine the range of stable elbow motion. Valgus stability should be tested with the elbow in pronation to compensate for deficient lateral stabilizers, if stable, the anterior MCL can be assumed to be intact.\textsuperscript{10}

Nonoperative treatment for terrible triad injuries involves concentrically reducing the ulnohumeral and radiocapitellar joints, immobilizing the elbow with the forearm in neutral and the elbow at 90° for 7 to 10 days, then return to mobilization as pain allows.\textsuperscript{8} Immobilization beyond this timeframe has been associated with irreversible reduction in range of motion and decreased functionality.

**OPERATIVE TREATMENT**

The primary goals of operative treatment for terrible triad injuries restoration of the osseous stability of the ulnohumeral and radiocapitellar joints and early mobilization to prevent arthrofibrosis. The complex anatomy of the elbow joint and the instability associated with terrible triad injuries pose several operative challenges. Preoperative planning is critical as the order and technique for each component of the repair can have implications for subsequent steps.

The majority of terrible triad injuries can be repaired using a lateral approach only (Figs 4A to D), but medial and posterior midline global approaches can also be used. The lateral approach permits clear visualization of the radial head through the interval of the anconeus (radial n.) and extensor carpi ulnaris (posterior interosseous n.). Injury to the radial head can itself be assessed using an arthrotomy along the anterior LUCL. When injuries warrant radial head excision and replacement, the coronoid can be repaired through the lateral approach after excision of the radial head. In the case of radial head internal fixation, coronoid repair can be achieved through a subsequent medial approach. Lastly, the global approach allows access to both the medial and lateral elbow; however, this approach requires extensive subcutaneous flaps that can lead to postoperative hematoma or seroma complications.

**Coronoid Repair**

The appropriate surgical management of coronoid fractures in terrible triad injuries is critical as the coronoid is a major ulnohumeral joint stabilizer; however, there is still some debate on the management strategy for the coronoid fracture.\textsuperscript{9} Some authors advocate that all coronoid fractures undergo fixation regardless of size if possible;\textsuperscript{15,21,22} whereas others have suggested type II coronoid fractures may only require fixation if varus internal rotary stability exists after radial head excision and ligamentous repair.\textsuperscript{11,23}

Current options for fixation of coronoid fractures include the use of lag screws, suture anchors, site-specific plates and suture lasso. The method of suture lasso fixation (Fig. 4A), which involves using a suture to encircle the coronoid fragment(s) and anterior capsule, has gained increasing popularity. Unlike open reduction and internal fixation (ORIF) and suture anchors, the suture lasso technique permits capturing of comminuted fragments and has resulted in a lower prevalence of implant failure, malunion and nonunion.\textsuperscript{15}

The authors advocate suture lasso fixation of every displaced coronoid fracture treated operatively in the setting of a terrible triad injury to allow secure reapproximation of the anterior capsule and recreation of the anterior coronoid buttress.\textsuperscript{24}

**Radial Head Repair**

The radial head is an important stabilizer of the elbow, acting as a buttress against posterior displacement of the ulna and providing stability against valgus and
The significant contribution of the radial head to elbow stability has led to the consensus opinion that it must be fixed or replaced in all terrible triad injuries. The authors advocate replacement of all radial head fractures with more than three pieces in the setting of the terrible triad injuries.

Current treatment options for radial head fractures include resection, ORIF or arthroplasty. Prior to 2002, resection of the radial head followed by cast immobilization was considered an adequate treatment option for radial head fractures. However, this treatment strategy has been largely abandoned due to poor long-term outcomes including severe instability, proximal radius migration, stiffness, degenerative arthritis and pain. Since the development of the Herbert screw and the low profile mini-plate system, ORIF has become a favorable alternative for both minimally and largely comminuted fractures as patient function and satisfaction continued to improve. Radial head arthroplasty (Fig. 4B) provides an alternative to ORIF when severe comminution precludes reconstitution of the radial head and has been shown to produce comparable outcomes.

In addition, radial head arthroplasty may allow improved stability, perhaps because the preparation for the implant requires removal of the remaining radial head, which allows excellent access for a secure repair of the coronoid. It should be cautioned, however, that proper radial head implant sizing in the ligament deficient elbow is a critical step to avoid overstuffing the joint.

The authors advocate replacement of all radial head fractures with more than three pieces in the setting of the terrible triad injuries.

**Ligamentous Repair**

The LUCL is the primary posterolateral stabilizer of the elbow and repair is universally recommended in the literature to prevent posterolateral rotary instability. Repair includes identification of the isometric point on the lateral condyle and fixation of the ruptured LUCL to the isometric point using either bone tunnels or suture anchors. Following LUCL repair, the anconeus and extensor carpi ulnaris should be repaired as secondary...
stabilizers. Unlike the LUCL, the MCL is not universally injured or repaired in terrible triad injuries and may actually heal through scarring following osseous and LUCL repair as the injury is effectively transformed into a simple dislocations.8

Using lasso repair of the coronoid, replacement or secure fixation of the radial head and LUCL repair, it is exceedingly uncommon to require an additional step (MCL repair or external fixator) to achieve stability (Figs 4C and D).15

**RECENT ADVANCEMENTS**

Outcome-based retrospective studies, improvements in anatomic classification of injury and the development of surgical protocols continue to shape understanding of when and surgically intervention should be undertaken in patients with terrible triad injuries.

In 2014, Chan et al conducted a retrospective study to assess the validity of the criteria for nonoperative treatment previously put forth by Matthew et al.20,30 Using the criteria, Chan et al found select patients treated nonoperatively had good function and stable elbow range of motion.20,30 Furthermore, recent clinical research has improved our understanding of risk factors for heterotopic ossification (HO), a well-known complication of traumatic elbow injuries.31 Shukla et al found that performing multiple closed reductions was a significant risk factor for HO, and that neither time to surgery, demographic factors nor the manner of management contributed significantly.31

Advancements in imaging quality and analysis have improved our understanding of fracture morphology and anatomy.32 In 2014, Mellema et al32 used quantitative three-dimensional (3D) CT to measure coronoid fracture fragment volume, number of fracture fragments, and articular surface involvement in terrible triad injuries and found a significant difference between fracture types and injury patterns with respect to these characteristics. Advanced imaging techniques such as this hold potential for guiding decision making and implant development.32

Radial head implant development and selection has posed a challenge to the field and is of particular interest, as clinical and radiographic outcomes remain contingent upon proper sizing and shape. Recent cadaveric studies have revealed limitations associated with sizing comminuted radial heads and provided insight into joint contact pressures associated with different implant shapes.33,34

Finally, surgical protocols for the treatment of terrible triad injuries continue to evolve and have demonstrated favorable outcomes.15,19,21,22,24,35 As recently as 2014, Fitzgibbons et al demonstrated that when applied, such systemic approaches allow for predicting elbow stability and functional range of motion.36 These protocols have not only improved outcomes in patients but also provide a standardized methodology for studying patient outcomes for this historically challenging area of research.

**REFERENCES**


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