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PICTORIAL ESSAY

Computed Tomography for Elbow Fractures: Adding Value to the Radiology Report

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INTRODUCTION

Computed tomography (CT) is frequently performed for elbow trauma and is regarded as a cornerstone for fracture pattern delineation and operative planning by the orthopaedic surgeon. Generating elbow trauma CT reports is superficially simple, but involves challenges in knowing what each component in an injury pattern means, understanding what impact it has on the treatment, and conveying the findings with precision and clarity using lexicon and classification systems that are comprehensible to the orthopaedic surgeon. We review several commonly encountered elbow injuries, highlight key points in the description of these injuries, and suggest ways in which the radiologist can add value to the radiology report.

RADIAL HEAD FRACTURE

The radial head is a key contributor to elbow stability and mechanical loading, bearing approximately 60% of the mechanical load across the elbow.[1] Radial head fractures are the most common type of elbow injury, accounting for approximately 30% of all adult elbow fractures.[1,2] The radial head is fractured when an axial load drives it into the capitellum.[3] It often occurs during a fall on an outstretched arm with the forearm pronated and elbow in slight flexion. They range from simple fractures to those associated with complex elbow instability.[2,4] The Mason and Johnston classification system (Table 1), reported in 1954 and modified in 1962, is the widely accepted classification system for fractures of the radial head.[5,6] The classification distinguishes non-displaced fractures (type 1), displaced fractures (type 2), fractures that are displaced with comminution (type 3), and fractures of the radial head with dislocation of the elbow joint (type 4). Broberg and Morrey added a metric

Table 1. Mason-Johnson classification[5,6] modified by Broberg and Morrey.[7]

	Description
Type 1	Non-displaced or minimally displaced (<2 mm)
Type 2	Displaced >2 mm or angulated
Type 3	Comminuted and displaced
Type 4	Fractures with associated elbow dislocation

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definition of displacement and an area of involvement of the articular surface to differentiate between Mason type 1 and 2. To be considered a type 2 fracture, the fragment should constitute ≥30% of the articular surface and be displaced by ≥2 mm.[7] Non-displaced or minimally displaced fractures of the radial head can be treated non-operatively.[1] Open reduction and internal fixation (ORIF) is generally indicated for Mason II fractures with >2 mm displacement, although Peyronnet et al[8] reported that selected Mason II fractures can be percutaneously reduced without internal fixation. For Mason III and IV fractures, surgical management includes ORIF and radial head arthroplasty (RHA). If the fracture morphology and bone quality of a comminuted radial head fracture allow for anatomic and stable fixation, ORIF may be performed. RHA remains the treatment of choice for fractures that do not allow anatomic and stable fixation.[1,2] When reporting radial head fractures, it is important to mention the degree of displacement, estimated proportion of articular surface involved, presence of comminution, and dislocation. Plain radiograph is the initial imaging modality to diagnose radial head fracture. However, a portion of radial head fractures are not visible on standard anteroposterior and lateral radiographs of the elbow and are referred to as 'occult' fractures. In these patients there is tenderness over the radial head and anterior displacement of the fat pad by haemarthrosis on a lateral radiograph.[3] CT with three-dimensional (3D) reformatted images is useful for comminuted fractures to further delineate fracture fragments and for preoperative planning (Figure 1). Radial head fractures are well known to have associated injuries resulting in complex elbow instabilities. These include but are not limited to: fractures involving the coronoid process,

Figure 1. (a) Lateral radiograph of the elbow demonstrating a non-displaced (<2 mm) radial head fracture (arrow) with anterior fat pad elevation, findings indicative of a Mason-Johnston type I fracture. (b) Lateral radiograph of the elbow demonstrating a displaced (>2 mm) radial head fracture. (c, d) Plain computed tomography images of the elbow in bone window demonstrating a Mason-Johnston type II displaced two-part fracture (arrows), with the anterior radial head fragment severely medially displaced anterior to the coronoid process. (e, f) Frontal and lateral radiographs demonstrate a Mason-Johnston type IV fracture with heavily comminuted radial head fracture and radiocapitellar dislocation.

capitellum, and distal humerus; dislocation of the distal radioulnar joint (Essex-Lopresti injury); and medial and lateral collateral ligaments (MCL and LCL) injuries. Kodde et al[4] reported that injuries concomitant to radial head fractures were present in 11% of patients and the risk for these associated injuries increases with age and the complexity of the radial head fracture according to the Mason and Johnston classification. Remember that radial head fracture may not be an isolated fracture but may represent an osteoligamentous lesion. Therefore, associated injuries should actively be explored in older patients with Mason II and III fractures by means of thorough physical examination and additional radiographic and magnetic resonance imaging studies.

DISTAL HUMERUS FRACTURE

Approximately 30% of all elbow fractures involve the distal humerus.[9] Fracture patterns can be broadly divided into supracondylar fractures, single column (condyle) fractures, bicolumn fractures (involving medial and lateral epicondyles), and coronal shear fractures (involving capitellum and trochlea). Potential fracture mechanisms include impaction of the proximal ulna onto the articular part (trochlea, capitellum) of the distal humerus. The impact can occur with the elbow flexed or extended. Partial sagittal fractures of the lateral or medial condyle are the result of indirect trauma in valgus or varus while in full or nearly full extension. These fractures are accompanied by capsular and ligament injuries on the opposite side of the joint leading to acutely unstable elbow. Isolated capitellum fractures are the result of compression of the articular surface by the radial head, either during the injury event with the elbow nearly in full extension or as a result of direct trauma to a highly flexed elbow.[10] Multiple fracture classifications have been published but none is comprehensive enough to fully cover all fractures.[11] Milch classification focuses on single column fractures (isolated medial and lateral column fractures) by classifying them into two types depending on whether the trochlear eminence remains a part of the fractured condyle.[12] It provides prognostic value but it does not guide towards the proper treatment options.[11] Bicolumn fractures are typically classified by Jupiter classification (Table 2) which emphasises column involvement and articular extension by describing fractures morphologically as high or low T, Y, or H, or a medial or lateral lambda.[13] The AO Foundation and Orthopaedic Trauma Association (AO/OTA) Comprehensive classification (Table 3) is a well-known worldwide reference to classify distal humerus fractures.[14] It aimed to use a more unified approach to enable the reporting of the fracture type more accurately. However, both Jupiter and AO/OTA classifications are unable to guide proper treatment and to predict the prognosis.[11] AO/OTA classifies fractures into extra-articular (type A), intra-articular single column (type B), and intra-articular bicolumn (type C). Each of them is further subdivided into three subtypes (1, 2 and 3) by the degree and location of fracture comminution. Management options depend on multiple factors including fracture type, intra-articular involvement, fragment displacement, bone quality, and joint stability. The primary treatment goals are to restore articular congruity, elbow stability and to obtain fixation that is stable enough to allow immediate postoperative elbow mobilisation and prevent it from stiffening. Distal humerus fractures are primarily treated surgically. Techniques range from conservative surgical treatment using internal fixation

Table 2. Jupiter classification.[13]

	Description (fracture morphology)
Type A	High T
Type B	Low T
Type C	Y
Type D	H
Type E	Medial lambda
Type F	Lateral lambda

Table 3. AO Foundation and Orthopaedic Trauma Association classification.[14]

	Subtype	Description
Extra-articular	A1	Avulsion fractures of condyles
	A2	Simple transverse fractures through metaphysis
	A3	Fractures with metaphyseal comminution
Partial articular	B1	Sagittal fractures of lateral condyle with simple vertical fracture line reaching articular surface
	B2	Sagittal fractures of medial condyle with simple vertical fracture line reaching articular surface
	B3	Frontal articular fractures in coronal plane
Complete articular	C1	Simple metaphyseal and articular fractures
	C2	Simple articular fracture with metaphyseal comminution
	C3	Comminuted fractures of both metaphysis and articular surface

in young patients to elbow joint replacement in older patients with comminuted fractures.[10] When using AO/OTA classification, it is important to report any fragment displacement, intra-articular involvement, single or bicolumn injury, and degree of comminution. Standard anteroposterior and lateral radiographs of the elbow are sufficient for detecting complete fractures. CT and 3D reconstruction show the shape and position of the bone fragments and are helpful in determining the appropriate surgical approach (Figure 2).[10]

CORONOID PROCESS FRACTURE

The coronoid process, like the radial head, plays a critical role in maintaining stability of the elbow. The articular surfaces of the coronoid and the radial head act as a combined buttress, resisting varus stress, and preventing posterior elbow subluxation.[15] Moreover, coronoid process serves as the attachment site for important stabilising ligamentous structures, namely the anterior band of the MCL (inserting on sublime tubercle of the medial coronoid base) and LCL (inserting on crista supinatoris). Fracture mechanism involves traumatic shear typically occurs as distal humerus is driven against coronoid with an episode of severe varus stress or posterior subluxation. Coronoid tip fractures are 'tip of the iceberg' lesions, appearing as unalarming fracture fragments that may be mistakenly thought of as minor injuries. In reality, they are much more sinister and commonly associate with elbow subluxation, dislocation, posterolateral rotatory instability, and ligamentous injuries (especially MCL and LCL). 'Terrible triad' injuries (a constellation of coronoid fracture, radial head fracture, and elbow dislocation) almost always have a type I or II coronoid fracture

Figure 2. Plain computed tomography images of the elbow in bone window demonstrating (a) single column intra-articular comminuted sagittal fracture of medial condyle, compatible with the AO Foundation and Orthopaedic Trauma Association classification 13-B2; (b, c) single column intra-articular fracture of lateral condyle (arrows) involving the lateral trochlear ridge, compatible with Milch II fracture; (d) bicolumn intra-articular fracture with fracture morphology compatible with Jupiter classification high-T type (transverse fracture proximal to or at upper olecranon fossa); and (e) bicolumn intra-articular fracture with fracture morphology compatible with Jupiter classification Y type (oblique fracture line through both columns with distal vertical fracture line) and the AO Foundation and Orthopaedic Trauma Association classification 13-C2.

including the anterior capsular attachment. Therefore, recognition of the specific fracture pattern is helpful in guiding treatment because coronoid fractures are only part of the more complex traumatic elbow instability.[16] Regan and Morrey[17] first classified coronoid fractures in 1989 into three types based on fragment size and percentage of the process fractured in the horizontal plane. Type 1 is classified as an avulsion at the tip. Type 2 is classified as fracture more than an avulsion, but <50% of the height of coronoid. Type 3 is classified as fracture involving >50% of the height. However, some coronoid fracture lines do not occur in a transverse plane but in a sagittal plane. Furthermore, the importance of anteromedial facet fracture which causes associated injury of the MCL that lead to development of varus and posteromedial rotatory instability is not emphasised in the old classification. Therefore, O'Driscoll et al[18] published a new and more comprehensive classification (Table 4) in 2003 that emphasises the structural importance of the anteromedial facet and the system has been widely adopted by orthopaedic surgeons. It classifies coronoid fractures based on fracture sites into three types namely tip fractures (type 1), anteromedial fractures (type 2), and basal fractures (type 3). Each one is further subdivided into two to three subtypes according to the specific location.[18] Available surgical treatment options were guided by O'Driscoll classification.[16] Coronoid fractures are often difficult to identify and characterise on radiographs. Moreover, many a time there is merely a tiny bone fragment near the tip of the coronoid process and clinicians may call it an avulsion fracture. This is incorrect because there is no anatomical structure that inserts directly onto the coronoid tip. CT is recommended for accurate fracture morphology assessment, classification and preoperative planning, while additional 3D reconstructions appear to improve the interobserver agreement of fracture classification compared with 2D images (Figure 3).[16] To report a coronoid fracture, one should pay attention to the morphology and site of fractures, size of fragments, and degree of fragment displacement. Associated injuries should be actively explored in CT and additional magnetic resonance imaging will be required.

Table 4. O'Driscoll classification.[18]

	Subtype	Description
Tip	1	Fractures ≤2 mm of coronoid height
	2	Fractures >2 mm of coronoid height
Anteromedial	1	Anteromedial rim fractures
	2	Anteromedial rim and tip fractures
	3	Anteromedial rim and sublime tubercle fractures
Basal	1	Coronoid body and base fractures
	2	Transolecranon basal coronoid fracture

OLECRANON FRACTURE

Olecranon fractures are common, representing approximately 10% of all upper limb fractures.[19] They are usually the result of a direct blow onto the elbow after a fall from standing height. Less commonly they result from an indirect tension injury from the triceps attachment.[20] The olecranon functions as a buttress which prevents anterior dislocation of elbow. It also provides an attachment site for the triceps tendon. Three main classification schemes exist for olecranon fractures. The most commonly used classification is the Mayo classification described by Morrey (Table 5). It is based

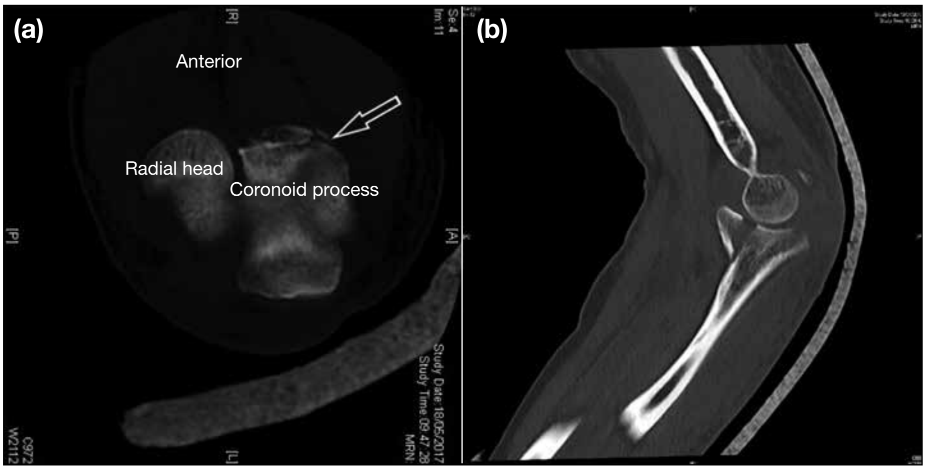

Figure 3. Plain computed tomography images of the elbow in bone window demonstrating (a) coronoid process tip fracture >2 mm height (arrow), compatible with Regan and Morrey classification type I and O'Driscoll classification tip fracture subtype II and (b) Regan and Morrey classification type III coronoid process fracture with fracture of >50% of height.

on several factors, including displacement, comminution, and elbow stability. Type I is non-displaced, type II is displaced but the elbow is stable, and type III is displaced with elbow instability (eg, fracture-dislocation). Groups are further subclassified into groups A and B based on the presence of comminution.[21] The Schatzker classification delineates olecranon fractures into six groups based on fracture orientation, articular surface impaction, comminution, and associated injuries.[22] The AO classification has a limited clinical role and is mainly reserved for research purposes. For management options, goals are to restore joint stability, articular congruity, and the triceps extensor mechanism with stable fixation to allow for early range of motion. Non-displaced fractures (Mayo IA and IB, <2 mm displacement) can be treated conservatively. Tension-band wiring is the most commonly used method of fixation for simple displaced fractures (Mayo type IIA) of the olecranon, with locking plate fixation and intramedullary nail fixation recommended for displaced comminuted or oblique fractures (Mayo type IIB). Excision and triceps advancement are reserved for those highly comminuted fractures or in instances of failed fixation.[20,23] With Mayo classification, the degree of displacement and comminution should be mentioned. Associated injuries such as fracture dislocation should be actively explored and reported. The fracture evaluation is usually based on the initial radiographs and CT scans (Figure 4).[24]

Table 5. Mayo classification.[21]

	Subtype	Description
Type I: non-displaced	A	Non-comminuted
	B	Comminuted
Type II: stable displaced	A	Non-comminuted
	B	Comminuted
Type III: unstable displaced	A	Non-comminuted
	B	Comminuted

TERRIBLE TRIAD INJURIES

Terrible triad of the elbow involves posterior elbow dislocation, coronoid process fracture, and radial head fracture (Figure 5a). These injuries are due to axial compression on the capitellum and shearing mechanism where the trochlea impacts the coronoid process tip during dislocation. The injury is commonly caused by different force vectors which occur during a fall such as rotation of forearm and fall on outstretched hand in a combination of valgus, axial, and posterolateral rotatory forces.[25] In posterior elbow dislocation, structures usually fail from lateral to medial. Stage I injuries involve the LCL complex which leads to posterolateral rotatory instability. Stage II injuries affect anterior and posterior capsule, with the trochlea perched on the coronoid process. Stage III injuries are defined by MCL damage, frank posterior elbow dislocation, and associated severe posterior and valgus instability. Capitellar injury is associated with chronic elbow dislocation and posterolateral rotatory instability. It is characterised by an osseous defect and detachment of a fragment of bone in the posterolateral margin of the capitellum (Osborne-Cotterill lesions) due to hyperextension of elbow joint loading shear force at posterior capitellum, often with concomitant injury to the lateral ulnar collateral ligament (Figure 5b and c).[26] These injury patterns are called "terrible" because they are associated with extensive ligament

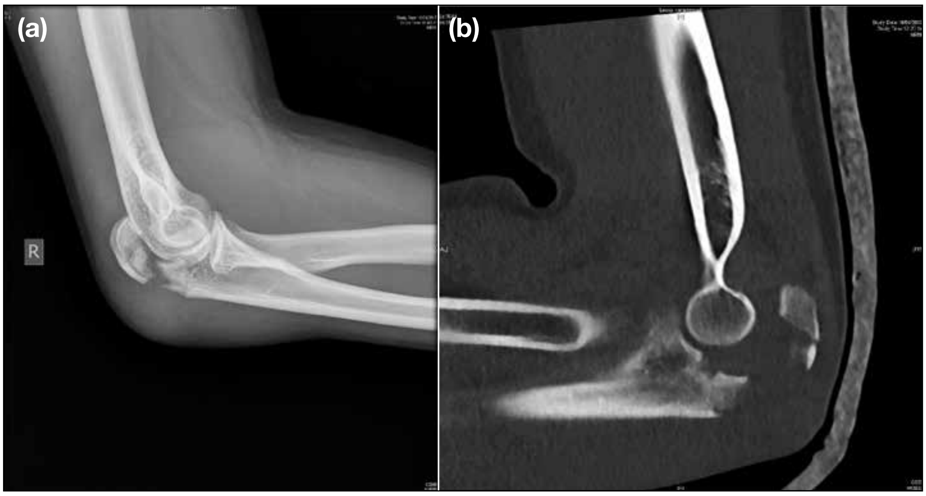

Figure 4. Lateral radiograph (a) and plain computed tomography (b) of the elbow demonstrating a Mayo class IIB stable displaced comminuted transverse fracture of olecranon with intra-articular involvement.

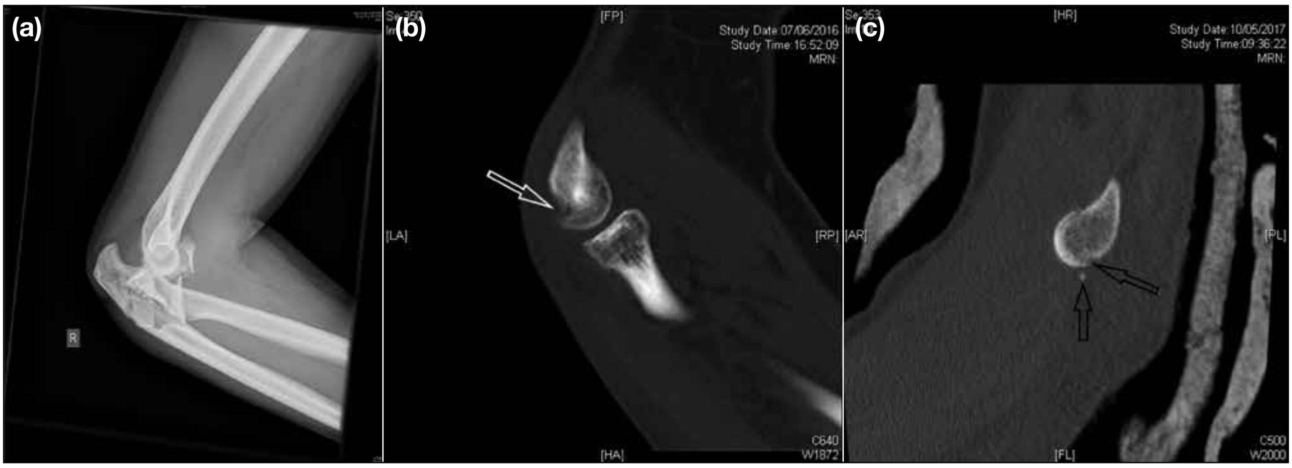

Figure 5. (a) Lateral radiograph of the elbow demonstrating posterior elbow dislocation, radial, coronoid and concomitant olecranon fractures. Injury pattern is known as terrible triad. (b, c) Plain computed tomography of the elbows of different patients demonstrating small impaction fracture (arrows) at posterolateral capitellum, suggestive of Osborne-Cotterill lesions. These lesions are associated with posterolateral rotary instability and lateral ulnar collateral ligament injuries.

Table 6. Key points for elbow trauma computed tomography reporting.

Radial head fracture	Report degree of displacement, estimated proportion of articular surface involved, presence of comminution and dislocation. Report whether fragment involves >30% of the radial head and displaced >2 mm to distinguish a Mason type 2 fracture (favouring operative management) from a type 1 fracture (conservatively managed). Regarded as possible osteoligamentous lesions rather than pure fractures; associated ligamentous injuries should be sought.
Distal humerus fractures	Multiple classification systems have been described but none is comprehensive. When using the AO/OTA classification, report any fragment displacement, intra-articular involvement, single- or bi-columnar injury and degree of comminution.
Coronoid process fracture	“Tip of the iceberg” lesions. Always assess for associated ligamentous injuries, concomitant fractures (especially of the radial head), elbow dislocation, and terrible triad injuries. O’Driscoll classification describes tip fractures (type 1), anteromedial fractures (type 2), and basal fractures (type 3), with emphasis on the integrity of the anteromedial facet.
Olecranon fractures	Mayo classification is most widely used and describes the degree of displacement, comminution, and presence of elbow instability (fracture dislocation).
Terrible triad Injuries	Constellation of elbow dislocation, coronoid process fracture, and radial head fracture. Known as ‘terrible’ for their association with extensive ligamentous damage, impaired function, and frequent complications such as persistent pain, severe chronic instability, and stiffness. Recognising this pattern is crucial as early surgery is paramount in avoiding complications. Osborne-Cotterill lesions are capitellar depression fractures associated with recurrent injury and posterolateral instability, and easily overlooked without a strong index of suspicion.

damage, persistent pain, poor function, and frequent complications, including severe chronic instability and joint stiffness.[27,28] Early detection is critical because early surgical intervention is paramount in avoiding complications. The treatment goal is to restore elbow stability by reconstructing fractures of radial head, fixation of the coronoid fracture and repairing lateral ligament complex.[25] Plain radiographs may not be enough to fully evaluate these injuries. CT examination with 3D reformatting should be used to guide treatment approach. Magnetic resonance imaging is also useful for assessing ligamentous injury.

CONCLUSION

It is useful for radiologists to understand common types and patterns of elbow injuries and become familiar with describing them clearly and concisely using valid terminology and classification systems to enhance communication with orthopaedic surgeons (Table 6). Conveying clinically relevant information in CT reports helps to guide clinical decision-making and allows timely delivery of appropriate surgical treatment to preserve function and prevent long-term morbidity.

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