Radial head fracture: a potentially complex injury
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The fracture of the head of the radius is a serious injury, and whilst the prognosis is good for recovery of a useful elbow, rarely it is a normal elbow.

FUNCTIONAL ANATOMY

The elbow plays an important role in the flexion-extension of the arm and supination-pronation of the forearm. It consists of three bones: the distal part of the humerus and the proximal parts of the ulna and the radius. These three bones articulate in the elbow in three separate joints: the radiohumeral (or radiocapitellar) joint, radioulnar joint and the ulnohumeral (or ulnotrochlear) joint. The radial head is an oval-shaped, concave dish that articulates with the spherical capitellum. It makes no contact with the capitellum during extension, but during flexion the radial head moves proximally and contact with the distal humerus increases. Supination decreases radiocapitellar contact and pronation increases the contact. The majority of the load from the forearm through the elbow is transferred by the radial head, especially in full extension. About 57% of the load applied to the hand crosses the radiocapitellar joint. The other 43% passes the ulnohumeral joint. However, this is highly dependent on the position of the elbow and muscle loading.

The three elbow joints are surrounded by a joint capsule. It covers the tip of the olecranon, the coronoid process and radial fossa, but not the humeral epicondyles. The capsule is most lax at 80 degrees of flexion and holds a capacity of 25-30 mL in this position. Patients with acute elbow injury therefore find this position more comfortable. The medial ligament complex consists of three parts: anterior, posterior and transverse segments (Fig. 1). The anterior and posterior ligaments originate at the medial epicondyle and insert to respectively the distal end of the coronoid process and medial margin of the semilunar notch of the olecranon. They contribute to valgus stability. The transverse part contributes little or nothing to elbow stability. The lateral collateral ligament complex contributes to

Figure 1: Anatomy of the medial collateral ligament complex. 1 = anterior, 2 = posterior, 3 = transverse ligament.
varus stability and consists of two parts: the radial collateral ligament and the annular ligament. The radial collateral ligament originates from the lateral epicondyle and inserts at the base of the coronoid process. The annular ligament originates and inserts on the lesser sigmoid notch and maintains contact between the radial head and ulna (Fig. 2).5

Elbow stability results from the interplay of the articular surfaces, ligaments and muscles. The radial head plays an important role in maintaining elbow stability. The three primary static stabilizers of the elbow are the ulnohumeral articulation and the medial and lateral collateral ligaments. Secondary constraints include the radial head, capsule and the common flexor and extensor origins. The muscles around the elbow, especially the anconeus, triceps and biceps, function as dynamic stabilizers. If the coronoid process or medial collateral ligament (MCL) are injured, the radial head becomes a critical stabilizer.6 The radiocapitellar joint is the primary restraint to proximal migration of the radius. The interosseus membrane, a fibrous membrane between radius and ulna, and the triangular fibrocartilage complex (TFCC) at the distal radioulnar joint also contribute to longitudinal stability of the forearm.7

Normal range of motion (ROM) is from full extension of 0° to 145° of flexion. Some hyperextension can be normal. Pronation and supination show large normal variations, but usually are 85° of pronation and 80° of supination. Interindividual variation is wide.3 Full ROM is not necessary for normal activities of daily living. Morrey et al. showed that for most activities in daily life flexion-extension of 130° to -30° and a pro-supination arc of 100° would be sufficient.8
RADIAL HEAD FRACTURE

Fracture of the radial head is common and accounts for up to one third of all elbow fractures.\textsuperscript{9} The incidence in the general population is estimated at 2.5 to 2.9 per 10,000 inhabitants per year.\textsuperscript{10, 11} Fracture of the radial head was probably first described by Paul of Aegina (AD: 625-690)\textsuperscript{12}: “The ulna and radius are sometimes fractured together and sometimes one of them only, either in the middle or at one end as the elbow or the wrist.”

In the first decades of the 20\textsuperscript{th} century it was stated that fracture of the radial head was caused by direct trauma, Flemming found that 75\% of the cases were caused by direct injury.\textsuperscript{13, 14} However, it is now generally agreed that the radial head fracture is the result of a fall on the outstretched hand with the elbow partially flexed and pronated.\textsuperscript{9, 15} (Fig. 3) Amis and Miller correlated elbow fractures to the angle of flexion of the elbow during a fall, the so-called “arc of injury”.\textsuperscript{15} In their experimental studies, the radial head fractures at a flexion angle < 80 degrees. With flexion of < 35 degrees either the coronoid process or the radial head (or both) may fracture.

\textbf{Figure 3:} Trauma mechanism of radial head fracture. (reproduced with permission)
CLASSIFICATION

A variety of classification systems for radial head fractures have been developed, of which most are based on the classification introduced by Mason in his classic paper of 1954. In the Mason classification the fractures are classified into three clinical types corresponding with a description of the radiological findings: a type I fracture is a fissure or marginal fracture without displacement, a type II fracture is a marginal sector fracture with displacement and type III fractures are comminuted, involving the whole radial head. Johnston added a fourth type to the Mason classification: radial head fracture with dislocation of the elbow joint. Hotchkiss quantified the amount of displacement in his management-based classification: type I indicates a fracture that is ≤ 2 mm displaced, a type II fracture is > 2 mm displaced but amenable to internal fixation, a type III fracture is comminuted and not amenable to internal fixation. The Broberg and Morrey modification states that a displacement of ≥ 30% of the articular surface and a dislocation of > 2 mm should be considered as a Mason type II fracture, opposed to the non-displaced type I fracture. Van Riet et al. developed the Mason-Mayo classification which includes the associated osseous and ligamentous injuries of the elbow by adding a suffix for injury to the olecranon, coronoid and/or ligaments to the Mason classification. Mason type I fractures account for 50-67% of all radial head fractures, type II fractures for 14-36% and type III fractures for 5-19% of all radial head fractures. Concomitant elbow dislocation (Mason-Johnston type IV) is seen in 2-14% of the radial head fractures.

ASSOCIATED INJURIES

In a large retrospective study of 333 patients with a radial head fracture, clinically relevant concomitant injuries of the ipsilateral upper extremity were diagnosed in 39% of the patients and there is a strong correlation between the likelihood of associated injury and the severity of the radial head fracture: the incidence increases from 20% in Mason type I fractures to 80% in type III fractures. The importance of these lesions in the treatment of patients with a radial head fracture is increasingly appreciated. Van Riet et al. found a clinically relevant lateral collateral ligament (LCL) lesion in 11% of the cases, a MCL lesion in 1.5% and a combination of both MCL and LCL lesions in 6%. 3-14% of all radial head fractures is accompanied by a dislocation of the elbow. It occurs after a fall on the (nearly) extended arm. The combination of an elbow dislocation, radial head fracture and coronoid fracture is called “the terrible triad of the elbow”, as it can result in severe joint instability and many post-traumatic complications. As the radial head forcefully comes into contact with the capitellum under the axial loading, (osteo)chondral lesions can occur. Itamura et al. found osteochondral lesions in 96% of Mason type II and III fractures using
magnetic resonance imaging (MRI).\textsuperscript{24} Capitellar fractures occur in \textbf{2\%}.\textsuperscript{21} Other associated injuries include acute longitudinal radioulnar dissociation (ALRUD) or Essex-Lopresti-lesion (radial head fracture, rupture of the membrana interossea between radius and ulna and a rupture of the triangular fibrocartilage complex (TFCC))\textsuperscript{25, 26}, a Monteggia injury\textsuperscript{21} and severe anterior displacement of the radial head may cause injury to the radial nerve. Posterior interosseous nerve injury has also been reported in literature.\textsuperscript{9, 27}

**DIAGNOSIS**

Patients with a radial head fracture usually present after a fall with elbow pain. On physical examination the radial head is painful on palpation and a hemarthrosis is seen. Elbow function, especially pro- and supination, is decreased because of pain. Ligamentous injury can be suspected in case of pain on palpation and/or ecchymosis of the medial and/or lateral aspects of the elbow. Aspiration of the hemarthrosis and intra-articular injection of a local anesthetic is helpful in determining if a restriction in motion, especially in rotational directions, is a consequence of pain or a true mechanical block of motion. In case of pain and swelling of the wrist and forearm, an ALRUD should be suspected. In case of a dislocation the forearm bones are displaced posterior to the distal humerus. Stability and neurovascular status should be examined. The diagnosis can be made with lateral, anteroposterior radiographs of the elbow. An additional radial head-capitellum view can be made. A positive fat-pad sign (Fig. 4), caused by the hemarthros, indicates presence of

![Figure 4: Positive fat-pad sign (arrows) in a patient with a Mason type I radial head fracture of the left elbow.](image)
a radial head fracture. If one suspects an ALRUD, additional radiographs of the forearm and wrist should be made, to see if proximal migration of the radius is present. Rupture of the membrana interossea can be diagnosed with MRI. A computer tomography (CT) scan is indicated in case of coronoid or capitellar fractures, to determine the amount of dislocation in Mason type II and III fractures or for pre-operative planning.

TREATMENT

Mason type I fractures are treated conservatively with early motion, with excellent results.\(^9\) Aspiration of the elbow joint can be performed, as 1 mL of intra-articular fluid decreases the range of motion (ROM) with 2 degrees. Intra-articular injection of an anesthetic does not improve functional results.\(^{28, 29}\) The preferred treatment for Mason type II and III fractures is still subject of discussion.\(^{30}\) Open reduction and internal fixation (ORIF) can be performed in displaced fractures, amenable for stable reconstruction and is indicated especially when forearm rotation is limited by the fractured radial head.\(^{31, 32}\) If the fractured radial head cannot be reconstructed, an arthroplasty can be performed. The main goal of prosthetic replacement is to supply the secondary stabilizing function of the radial head and equalize load transmission across the elbow joint. Radial head prostheses are available in several designs, including monoblock metal implants\(^{33, 34}\), and bipolar prostheses\(^{35}\). In the past, silicon prostheses have been used, but they are abandoned due to high failure rates and silicon synovitis.\(^{36-38}\) In general, excision of the radial head can only be performed in isolated comminuted radial head fractures or as a delayed treatment after initially conservative treated fractures that remain symptomatic, providing that the interosseus membrane and the MCL are intact.\(^9\) As Jones already stated in 1935\(^{39}\): although the prognosis of radial head fractures is generally good, it rarely is a normal elbow. Persistent pain, reduced range of motion, reduced grip strength, instability, and wrist pain are frequently reported after surgically or conservatively treated radial head fractures.

OUTLINE OF THE THESIS

This thesis contains five parts, each highlighting a different aspect of the elbow with a fractured radial head. The first part focuses on a general introduction on the topic of radial head fractures and its current concepts in diagnosis and treatment. The second part aims to describe the epidemiology of radial head fractures and their associated osseous injuries in an European population. Radial head fractures and osteoporosis are linked, in order to explain the typical age and sex distribution of patients with a radial head fracture. The incidence and clinical relevance of associated osseous, chondral and ligamentous lesions
found with MRI of the elbow in patients with a radial head fracture are discussed in part III. In part IV we look to the inter- and intra-observer reliability of the Mason-Hotchkiss classification of radial head fractures. We also focus on treatment of type II radial head fractures with a systematic review of the current literature and the results of cemented and press-fit bipolar radial head prosthesis are discussed. A general discussion, conclusions of this thesis and recommendations for future research are discussed in the fifth and final part.

Part I: Introduction and current issues
In chapter 2 current issues on radial head fractures are discussed, as a more extended introduction to the matter of this thesis. An overview of the most recent literature on diagnosis, fracture classification, associated injuries and treatment of radial head fractures is provided.

Part II: Epidemiology of radial head fractures
Over the past years an increasing awareness on the importance of associated injuries in treating radial head fractures has increased. Few reports on the epidemiology of radial head fractures and their associated osseous injuries are currently available and little is known about the incidence of radial head fractures and their associated injuries in the European population. Recent literature shows an increased mean age of female patients with radial head fractures compared with male patients with radial head fractures. However, data on epidemiology of radial head fractures and specifically in relation to age distribution and male-female ratios of radial head fracture are scarce. In chapter 3 it is our aim to describe the epidemiology of radial head fractures, especially the age distribution and male-female ratio, and their associated osseous injuries in the Dutch population. As age increases above 50 years, the number of females with a radial head fracture becomes significantly higher than the number of males with a radial head fracture. These findings suggest a possible link between radial head fractures and osteoporosis. This was the main research question in chapter 4 of the retrospective case-control study, comparing the bone mineral density of females ≥ 50 years old with a radial head fractures to women of the same age without a fracture. Our hypothesis was that female patients ≥ 50 years old with a radial head fracture have an increased relative risk on osteoporosis. Identifying radial head fractures as fragility fractures may improve case-finding for osteoporosis and preventing other fragility fractures, as radial head fractures occur earlier in life, compared to hip and vertebral fractures.

Part III: Associated injuries of radial head fractures
Radial head fractures are frequently accompanied by associated osseous, chondral and ligamentous injuries of the ipsilateral upper extremity. Especially ligamentous and
Chondral injuries commonly remain undetected by conventional radiographs, but may have consequences for treatment. Clinically relevant associated injuries occur in up to 39% of patients with a radial head fracture. On the other hand, Itamura et al. found concomitant lesions in up to 96% of Mason type II and III fractures using MRI of the elbow. Especially in patients with a more complex elbow trauma, such as elbow dislocation, diagnosis and understanding of the concomitant injuries is of great importance for an adequate treatment. The first aim of the study in chapter 5 was to describe the incidence of associated injuries in patients with a radial head fracture detected with MRI of the elbow. The hypothesis was that in the general population with a radial head fracture, the incidence of associated injuries found with MRI is lower than the incidence reported by Itamura et al. The clinical relevance of these injuries is unclear. In chapter 6 the patients with a radial head fracture who underwent a MRI of the elbow were evaluated after at least 12 months. It was our hypothesis that not all of the injuries found in these patients with MRI are of clinical relevance, as the incidence of clinically relevant associated radial head fractures is lower, compared to the incidence reported by Itamura et al. MCL injury can be seen in radial head fractures, especially in patients with concomitant elbow dislocation, and can cause chronic valgus elbow instability in these patients. Injury to the MCL of the elbow is discussed in a broader spectrum and more in detail in chapter 7, as this injury can also occur in (throwing) athletes. As little is known about this injury and it is uncommon in daily orthopaedic practice, we performed a literature search on the subject of MCL injury and tried to answer the most important questions on incidence, etiology, diagnosis and treatment of this injury.

Part IV: Classification and treatment of radial head fractures

The final part of this thesis focuses on the classification and treatment of radial head fractures. As mentioned earlier, radial head fractures can be classified according to the Mason classification, or one of its modifications. A fracture classification system should name and describe fractures according to their characteristics, providing a hierarchy of those characteristics. It should provide a guideline for treatment or intervention and should predict a clinical outcome. Ideally, a classification should be valid, reliable and reproducible by observers with different levels of experience. Few studies are currently available on the inter- and intra-observer agreement of the Mason classification and its modifications. To our knowledge, only one study of the Mason-Hotchkiss classification is available. The inter- and intra-observer reliability of the Mason-Hotchkiss classification are discussed in chapter 8. Only a few studies on inter- and intra-observer reliability of the Mason classification or its modifications are available. None of these studies provide information on whether the clinicians’ experience improves agreement. It was our hypothesis that experience will improve the agreement.
Treatment of Mason type I fractures is non-operative, with early mobilization, and type III fractures should be managed operatively. However, the best treatment of type II fractures that are not associated with other fractures or ligament injuries (so-called “isolated fractures”) is still debated. Some favor non-operative treatment and others favor open reduction and internal fixation (ORIF).\textsuperscript{31} The aim of the systematic review in chapter 9 was to combine the results of relevant studies on treatment of displaced partial articular radial head fractures without associated elbow dislocation or other elbow fractures, to inform the debate between operative and non-operative treatment. We hypothesized that current evidence is not strong enough to provide a definitive answer to the optimal treatment of the isolated Mason type II fracture.

Comminuted, type III fractures, which are not amenable for reconstruction, can be treated with a radial head prosthesis or excision of the radial head. Replacement of the comminuted fractured radial head is regarded to be the best treatment option when the forearm or elbow is unstable as a result of concomitant injuries.\textsuperscript{9} The floating radial head prosthesis is a bipolar radial head prosthesis and is available in two types: a long-stemmed cemented prosthesis and short-stemmed press-fit prosthesis. The more recently introduced press-fit system possibly allows easier revision, which may be required in young, demanding patients and it is easier to insert, as the stem is shorter and straight. Only a few small case series on the short and medium term results of the cemented bipolar design have been published\textsuperscript{35, 53-57}, and to our knowledge no results of the more recent, press-fit bipolar floating radial head prosthesis have been published. In chapter 10, the main goal was to describe the clinical results of the cemented and press-fit bipolar radial head prosthesis. It was our hypothesis that bipolar radial head implants have comparable clinical results to other implants and that there is no difference in functional outcome between the press-fit and cemented design.

Part V: General discussion, summary and conclusions

The chapter 11 of this thesis is the general discussion in which the previous chapters are put into perspective, with a special focus on the relevance of the results for daily clinical practice. Furthermore, conclusions are drawn and recommendations for future research are discussed in final chapter 12.
**REFERENCE LIST**


