PROXIMAL FOREARM FRACTURES: Epidemiology, functional results and predictors of outcome

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Declaration

This thesis and its composition is my own work and includes nothing of work done in collaboration, except where specifically indicated in the acknowledgement section and the text. The candidate confirms that appropriate acknowledgement has been given where reference has been made to the contribution of others. Where other sources of information are cited, full references are provided.

I have carried out the work described and presented here, under the supervision of Professor Margaret M. McQueen and Professor Charles M. Court-Brown. I have not submitted this work in candidature for any other degree, diploma or professional qualification. It does not exceed the word limit of 100,000 words set by the College of Medicine and Veterinary Medicine.

Andrew D Duckworth

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LIST OF ABBREVIATIONS

AO	Arbeitsgemeinschaft für Osteosynthesefragen
AP	Anteroposterior
CT	Computerised tomography
DASH	Disabilities of the Arm, Shoulder and Hand
DEXA	Dual-energy X-ray absorptiometry
DRUJ	Distal radial ulnar joint
EOTU	Edinburgh Orthopaedic Trauma Unit
HO	Heterotopic ossification
IMD	Index of Multiple Deprivation
IOM	Interosseous membrane
LCL	Lateral collateral ligament
MCID	Minimal clinically important difference
MCL	Medial collateral ligament
MES	Mayo Elbow Score
MRI	Magnetic resonance imaging
MVC	Motor Vehicle Collision

OES	Oxford Elbow Score
ORIF	Open reduction internal fixation
OTA	Orthopaedic Trauma Association
PRCT	Prospective randomised controlled trial
PROM	Patient reported outcome measure
ROM	Range of motion
SD	Standard deviation
SMFA	Short Musculoskeletal Functional Assessment
TBW	Tension Band Wiring/Wire
TFCC	Triangular fibrocartilage complex
95% CI	95% confidence interval

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ABSTRACT

Proximal forearm fractures account for over 10% of all upper limb fractures. There is limited epidemiological data available and much of the literature focuses on the more complex fracture patterns, with the role of non-operative management for the isolated proximal forearm fracture still to be defined. Prospective short and long-term patient reported outcome data for simple isolated fractures of the radial head and olecranon would help define the indications for the non-operative management of these injuries. This thesis aims to test the hypothesis that non-operative management provides a comparable outcome to operative intervention for defined fractures of the proximal forearm.

A large prospective database of 6872 fractures collected over a one-year period was used to define the epidemiology of proximal forearm fractures. A separate large prospective study carried out over an eighteen-month period using a pre-defined management protocol for all isolated radial head and neck fractures was analysed to determine the short and long-term outcome. Additional retrospective databases were collected and analysed to determine the short and long-term outcome for the non-operative and operative management of olecranon fractures, as well as the operative management of complex radial head fractures. Finally, two prospective randomised controlled trials (PRCTs) of isolated displaced fractures of the olecranon were carried out to compare 1) tension band wire (TBW) versus plate fixation in younger patients (<75 years) and 2) operative versus non-operative management in elderly patients (≥75 years). The primary outcome measure for these studies was the upper limb specific patient reported Disabilities of the Arm, Shoulder and Hand

(DASH) score. Secondary outcome measures included surgeon reported outcome scores, complication rates and cost.

The incidence of proximal forearm fractures was 68 per 100,000. Radial head fractures fit a type D distribution curve (unimodal young man, bimodal woman) and radial neck type A (unimodal young man, unimodal older woman). Proximal ulna and olecranon fractures were both a type F (unimodal older man, unimodal older woman), with an increasing incidence after the 6th decade. Over 90% of proximal radial fractures were isolated stable fractures.

Prospective analysis of 201 isolated proximal radius fractures found that the patient and surgeon reported outcome following primary non-operative management for Mason type 1 and type 2 (n=185) fractures was excellent in the short and long-term, with <2% of patients undergoing secondary surgical intervention. At a mean of 10 years post injury (n=100), the mean DASH score was 5.8 and 92% of patients were satisfied. Factors associated with a poorer short and long-term patient reported outcome included increasing fracture displacement (≥5mm) and socioeconomic deprivation. Retrospective analysis of 105 acute unstable complex radial head fractures found that the mean short-term functional outcome was good (mean Broberg and Morrey Score 80) following radial head replacement. In the long-term (mean 7 years), 28% of patients required removal or revision of the prosthesis, with younger patients and silastic implants independent risk factors (both $p<0.05$).

Retrospective analysis of 36 operatively managed isolated displaced olecranon fractures found satisfactory short and long-term outcomes, with the symptomatic metalwork removal rate 47% and the mean DASH 2.5 at a mean of seven years post injury. In the PRCT of plate (n=34) versus TBW (n=33) fixation, comparable functional and patient reported outcomes (DASH 8.5 vs 13.5; p=0.252) were found at one year following injury. Complication rates were significantly higher in the TBW group (63.3% vs 37.5%; p=0.042), predominantly due to a significantly higher rate of symptomatic metalwork removal (50.0% vs 21.9%; p=0.021), resulting in equivocal costs for both techniques (p=0.131). In older lower-demand patients, short and long-term retrospective analysis found very satisfactory outcomes following non-operative management of isolated displaced fractures of the olecranon, with patient satisfaction 91% and no patients requiring surgery for a symptomatic non-union. The preliminary results of the PRCT of non-operative (n=8) versus operative (n=11) management demonstrated comparable functional and patient reported outcomes at all points over the one-year following injury (all $p \geq 0.05$), with a higher rate of complications (81.8% vs 14.3%; p=0.013) and cost (p=0.01) following surgical intervention.

The association found between fragility and the epidemiology of proximal forearm fractures highlighted the importance of considering non-operative management for these injuries. These findings support non-operative management for isolated stable radial head and neck fractures. For more complex injuries when radial head replacement is indicated, there is a high rate of removal or revision, with younger patients most at risk. In younger active patients with an isolated displaced fracture of the olecranon, TBW and plate fixation provide comparable short-term results, with TBW fixation as cost effective despite an increased rate of metalwork removal. In older lower demand patients, this data provides strong evidence for the non-operative management of isolated displaced olecranon fractures.

LAY SUMMARY

Fractures around the elbow are common and problematic injuries. Some fractures are complex and require surgery. However, a large number of these fractures are simple isolated injuries where surgery can be avoided and will likely result in a good outcome for the patient. Unfortunately there is a lack of information, in particular how the patient rates their outcome, for simple isolated fractures of the radial head and olecranon. These are two of the most common injuries occurring around the elbow. This work aimed to determine the outcome of using non-operative management for these fractures. Using a combination of prospective and retrospective databases, along with two prospective randomised controlled trials, a variety of outcomes were looked at including patient satisfaction and complications. The primary outcome measure for this thesis was the Disabilities of the Arm, Shoulder and Hand (DASH). This is a simple 30 point questionnaire that a patient completes at various time points following injury with regards their elbow and how it is affecting them. Patients are asked to grade (five point scale) questions about simple activities of daily living, as well as about current symptoms e.g. pain.

When looking at the number and type of injuries, it was found that the majority were simple isolated fractures of the radial head or olecranon, with an increasing number occurring in older female patients in particular. This further emphasised the importance of considering the role of non-operative management, as surgery is inevitably associated with increased complications in the elderly. From data collected on a large number of patients, very good short and long-term results were found using a sling and simple early exercises for over 90% of fractures of the

radial head, with <2% of patients requiring secondary surgery. Similar good results were found when using non-operative management for olecranon fractures in lower demand elderly patients. When surgery is required for these injuries in younger more active patients, the two techniques commonly used (plate and tension band wire fixation) for olecranon fractures gave comparable outcomes, with radial head replacement providing a satisfactory result for the radial head.

In conclusion, isolated simple fractures of the radial head can be managed effectively without surgery. This is also the case for isolated displaced olecranon fractures in lower demand elderly patients. In younger active patients with an isolated displaced fracture of the olecranon, TBW and plate fixation are both valid techniques.

1 INTRODUCTION AND LITERATURE REVIEW

1.1 Introduction

Despite proximal radial and ulna fractures accounting for over 10% of all upper limb fractures, many questions remain regarding the epidemiology, management and outcome of these injuries.

Radial head fractures are the most frequent fracture type reported around the elbow[1-3]. Fractures have been documented to occur in isolation or with other associated osseous and soft tissue injuries[1-3], with awareness for the potential patterns of injury essential in determining the appropriate management to attain restoration of elbow function. Diagnosis is routinely made with plain radiographs, although the use of further imaging modalities such as CT is increasing with an aim to better understand the injury patterns that occur. The Mason classification is the most commonly used system for classifying these injuries throughout the literature. Management includes non-operative treatment for isolated stable radial head fractures (Mason type 1 and type 2), with a variety of operative techniques used for the unstable fracture patterns (Mason type 3)[1,3-6].

Recently there has been an increased appreciation for the role of the radial head in elbow stability, the benefits and limitations of the fracture classification systems available, as well as the clinical relevance of associated injuries. However, despite extensive research into these injuries, controversies still exist regarding the role of further imaging modalities, the use of non-operative management, as well as the indication and technique for operative intervention. There is a lack of prospective short and long-term patient reported outcome data for the simple isolated radial head and neck fractures, which clearly defines the indication and outcome following the non-operative management of these injuries.

Olecranon fractures account for between 10-20% of all fractures occurring around the elbow[7,8]. There is limited conclusive evidence regarding the epidemiology, optimal treatment and outcome of isolated olecranon fractures. A range of fracture complexity exists and there are a number of fixation techniques to choose from when managing these injuries. Although some decrease in the range of motion can be expected, overall a good functional result for the patient is felt to be attainable despite a lack of documented evidence to support this[9,10].

Patients with undisplaced olecranon fractures can be routinely managed non-operatively[9,11]. The aims of treatment for displaced olecranon fractures are the restoration of function and stability to the elbow joint[7]. The technique employed should allow preservation and reconstruction of the articular surface with minimal associated complications. Tension-band wiring (TBW) is the most recognised and commonly used fixation method, although plate fixation and intramedullary screw fixation are noted alternatives[7,9,12-17]. Potential problems with the TBW technique are wound breakdown, infection, prominent metalwork, malunion and non-union[7,9,14,18-20], and long-term outcome data is lacking. Plate fixation is considered superior in distal/comminuted/oblique fractures and fracture-dislocations, with superior fracture reduction and fixation results, as well as a lower rate of re-operation[9,12,20,21]. There is only one prospective randomized trial in the literature comparing TBW and plate fixation for displaced olecranon fracture[20]. However, this study was performed in 1992 with less sophisticated plates when compared with the location specific plates currently available, as well as including comminuted and open fractures. A direct comparison of these techniques is warranted.

The above fixation techniques can be employed in elderly people, although difficulties associated with fixation in osteoporotic bone, wound breakdown and other complications is reported[11,18,22-24]. Fracture excision with advancement of the triceps has been put forward as an alternative option for osteoporotic patients[17,25], although concerns regarding complications and triceps weakness have been documented[26,27]. However, there is minimal data regarding the outcome of non-operative management for displaced fractures of the olecranon, particularly in elderly patients with multiple co-morbidities, lower functional demand and poor bone quality[28-30].

For the literature review, an initial systematic search and screen of the electronic databases PubMed, EMBASE, and the Cochrane Controlled Trials Register was performed from 1960 through to December 2010. Search terms included “radial head” AND “fracture OR trauma”, “olecranon” AND “fracture OR trauma”, and “elbow” AND “fracture OR trauma OR dislocation”. For all the selected articles a further search of the reference lists was made to ensure that any further relevant articles not identified by the original search were included. The search was repeated prior to submission for the dates January 2010 to July 2015, to include any new literature that was published whilst completing the thesis.

1.2 Anatomy

1.2.1 Clinical Anatomy

The elbow joint is an intrinsically stable complex hinge joint, with two osseous stabilising columns in the form of the radio-capitellar and ulno-humeral articulations, which is reinforced through the soft tissue capsuloligamentous attachments (Figure 1.1)[31-34]. The radial head also articulates with the ulnar sigmoid notch to form the hyaline proximal radio-ulnar joint.

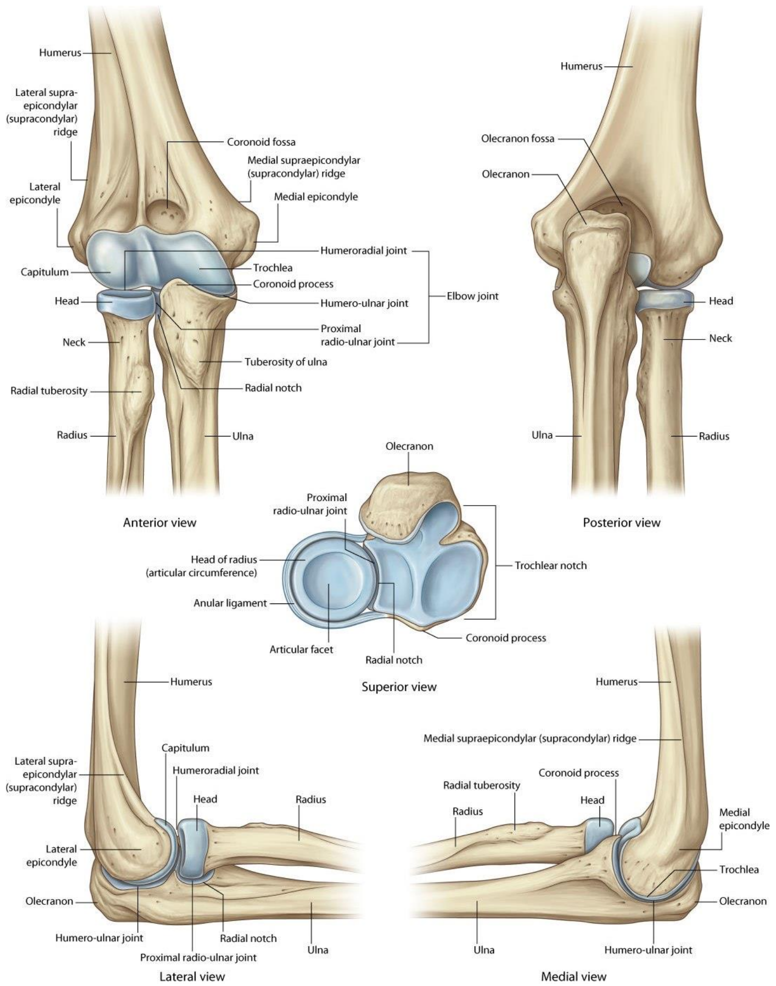


Figure 1.1: Elbow joint articulation. (With permission from Gray's Atlas of Anatomy. 1st ed. Elsevier; 2007)

The elbow articular surface is covered with hyaline cartilage (Figure 1.2) with a characteristic 'bare area' found on the ulna trochlea notch at the anterior third posterior two-third junction, which has been demonstrated to be approximately 5mm in size and corresponds to the base of the coronoid[9,35,36]. Important features of the ulno-humeral articulation includes a 180 degree capture throughout the arc of motion, the 30 degree posterior tilt of the trochlear notch, the width and groove of the trochlea, anterior translation of the trochlea relative to the humeral diaphysis, and the articulation of the anteromedial coronoid facet with the medial edge of the trochlea[34,37,38]. The lateral aspect of this articulation plays an increased role when there is loss of the radio-capitellar articulation[34].

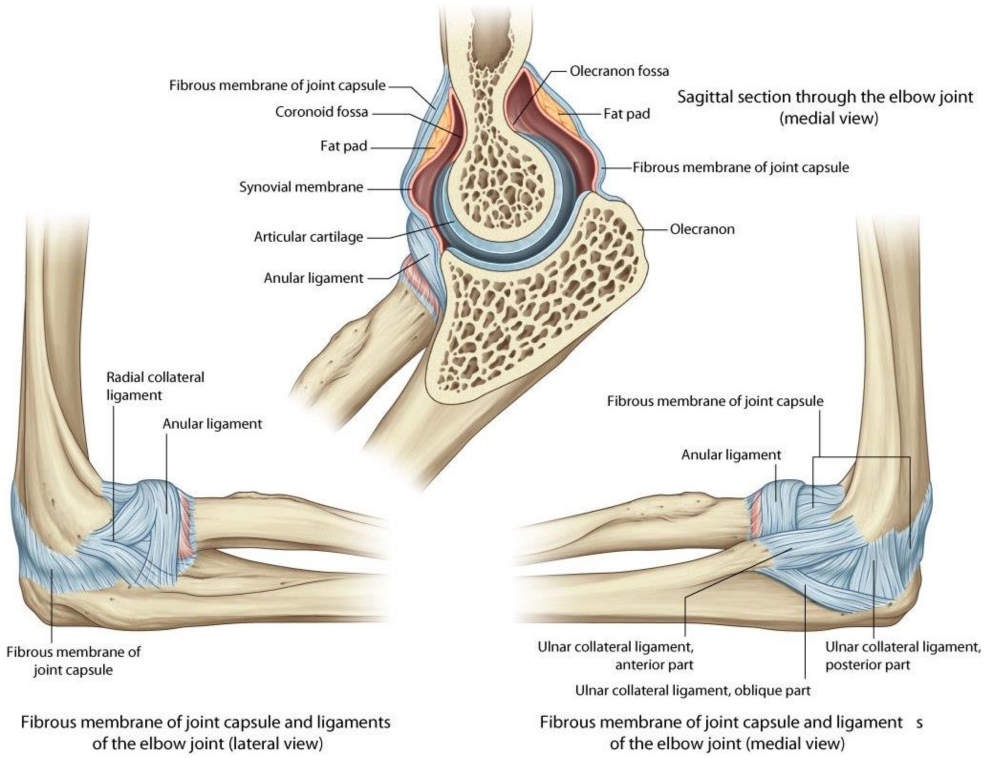


Figure 1.2: A sagittal section through the elbow joint, with medal and lateral views of the ligamentous stabilisers. (With permission from Gray's Atlas of Anatomy. 1st ed. Elsevier; 2007)

The triceps tendon has a broad insertion into the posterior third of the proximal ulna, associated closely with the periosteum of the olecranon, the aponeurosis, the common extensor origin (ECU fascia) and anconeus[9,39]. Although the tendon insertion is confluent, the medial head tendon is found deep to the long and lateral head tendons[36,39]. Compressive forces across the elbow joint come from a combination of the triceps and brachialis, which inserts into the coronoid process of the proximal ulna[9]

Along with the ulno-humeral articulation i.e. the coronoid (sagittal translation and varus stress), the lateral (varus stress) and medial (valgus stress) collateral ligament complexes act as the primary stabilisers of the elbow (Figure 1.2)[31-33,36,40,41]. The coronoid is not only a primary stabiliser to varus stresses, it also contributes to axial, posteromedial and posterolateral rotatory forces[36,42,43]. Secondary stabilisers include the anterior joint capsule, the flexor and extensor muscles that bridge the elbow (triceps, biceps, anconeus), and the radial head[31-33]. These stabilisers of the elbow aid stability by limiting posterior translation, as well as rotational and angular stresses, with the radial head a key contributor[32,42-58]. It has been suggested that the larger the size of fracture to the coronoid, the more unstable the elbow becomes[59]. The importance of the radial head and the radiocapitellar articulation for stable elbow and forearm motion is now strongly recognised[32,42-58], with the articulation capable of carrying up to 60% of the load transmitted through the elbow, which is maximal between 0-30 degrees of the arc of motion[48,60].

The vascular supply to head of the radius is through a peri-cervical arterial ring that is formed from branches of the radial recurrent artery and from a branch of the ulnar artery[36,61]. The neck is supplied by a branch of the interosseous artery, with the nutrient artery providing the intraosseous supply[36,61].

1.2.2 Pathoanatomy and biomechanics of injury

Fractures to the radial head, like other injuries to the elbow, routinely occur in specific patterns, with early recognition aiding diagnosis, management and prognosis[34,62]. A fracture of the radial head occurs when it impacts with the capitellum proximally, with the pattern of injury determined by the mechanism and energy of the injury, as well as the pre-existing bone quality of the patient[34,63].

Fractures of the radial head +/- coronoid commonly occur when the elbow is flexed from 0-80 degrees and the forearm pronated[63]. When the elbow dislocates the soft tissue capsuloligamentous attachments are disrupted in a lateral to medial direction with the anterior band of the MCL the final structure to be injured (Figure 1.3)[64]. Fracture to either the radial head and/or the coronoid is possible due to impaction against the distal humerus. Potential mechanisms of fracture to the radial head can include[36]:

1. A valgus force leads to radial head impaction on the capitellum causing fracture, which can be associated with a rupture of the MCL.
2. A posterolateral rotational force and subluxation that causes a partial articular shear fracture of the anterior segment of the radial head, with or without

associated rupture of the LCL. This can be associated with an elbow dislocation +/- a fracture of the coronoid (the 'terrible triad').

3. An axial force may be applied to the forearm leading to a fracture of the radial head secondary to impaction on the capitellum. When such a force is severe enough it can lead to disruption of forearm stability (the Essex-Lopresti type lesion).

4. A final mechanism of fracture occurs when the radial head dislocates as part of a posterior olecranon fracture-dislocation (Monteggia variants)[34].

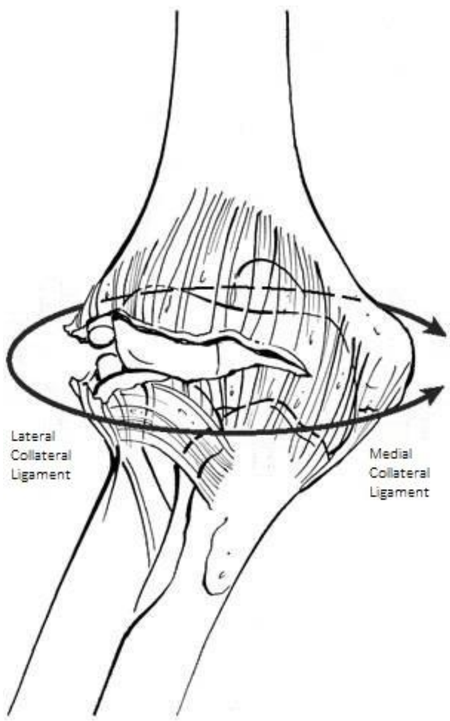


Figure 1.3: The elbow ligamentous and capsule structures are injured in a lateral to medial direction during a dislocation of the elbow. (Adapted from Rockwood and Green's Fractures in Adults. 6th ed. Lippincott Williams & Wilkins; 2006)

Injury to the medial collateral ligament (MCL) or coronoid process leads to the radial head becoming a primary stabiliser of the elbow[65], along with the dynamic muscular stabilisers that cross the joint[66-68]. Morrey et al demonstrated that the radial head contributes 30% of valgus stability with a functioning MCL, but this rises up to 60% with a deficient MCL[32]. With loss of the radial head one study demonstrated a significant increase in posterolateral laxity, with a mean of 18.6 degrees[43]. Shephard et al demonstrated that radial head excision and associated radial shortening resulted in loss of function to the interosseous membrane (IOM)[51]. With an intact IOM, distal loading of the ulna will be less than 50% of the applied wrist force, but with a deficient IOM almost 100% of the applied wrist force will be transferred to the ulna[51].

With an increasing appreciation for the role of the radial head, in particular radiocapitellar contact, for stable elbow and forearm motion [31,32,44,47-50,52,53], it is essential to consider this concept when determining the appropriate management options for all injury patterns involving a fracture of the radial head[69], particularly given that the more complex injury patterns are frequently seen with loss of cortical fracture contact[70], and with increased rates of ulno-humeral arthritis found with loss of the radial head and radiocapitellar contact[71].

There is recent evidence to suggest that consideration should also be given to the isolated partial radial head fracture, as a recent study using quantitative 3D CT analysis of Mason type 2 fractures determined that the most common location for injury was the anterolateral quadrant with the forearm in neutral rotation[72]. The anterolateral quadrant of the radial head is known to have an important role in preventing posterior subluxation of the head and posterior dislocation of the elbow[31,69]. Radial head fracture size has also been found to influence elbow stability[73,74]. One cadaveric study demonstrated an inverse relationship between radiocapitellar joint stability and radial head fracture size[73], with another in vitro study concluding that internal fixation of displaced radial head fractures ≤1/3 of the articular diameter may confirm biomechanical advantages to elbow joint stability[74].

From anatomical studies, fractures of the olecranon are thought to occur when the elbow is flexed to about 90 degrees[63]. Fractures of the radial head +/- coronoid occur at 0-80 degrees, with fractures of the distal humerus occurring when the elbow is flexed more than 110 degrees[63]. The process of the olecranon prevents anterior subluxation of the ulna, with both varus–valgus angulation and ulnohumeral rotation increasing progressively with sequential excision of up to 75% of the olecranon, with gross instability at greater than 87.5%[36,75].

Fractures of the olecranon can follow either direct or indirect trauma. A direct blow to the elbow, common given the subcutaneous location of the olecranon, leads to impaction of the proximal ulna into the distal humerus, often resulting in a comminuted fracture pattern[9,10,76]. Alternatively, an indirect traction type injury occurs with tension and forceful contraction of the triceps e.g. fall on the outstretched hand, leading to a short oblique or transverse fracture of the olecranon[9,10,76]. With either mechanism, the complexity and subsequent displacement is determined by the force of the original injury, bone quality, disruption of the triceps aponeurosis, and the force of the triceps contraction[9]. Transolecranon/anterior fracture-dislocations and posterior Monteggia type fractures of the proximal ulna are frequently complex injuries that occur following high energy trauma, although the posterior Monteggia fractures do regularly occur following a low energy fall in osteoporotic bone[36].

1.2.3 Operative anatomy

For fractures of the radial head, the Kocher exposure utilises the posterolateral interval to the elbow between extensor carpi ulnaris (ECU) and anconeus if care is taken to protect the LCL, and is the most utilised operative approach for fractures of the radial head (Figure 1.4)[34].

Using this exposure, the vast majority of injuries can be dealt with, particularly given that a large proportion of radial head fractures requiring operative intervention are associated with dislocations and soft tissue disruption, leading to auto dissection of some of the capsuloligamentous structures[62,77,78]. During the Kocher approach, it is advised to use the posterior margin of ECU when dissecting through the joint capsule and the annular ligament, whilst also protecting the lateral ligamentous complex and avoiding posterior elevation of the anconeus throughout[33,34]. The Kocher approach has the advantage of providing good access to the radial head, in particular fragments that have displaced posteriorly, whilst also affording protection to the posterior interosseous nerve (PIN) as it passes around the radial neck. The PIN is protected in the lateral approach by pronating the forearm[79], whilst supinating the forearm protects the nerve during an anterior approach[34].

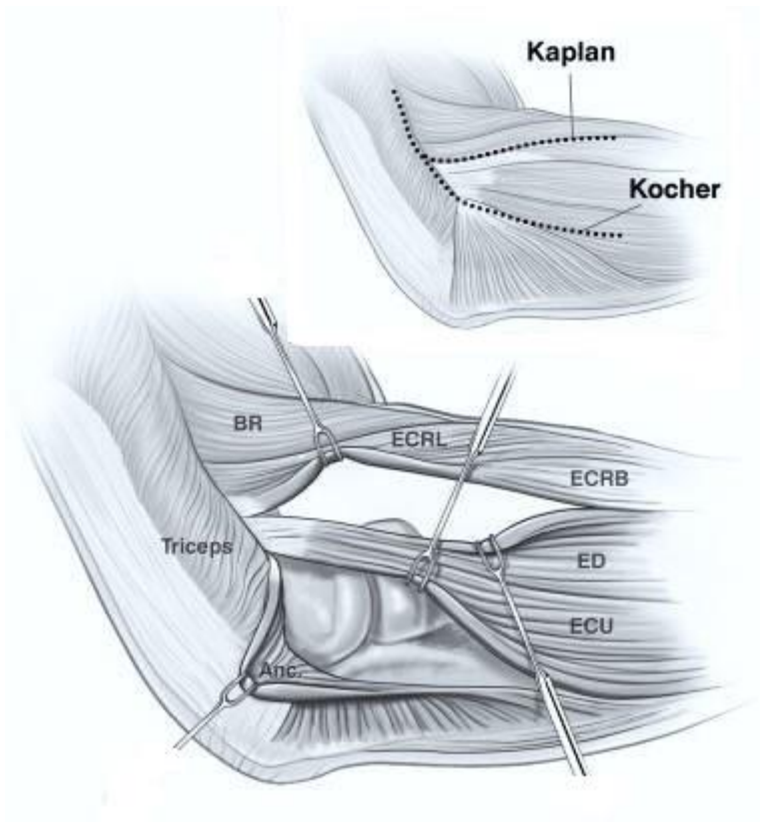


Figure 1.4: The Kocher and Kaplan exposures for approaching fractures of the radial head. (Adapted from Bell S. Current Orthopaedics. 2008; 2(2):90–103)

Some surgeons now prefer a more anterior approach, such as those described by Kaplan and Hotchkiss (Figure 1.4)[34,80]. With a more anterior exposure this involves splitting the extensor digitorum communis (EDC) or between the EDC and the extensor carpi radialis brevis (ECRB)[34,80] because it better protects the LCL and provides good anterior exposure. The key is to stay anterior to the anteroposterior midpoint of the capitellum. When exposure down the neck of the radius is needed, the PIN is protected in the lateral approach by pronating the forearm[79]. This exposure allows increased protection to the lateral collateral ligament (LCL) complex (which is unlikely to be damaged in isolated partial radial head fractures), as well as increased exposure to the coronoid.

The operative exposure of unstable complex fractures is usually simplified because elbow fracture-dislocations are associated with avulsion of the origins of the LCL and EDC from the lateral epicondyle, and these structures can be mobilized distally providing excellent exposure to the radial head and ulnohumeral joint. There is usually a small rent in the fascia indicating the interval to be developed. Fractures associated with a proximal ulna fracture can often be addressed through the posterior rent in the muscle by recreating the deformity. Another alternative is the Wrightington approach, elevating the anconeus from the proximal ulna and then performing an osteotomy to remove the insertion of the LCL complex at the crista supinatoris[81].

The proximal radius has a precise and complex anatomy with an elliptical cross section, three articulating surfaces (radio-capitellar, lesser sigmoid notch, lateral trochlea) and the angulation of the head and neck relative to the shaft. This makes implant development, as well as operative fixation and replacement, difficult[82]. When placing implants the non-articular 90 degree arc, the so-called safe zone, of the radial head is used to prevent impingement of the proximal radio-ulnar joint. There are various techniques for identifying the non-articular part of the proximal radioulnar joint on the radial head (Figure 1.5):

- between Lister's tubercle and the radial styloid[83];
- forearm in neutral rotation, lateral 90 degree arc[84];
- forearm in full supination, plate placed as posteriorly as able[85].

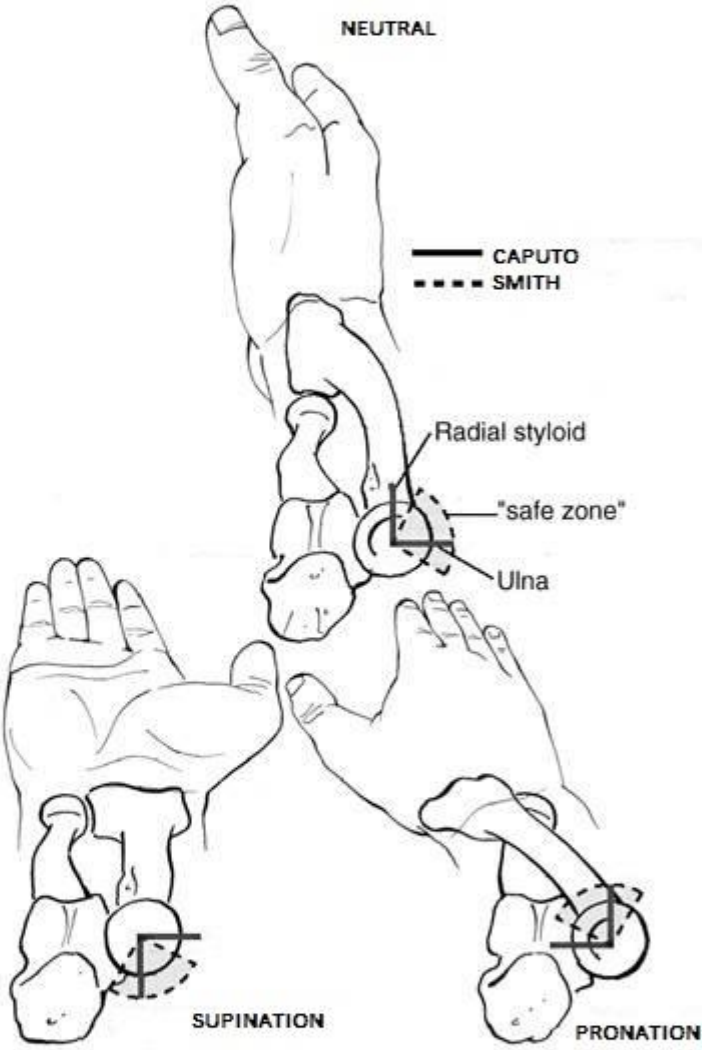


Figure 1.5: The so-called safe zone of the radial head. (Adapted from Rockwood and Green's Fractures in Adults. 6th ed. Lippincott Williams & Wilkins; 2006)

Implants applied outside this zone should be countersunk beneath the surface of the bone. Plate and screw fixation is predominantly employed for fractures involving the whole head, although anatomical conformance is noted to have on-going issues[34,86,87], and some authors favour planned implant removal to improve forearm rotation[84]. Other surgeons try to avoid using a plate and screws, placing oblique screws from the head to the neck instead[88], or foregoing fixation of the head to the neck altogether[89].

The approach to the olecranon is simpler and more consistently documented in the literature. A posterior longitudinal midline skin incision is made to the proximal ulna utilising full thickness lateral and medial fasciocutaneous flaps to allow adequate exposure of the fracture site, with length variable and dependant on the type of hardware being used to fix the fracture and the complexity of the injury[34,36]. The incision commonly starts proximal to the olecranon prominence and extends over the prominence of the olecranon, continuing distally along the subcutaneous ulna border for usually 3-4cm past the mid-point of the olecranon[10,14]. A direct midline incision may result in reduced subcutaneous nerve damage[90]. However, some surgeons prefer to pass over the medial or lateral border of the olecranon rather than directly over it, with the advantage of a medial incision the ease in dissecting out the ulnar nerve when required[34]. There is routinely no indication to dissect out or transpose the ulnar nerve, which is often identified with palpation alone[10,14]. Periosteum and muscle should undergo minimal elevation[34]. Full-thickness sub-periosteal dissection is performed between the FCU and ECU interval as necessary to identify the fracture site and the proximal ulna, with FCU and anconeus elevated as required off the medial and lateral aspects of the ulna to allow visualisation of the joint and fracture fragments[36]. For an isolated fracture the collateral ligaments are preserved throughout.

1.3 Radial head fractures

1.3.1 Epidemiology

It has been estimated that fractures of the radial head account for 4% of all fractures, over 30% of all elbow fractures and over 50% of all proximal forearm fractures[91,92]. The incidence of radial head fractures is 25-35 per 100,000 adult individuals per year from published studies[93,94], with an approximately equal gender ratio and a mean age at injury of 40 years[91,93-95]. Approximately 90% of these injuries are not associated with an elbow dislocation, forearm instability, or other fracture i.e. stable injuries[70,94,96-98]. Injury usually occurs from indirect trauma following a fall from standing height onto the outstretched hand, with the elbow flexed from 0-80 degrees and the forearm pronated[63,99]. Higher energy injuries include a fall from height and sports[94]. One recent study has suggested that males more frequently sustain their fracture at a lower mean age than females, with a potential link to osteoporosis suggested[94]. Open radial head fractures are very rarely reported in the literature; however, when these do occur they are often associated with other injuries around the elbow e.g. a fracture of the proximal ulna.

There is no literature that defines and contrasts the distinct epidemiological characteristics of radial head and neck fractures. For this reason, some authors question whether these injuries should be considered and analysed as separate entities. Radial head fractures are thought to be twice as common as radial neck fractures, with the mean age and gender distribution comparable[92,94].

1.3.2 Diagnosis and Classification

Clinical assessment

Fractures of the radial head occur when an axial load drives the radial head into the capitellum[63,99], commonly following a fall from standing height onto an outstretched arm. Patients present with elbow pain (distension of the joint capsule secondary to haemarthrosis), associated swelling and point tenderness over the radial head, with a reduced range of movement in all directions. Crepitus may be felt on forearm rotation and/or a frank block to forearm rotation. Distal neurovascular status should always be tested and documented. Initial and repeated assessments of the arc of motion, forearm rotation, as well as elbow and forearm stability are essential, particularly if there is concern regarding a block to forearm rotation.

There is no evidence that examination for a bony block to forearm rotation is reliable or accurate. It can be difficult to distinguish reluctance to move the forearm due to pain from a true impairment of motion from a displaced fracture fragment. A few patients with full forearm rotation have palpable crepitation over the radial head with forearm rotation, but it is not clear if this is associated with greater discomfort or impairment in the long-term. Some authors suggest aspiration of the hemarthrosis to relieve pain and determine if there is a mechanical block to motion that might merit operative treatment[100-104]. A study of 16 nondisplaced radial head fractures found that aspiration reduced articular pressure and provided pain relief (from 5.5 to 2.5 on a 10-point visual analogue scale)[104]. A randomized trial comparing 20 patients with nondisplaced radial head fractures treated with aspiration to 20 treated with aspiration plus intra-articular injection of anaesthetic showed no difference in outcome[103].

Patients with a high-energy injury mechanism (e.g. a fall from a height) merit careful evaluation as even well-aligned and apparently stable fractures on occasion prove to be unstable and part of a more complex injury[34,94,105]. Extensive tenderness, swelling and ecchymosis may indicate possible forearm or elbow instability, particularly over the medial collateral ligament complex, interosseous ligament of the forearm, and the DRUJ. Valgus and varus stability is usually assessed with elbow in full extension and at 30 degrees of flexion[106,107]. The pivot shift test is used to assess posterolateral instability[40,41,106,108], with a recent study documenting very good inter- and intra-observer reliabiltiy[108]. In the case of the suspected Essex-Lopresti lesion, a thorough assessment of forearm swelling and tenderness is required, as well as determining any clinical disruption to the DRUJ, with axial compression test used by some clinicians[96]. When a fracture of the radial head is associated with a dislocation of the elbow, deformity and complete loss of elbow motion is commonly seen with associated swelling and ecchymosis. Emergent reduction and assessment of the skin and neurovascular status are paramount[34,109-111].

Imaging

Standard AP and lateral radiographs of the injured elbow are necessary for making the diagnosis (Figure 1.6). These views should identify fractures of the radial head or neck, dislocation of the elbow, injury to the distal humerus and any fractures to the proximal ulna. A percentage of radial head and neck fractures are not visible on radiographs (so-called "occult" fractures). In this setting, the diagnosis is based on displacement of the anterior fat pad by haemarthrosis on a lateral radiograph combined with tenderness over the radial head.

Figure 1.6: Standard AP and lateral radiographs of the elbow.

For suspected radioulnar dissociation (interosseous ligament injury), bilateral posterior-anterior (in neutral rotation) and true lateral radiographs of both wrists are useful to look for subluxation or dislocation of the DRUJ[112-114]. The degree of radial shortening indicative of an Essex-Lopresti lesion is debated, with figures ranging from 2mm to 1cm (Figure 1.7)[114,115]. Further work is needed to better define the degree of radial shortening that is acceptable. However, a high index of suspicion is essential with increasing fracture complexity and higher energy injuries[105,116].

It is difficult to test the reliability of ultrasound, CT and MRI for the diagnosis of interosseous ligament injury because it is so uncommon[117-121]. In cadavers MRI had an accuracy of 96%, with a sensitivity ranging from 88-93% and specificity of 100%[119,121]. Most unstable fractures of the radial head merit operative treatment and intra-operative assessment using the push-pull test (axial traction and compression of the hand and wrist looking for more than 3 millimetres change in the distance between the radial neck and the capitellum) following radial head excision may be an adequate test for the diagnosis of interosseous ligament injury and forearm instability[122].

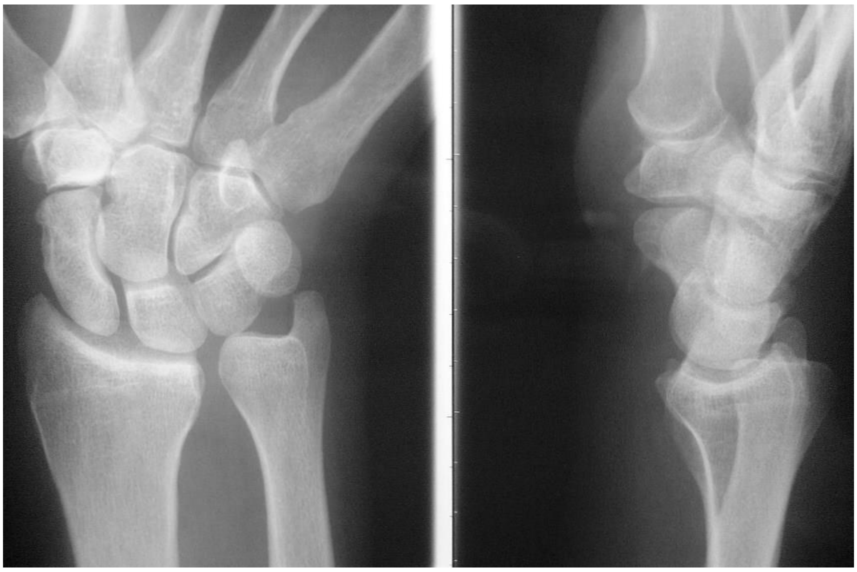


Figure 1.7: Radial shortening suggestive of an Essex-Lopresti type injury.

Mason classification (Table 1.1)

Mason classified "marginal" and "nondisplaced" fractures of the radial head as type 1, and "displaced" partial fractures that were more than a "marginal fragment" as type 2, but he did not quantify these terms[123]. Broberg and Morrey suggested that to be considered a type 2 fracture, the fragment should be more than 30% of the articular surface and more than 2 millimetres displaced, but this was not based on data, and has only moderate reliability (Figure 1.8)[124-128].

Classification		**Description of fracture pattern**	**Intra-Observer** **Inter-Observer**
Mason	**1**	Non-displaced fracture	Satisfactory
	2	Displaced partial head fracture	Moderate
	3	Displaced entire head fracture	
Johnston	**1**	Non-displaced fracture	
	2	Displaced partial head fracture	Satisfactory
	3	Displaced entire head fracture	Moderate
	4	Fracture with elbow dislocation	
Broberg & Morrey	**1**	Fracture with <2mm displacement	
	2	Facture ≥2mm displacement & ≥30% articular surface	Excellent
	3	Comminuted fracture	Moderate
Hotchkiss	**1**	Non-displaced/displaced marginal fracture, no block to forearm motion, manage non-operatively	NA
	2	Displaced fracture amenable to open reduction internal fixation	Moderate
	3	Displaced fracture not amenable to ORIF → for excision or replacement	

Table 1.1: Description and reliability of the original Mason classification and the three commonly used modifications[125-128]. Reliability data is based upon interpretation of plain radiographs.

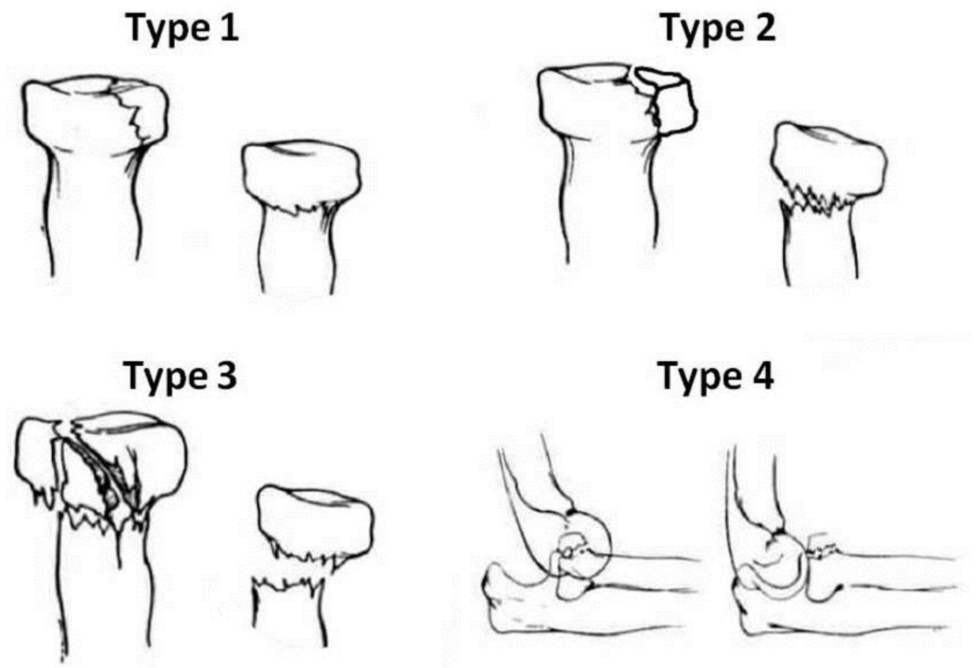


Figure 1.8: A pictorial representation of the Broberg and Morrey modification of the Mason classification. (Adapted from Herbertsson et al J Bone Joint Surg Am. 2004 Mar; 86-A(3):569-74)

The inclusion of neck fractures and fractures associated with a dislocation of the elbow in Broberg and Morrey's modification of the Mason classification may not be helpful given the importance of characterizing the radial head fracture even when it is associated with other injuries[34]. Hotchkiss modified the Mason classification based on clinical parameters such as mechanical block to forearm rotation and ability to repair the fracture[80], but it is not clear that either of these can be diagnosed reliably or accurately. According to the Mason classification, the vast majority of radial head fractures are Mason type 1 and type 2 injuries, accounting for almost 90% of all fractures[94]. Mason type 3 fractures account for just over 10%.

There is conflicting evidence regarding the benefit of a specific oblique radial head capitellum or external rotation view to better define displacement or improve reliability[129,130]. Guitton et al developed a methodology to quantitatively analyse radial head fracture fragment morphology using 3D-CT (Figure 1.9) in 46 patients[131].

Figure 1.9: A 3D-CT used to quantitatively analyze radial head fracture fragment morphology.

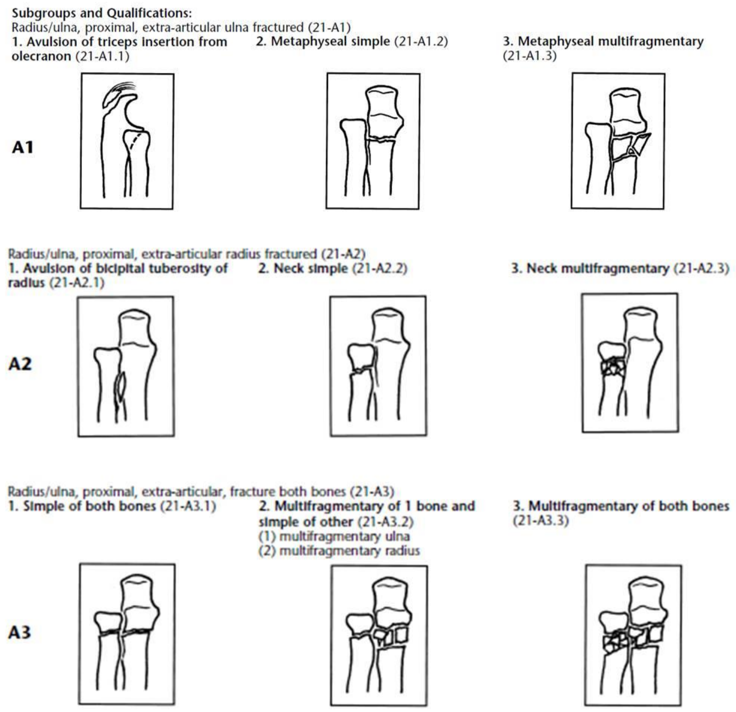
Radiographically unstable fractures as defined by Rineer and colleagues[70] (loss of cortical contact of at least one fracture fragment with a gap on radiographs) were found in 100% of whole head fractures. They determined that unstable, displaced partial head fractures associated with one of the complex injury patterns described above, are often complex displaced fractures with multiple small fragments. In another study of 24 patients with a Mason type 2 fracture of the radial head, quantitative 3D CT was used to determine the exact location of the fracture and found that the most common location is the anterolateral quadrant with the forearm in neutral rotation[72]. Guitton et al randomized 85 orthopaedic surgeons to evaluate 12 radial head fractures using either radiographs and 2D CT, or radiographs and 3D CT[132]. They found 3D CT did not significantly improve the inter-observer agreement of the Broberg and Morrey modification of the Mason classification.

Some authors have questioned the suitability of employing the Mason classification systems for fractures of the radial head and neck. Association with prognosis is unknown. Furthermore, systematic review is felt to be hampered due to different authors employing different modifications of the Mason classification, whilst also incorporating radial head and neck fractures together in their analysis[133].

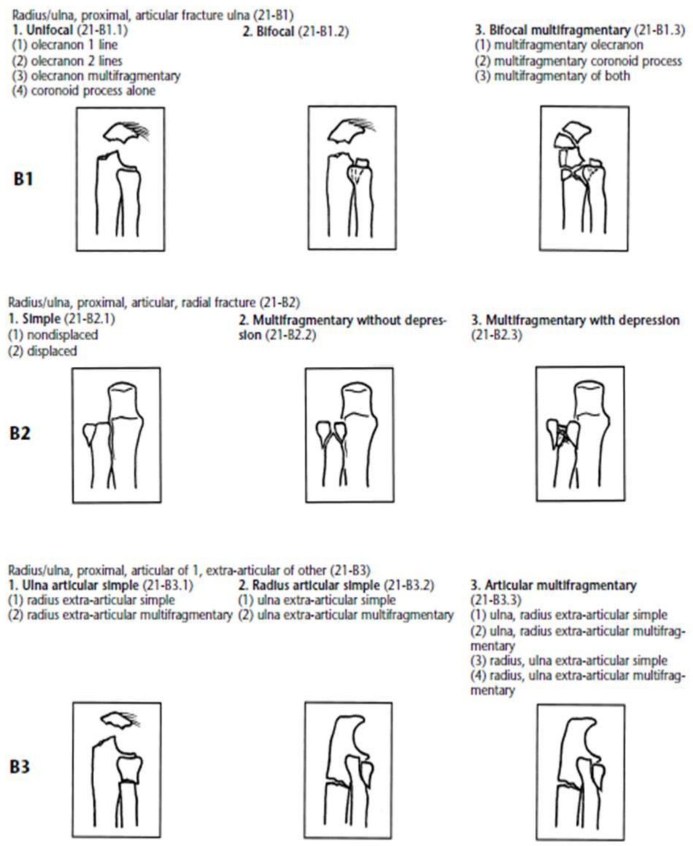
AO-OTA classification

The AO-OTA classification combines proximal forearm fractures under one classification system (Figure 1.10)[134,135]. Type A fractures are extra-articular of either the radius or ulna, type B fractures are intra-articular of the radius or ulna, and type C fractures are intra-articular fractures of both bones.

Ring et al found that with greater than three fragments of comminution (21-B2.3), there was a significantly increased risk of early fixation failure, non-union and loss of forearm rotation[77]. However, the usefulness in the clinical setting has been questioned due to complexity and reproducibility, with recent studies concluding that the inter-observer reliability to be poor to fair and the intra-observer reliability to be poor[127,128].


Subgroups and Qualifications:
Radius/ulna, proximal, extra-articular ulna fractured (21-A1)
1. Avulsion of triceps insertion from olecranon (21-A1.1)
2. Metaphyseal simple (21-A1.2)
3. Metaphyseal multifragmentary (21-A1.3)
A1
Radius/ulna, proximal, extra-articular radius fractured (21-A2)
1. Avulsion of bicipital tuberosity of radius (21-A2.1)
2. Neck simple (21-A2.2)
3. Neck multifragmentary (21-A2.3)
A2
Radius/ulna, proximal, extra-articular, fracture both bones (21-A3)
1. Simple of both bones (21-A3.1)
2. Multifragmentary of 1 bone and simple of other (21-A3.2)
(1) multifragmentary ulna
(2) multifragmentary radius
3. Multifragmentary of both bones (21-A3.3)
A3

A


Radius/ulna, proximal, articular fracture ulna (21-B1)
1. Unifocal (21-B1.1)
(1) olecranon 1 line
(2) olecranon 2 lines
(3) olecranon multifragmentary
(4) coronoid process alone
2. Bifocal (21-B1.2)
3. Bifocal multifragmentary (21-B1.3)
(1) multifragmentary olecranon
(2) multifragmentary coronoid process
(3) multifragmentary of both
B1
Radius/ulna, proximal, articular, radial fracture (21-B2)
1. Simple (21-B2.1)
(1) nondisplaced
(2) displaced
2. Multifragmentary without depression (21-B2.2)
3. Multifragmentary with depression (21-B2.3)
B2
Radius/ulna, proximal, articular of 1, extra-articular of other (21-B3)
1. Ulna articular simple (21-B3.1)
(1) radius extra-articular simple
(2) radius extra-articular multifragmentary
2. Radius articular simple (21-B3.2)
(1) ulna extra-articular simple
(2) ulna extra-articular multifragmentary
3. Articular multifragmentary (21-B3.3)
(1) ulna, radius extra-articular simple
(2) ulna, radius extra-articular multifragmentary
(3) radius, ulna extra-articular simple
(4) radius, ulna extra-articular multifragmentary
B3

B

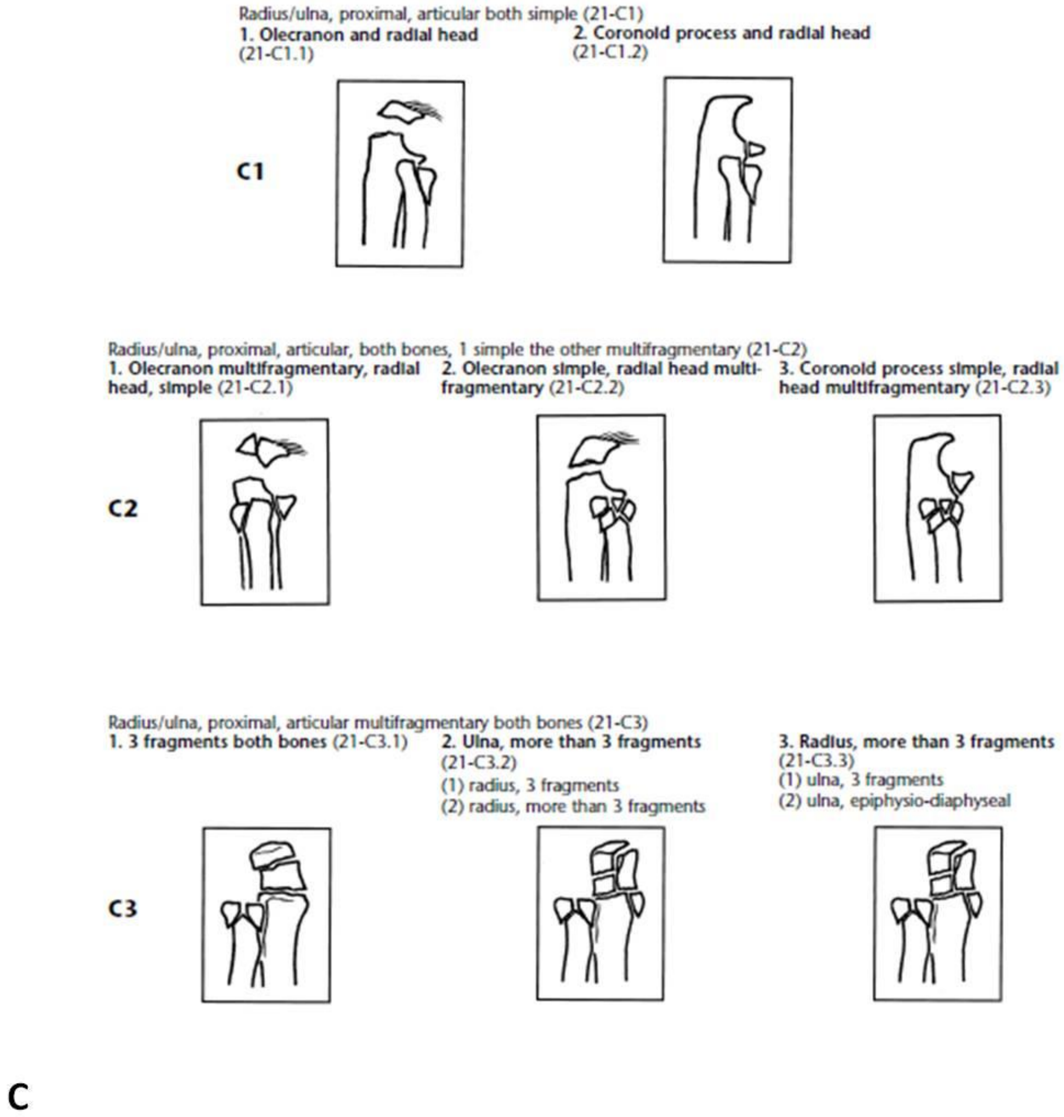


Figure 1.10: The AO-OTA classification of proximal forearm fractures. A: Type A fractures. B: Type B fractures. C: Type C fractures. (From Marsh et al J Orthop Trauma. 2007; 21 Supplement 10 pp: S1-S163.)

Stable vs. unstable injuries

Some authors have suggested that fractures of the radial head commonly occur in two distinct clinical scenarios:

1) a stable isolated non-displaced or minimally displaced fracture where restoration of motion is the primary concern and long-term problems from slight articular incongruity are debatable (Figure 1.11)

Figure 1.11: AP radiograph of a stable isolated fracture with an articular step, but no gap between the fragments.

2) an unstable fracture that occurs as part of a complex injury to other bones or ligaments where contact between the radial head and the capitellum is important to the alignment and stability of the elbow and forearm (Figure 1.12)[34,69,107,136]

Figure 1.12: AP radiograph of an unstable displaced fracture of part of the radial head. The missing fragment can be seen behind the capitellum/lateral column, superior to the radial head. This fracture likely occurred as part of an elbow fracture-dislocation.

Isolated, minimally displaced fractures are nearly always impacted (fractured but difficult to move; stable), whereas fractures as part of a complex injury usually create fragments that are detached and mobile with little or no soft tissue attachments (unstable)[34,69,70,97,98,107,136,137]. This simple classification may help to better guide treatment and prognosis, although there is no data to support this to date.

Associated injuries

The rate of radial head fractures associated with an ipsilateral upper limb injury ranges from 26-95% in the literature[2,94,95,97,98], with the rate of associated osseous injuries quoted at around 10%[93]. The wide variation documented is possibly due to the diagnostic methods used for detecting associated injuries e.g. higher rates seen when MRI employed for all cases, what the authors have defined as a clinically relevant associated injury, as well as the catchment population examined e.g. a referral practice with a higher number of complex injury patterns seen. A clear association has been documented between increasing fracture complexity according to the Mason classification and the rate of associated injuries[94], with the rate of any associated injuries in Mason type 3 fractures noted in some studies to be 100%[93-95,98]. The distinct associated patterns of injury are detailed below.

Most fractures of the radial head are stable isolated non-displaced or minimally displaced fractures of the neck or the anterolateral portion of the radial head (Mason type 1 and 2)[72]. These fractures are characterised by an intact periosteum, minimal gap between the fracture fragments, and are impacted into a stable position and not easily moved. The radiocapitellar contact is preserved and elbow or forearm instability is absent. Clinically relevant associated injuries are not seen; however, incomplete injury to the collateral ligaments and capitellar bone bruises are frequently seen when routine MRI is used to study stable isolated fractures[97,98,137]. One recent study documented MRI evidence of ligament injury in over two-thirds of stable fractures of the radial head, but found they did not affect motion or the Mayo Elbow Score (MES)[98,137]. One caveat is the patient who has sustained a high-energy injury with an apparently stable fracture, which on occasion may prove to be unstable and part of a more complex injury[34,94,105].

Displaced unstable fractures are often complex fractures associated with other fractures and complete ligament injuries (Mason type 3)[70,94,96-98]. For these injuries, the literature would suggest it is important to consider mechanism of injury, radiographic characteristics and clinically significant associated injuries. Unstable fractures are loose and easily moved with some disruption of the periosteum, leading to loss of the radiocapitellar contact and potentially elbow and forearm instability.

Davidson et al performed a prospective clinical examination and radiographic assessment of 50 consecutive radial head and neck fractures and found that 100% of patients with a displaced comminuted radial head fracture had evidence of clinical axial or valgus instability, with no instability seen in patients with a nondisplaced or minimally displaced fracture[96]. Rineer et al examined 291 patients with 296 radial head fractures and found a proximal ulna fracture or an elbow dislocation in 0% of minimally displaced fractures (Mason type 1), with a rate of 100% in displaced whole head fractures (Mason Type 3)[70]. They found that a radiographic definition of radial head fracture instability as complete loss of contact of at least one fracture fragment was strongly associated with an associated proximal ulna fracture or elbow dislocation.

Particularly in elderly patients, apparently unstable displaced and/or comminuted fractures of the radial head are sometimes observed without elbow dislocation or proximal ulna fracture, but it is probably best to consider the fracture as a marker for a complex unstable injury until proved otherwise[34]. It can be useful to look for one of several unstable injury patterns[69,94,136]:

1. Radial head fracture with posterior dislocation of the elbow[124,138]
2. Terrible triad injury: radial head fracture with posterior dislocation of the elbow and fracture of the coronoid process[53,138]
3. Radial head fracture with complete MCL rupture or capitellum fracture

4. Radioulnar dissociation (Essex-Lopresti lesion and variants): radial head fracture + rupture of the interosseous ligament + rupture TFCC[139,140]

5. Proximal ulna fracture with radial head fracture[141-143]

1.3.3 Management and Complications

Non-operative

A large proportion of fractures of the radial head are isolated stable injuries (Mason type 1 and type 2), for which non-operative management achieves a good or excellent result with full forearm rotation, no or minimal restriction of the flexion arc, and no or minimal arthrosis in the long-term (Table 1.2)[4,5,133,144-148]. The predominant adverse outcome of a Mason type 1 (undisplaced or minimally displaced fracture) is elbow stiffness. Herbertsson et al documented full motion and only 3 patients with occasional pain among 32 Mason type 1 fractures evaluated a mean of 21 years after injury[147].

Author (year)	Patients (n)	Mean age yrs (range)	Male/Female	Mean Follow-up (months)	Mean elbow flexion arc Mean forearm rotation arc	Outcome	Complications
Mason type 1 – Non-operative							
Herbertsson et al. (2005)	32	46	12/20	252	138° 167°	91% no subjective complaints	Arthrosis (n=0)
Smits et al. (2014)	83	42	31/52	46	- -	Mean DASH 5.9	-
Mason type 2 – Non-operative							
Miller et al. (1981)	39 (24 non-op)	-	-	120	- -	Good outcome 76.5% Full ROM 58.8% (n=20)	Ongoing pain (n=8)
Khalfayan et al. (1992)	26 (16 non-op)	39	17/9	18	123° 154°	Mean Broberg and Morrey 77 44% good or excellent	Subsequent surgery (n=2) Arthrosis (n=16)
Akesson et al. (2006)	49	49	15/34	228	134° 173°	82% no subjective complaints	Delayed radial head excision (n=6) Arthrosis (n=28/34)
Mason type 2 – Operative							
Khalfayan et al. (1992)	26 (10 op)	39	17/9	18	141° 175°	Mean Broberg and Morrey 92 90% good or excellent rating	Subsequent surgery (n=2) Arthrosis (n=1)
Michels et al. (2007)	14			66	139° -	Mean Broberg and Morrey 97.6 100% good or excellent Mean patient satisfaction 9.5/10	Residual pain (n=2) Arthrosis (n=3)
Lindenhovious et al. (2008)	16	39	9/7	264	129° 166°	Mean DASH score 12 Mean MES 89 81% good or excellent Mean ASES score 93 Mean patient satisfaction 7.8/10	Implant removal (n=140 Infection (n=2) Block to motion (n=2) PIN palsy (n=1)
Ertürer et al. (2010)	21 (11 screw fixation)	40	7/4	32	131° 144°	Mean Broberg and Morrey 94.5 91% good or excellent Return to work 11.7 weeks	-

Table 1.2: Details of selected studies reporting on the non-operative and operative management of Mason type 1 and type 2 fractures.

(Adapted from Kaas et al. J Hand Surg Am. 2012 Jul;37(7):1416-21[149])

Early mobilisation appears to be safe and effective for isolated stable fractures of the radial head. Liow et al compared immediate active mobilisation or 5 days of immobilisation prior to active mobilisation in a prospective randomized trial and found no differences after the first week, and excellent outcomes in all patients[145]. A randomized trial comparing two-weeks' immobilization in either 90 degree of flexion (n = 29) or full extension (n = 23) versus no immobilization (n=29) found that patients immobilized in flexion lost some extension[150]. A prospective cohort study of 71 patients with a stable isolated partial articular radial head fracture found that a protective mind set (limited confidence with stretch pain) was associated with reduced elbow motion one month after injury[151]. A recent prospective study randomised 180 isolated stable fractures to either 1) immediate mobilization, 2) a sling for 2 days and then active mobilization, or 3) immobilization in a cast for 7 days prior to mobilization[152]. They found early mobilization to be safe and effective, with a delay of 48 hours prior to early mobilization advantageous.

Despite limited evidence, there is a consensus that the only clear indication for surgery for an isolated minimally displaced stable radial head fracture (Mason type 2) is a mechanical block to forearm rotation, and that such a block is unusual[1,3,34,80,133,153]. Akesson et al analyzed 49 patients at an average of 19 years after nonoperative treatment for an isolated Broberg and Morrey Mason type 2 fracture and found 82% had no pain, but 12% had delayed radial head excision four to six months after injury for unclear reasons[133]. Miller et al reported on the non-operative management of 34 patients with Mason type 2 (isolated partial) fracture of the radial head at a mean of 10 years post injury[144]. According to the Radin and

Riseborough score 76% (n=24) achieved a good outcome with a minor limitation affecting recreational sports occurring in 8.8%. It should be noted that in this study non-operative management employed casting for three weeks and six patients required acute radial head excision.

A systematic review that compared the results of non-operative management with a range of surgical interventions for fractures of the radial head fractures found that there was inadequate data to draw definitive conclusions on the optimal treatment of complex unstable radial head fractures[5].

Selected patients with an unstable fracture of the radial head (Mason type 3) can be treated non-operatively if the patient accepts the potential drawbacks[124,154-157]. Broberg and Morrey reported the long-term outcome in patients who sustained a Broberg and Morrey type 2 (n=7) or type 3 (n=17) radial head fracture associated with a dislocation of the elbow, which were treated with cast immobilization, with (n=14) or without (n=10) acute radial head resection[124]. Associated injuries were seen in 42% (n=10), with six associated coronoid fractures. In those treated with primary conservative treatment alone, delayed radial head resection to improve forearm rotation was common among Mason type 3 fractures (6/7), but not Mason type 2 fractures (0/3). Josefsson et al reported the outcome of in 23 patients with a displaced radial head fracture (17 type 2, 6 Type 3) and an associated elbow dislocation and found that 50% (4/8) with an associated coronoid fracture suffered a re-dislocation (3 acute radial head excision, 1 non-operative)[138].

ORIF

Several retrospective case series describe good results with operative fixation of slightly displaced, stable, isolated radial head fractures (Figure 1.13, Table 1.2)[158-160].

Figure 1.13: A radiograph post ORIF of a Mason type 2 radial head fracture. (Adapted from Yoon et al Clin Orthop Relat Res. 2014 Jul;472(7):2105-12)

In a retrospective review, Khalfayan and colleagues reported good results in 9 of 10 operatively-treated patients compared to 7 of 16 patients managed nonoperatively[158]. However, these findings have not been replicated and there are no prospective studies. Lindenhovius et al reported the long-term outcome of 16 patients managed with open reduction internal fixation (ORIF) for an isolated Mason type 2 fracture at a mean follow-up of 22 years[153]. They reported a complication rate of 31%, a mean flexion arc of 129 degrees, a mean Disabilities of Arm, Shoulder and Hand (DASH) score of 12 points, and good or excellent MES in 81%. The authors concluded that the long-term results of operative treatment gave no appreciable advantage over non-operative management, with an increased rate of complications, but operative techniques and implants have evolved since the time those patients were treated. Zaratini et al compared the medium term outcome of radial head resection (n=24) with ORIF (n=35) for isolated stable Mason type 2 fractures and found superior surgeon and patient reported outcome scores for ORIF[161].

Many of the favourable studies of ORIF for radial head fractures documented the treatment of isolated partially displaced fractures of the radial head, where a good result might be expected even with non-operative management[158,162-165]. ORIF of displaced whole head fractures (Mason type 3) has been associated with high rates of early failure, nonunion, and poor functional results in some series[77,96,166-168]. Fragmentation of the head (more than 3 fracture fragments including the neck/shaft as a fragment), metaphyseal bone loss, unrepairable fragments, and misshapen fragments all make ORIF less appealing. It is unclear if series reporting good results of ORIF for displaced whole head fractures are excluding fractures with these characteristics[169].

Radial head excision

It is now generally accepted that radial head excision should not be performed in the presence of associated acute elbow or forearm instability, with restoration of the radiocapitellar contact essential[124,154-157]. For traumatic elbow instability, once the ligaments are healed and the elbow is no longer at risk of dislocation or subluxation, resection of a deformed radial head can improve forearm rotation and is associated with very good long term outcomes[170,171]. It is unclear if partial resection leads to instability or crepitation, as well pain or arthrosis in the longer term.

Biomechanical studies have demonstrated that radial head fracture size and excision influence stability in both the intact and ligament deficient elbow joint[42,73,74]. Partial radial head resection leaves the elbow prone to dislocation or subluxation since the most important anterolateral part of the head is usually fractured[31,69,72]. Beingessner et al. performed a cadaveric study that reproduced radial head fractures through the anterolateral quadrant and applied different shearing loads to the elbow at varying degrees of flexion, reporting an inverse relationship between radiocapitellar joint stability and a decreasing shear load required as the fracture size increased[73]. A further in vitro study by this group found that performing internal fixation of displaced radial head fractures ≤1/3 of the articular diameter may confirm biomechanical advantages to elbow joint stability[74].

Janssen and Vegter reported excellent (17) and good (3) results according to the Broberg and Morrey score in 21 patients managed with early radial head resection for isolated Mason type 3 fractures, suggesting that replacement be reserved for the unstable elbow[172]. Broberg and Morrey, as well as Josefson and colleagues, found that elbow dislocations associated with a fracture of the radial head alone were stable; however, radial head excision alone is risky when there is an unstable coronoid fracture (terrible triad injury) and is contraindicated when there is interosseous ligament injury of the forearm[34,169-177]. If excision is considered, the push-pull test should demonstrate no more than 2 to 4 millimetres of movement of the radius[122], and the elbow should not dislocate in full gravity extension after the lateral collateral ligament complex is reattached to the lateral epicondyle. Potential sequelae of radial head excision in the setting of an unstable complex fracture pattern include proximal radial migration, radioulnar convergence and elbow or forearm instability[113,168,178,179].

Antuna and colleagues evaluated 26 patients (6 Mason type 2, 20 Mason type 3) less than 40 years of age a mean of 24 years after resection of a comminuted radial head fracture, excluding patients with associated fractures and ligament injuries[175]. The average MES was excellent (95) and the mean DASH was 6. Twenty-two patients had evidence of longitudinal migration of the radius, with an average of 3.1 mm ulnar positive variance (range, 0 to 9 mm), however, only three were >5 mm. Three patients had ongoing wrist pain, all of whom had proximal migration of the radius (1 with DRUJ instability on clinical examination). Four patients had increased valgus laxity and two had moderate posterolateral rotatory instability. Similar positive findings were reported in other recent long-term retrospective series from Italy and Spain[176,177].

Ikeda et al compared radial head resection (n=15) with ORIF (n=13) for 28 Mason type 3 radial head fractures associated with 16 elbow dislocations, five coronoid fractures and one capitellum fracture[169]. They documented superior results of ORIF an average of 10 years and 3 years post injury in terms of the Broberg and Morrey score and the American Shoulder and Elbow Surgeons Elbow Assessment Form (both $p<0.05$).

Prosthetic Replacement

Replacement of the radial head with a prosthesis is indicated for fractures that are associated with elbow or forearm instability and cannot be stably and reliably fixed (Figure 1.14).

Figure 1.14: A metallic radial head replacement for a terrible triad injury of the elbow.

Radial head replacement is recommended over ORIF for Essex-Lopresti injury variants as chronic forearm pain and instability have been associated with failure of ORIF[113]. It is not clear how to balance the drawbacks of no radial head (occasional slight valgus or posterolateral instability and potential acceleration of ulnohumeral arthrosis)[31,32,44,47-50,52,53,71], with the potential for long-term problems following insertion of a radial head prostheses[82,180-185].

The proximal radius has a precise and complex anatomy with an elliptical cross section, three articulating surfaces (radio-capitellar, lesser sigmoid notch, lateral trochlea), and an angulation of the head and neck relative to the shaft which are difficult to replicate with a prosthesis[82,186]. The first widely used radial head prostheses made of silicone rubber were associated with fragmentation and destructive synovitis[187-196] and have given way to more rigid prostheses made of metal, pyrocarbon, and even methylmethacrylate[69,182,183,197-207].

Some radial head prostheses attempt to replicate the anatomy of the radial head and are rigidly fixed to the neck. Others incorporate some motion intended to compensate for nonanatomic features. Examples include a prosthesis with a smooth stem that is not rigidly fixed to the neck and prostheses with a mobile articulation at the neck (so-called bipolar prostheses) [180,182,198,208-211]. The bipolar prosthesis provides improved alignment with the capitellum, as well as a reduction of the force across the radiocapitellar joint[212,213]. Potential problems with bipolar designs are less stability when there is associated soft tissue disruption[213-215], as well as the development of osteolysis related to polyethylene wear[206,216]. Potential problems with a monoblock design rigidly fixed to the neck include increased rates of predominantly asymptomatic loss of bone at the radial neck[210,217]. Comparable short to mid-term clinical results have been reported for the loose spacer and the cemented bipolar implants[182,198,202,210,216,218]. When resources are limited, a loose, smooth prosthesis can be made out of methacrylate bone cement[201,204].

Harrington et al reviewed 20 patients at a mean of 12 years after insertion of a loose, smooth stemmed metal prosthesis. Eighty per cent had good or excellent elbow function and they did not identify any problems with the prosthesis over the long-term[180]. A recent prospective randomised controlled trial with two year follow-up compared a monopolar fixed neck, titanium radial head prosthesis matched to each patient (n=22) with ORIF (n=23) and found significantly better results (91%

good or excellent vs. 65%, $p<0.01$) and a lower rate of complications (13.6% vs 47.9%, $p<0.01$) with replacement[205]. Comparable results were reported from another short-term randomised controlled trial by Ruan et al using a bipolar cemented Tornier prosthesis[200].

A noted complication of radial head replacement is related to ‘over stuffing’ the joint, which can be associated with pain and stiffness[82,181,219,220]. Recent data has suggested that the proximal edge of the prosthesis should sit no more than a millimetre proximal to the corner of the lesser sigmoid notch on the coronoid to avoid radiocapitellar erosions, synovitis, ulnohumeral malalignment and arthritis[82,202,221,222], with contralateral elbow radiographs potentially helpful in the diagnosis[223]. Others have suggested intra-operative visualisation of the lateral ulnohumeral joint space[220].

Additional complications include nerve injury and dislocation, with the overall rate of complications wide ranging. Some surgeons confidently ascribe proximal forearm pain to radiographic changes associated with loose prostheses[217,224], while others find no association between radiographic changes and symptoms, at least with prostheses that are intentionally loose[198,225].

1.4 Olecranon fractures

1.4.1 Epidemiology

There is almost no literature clearly documenting the epidemiology of olecranon fractures despite them being one of the most common injuries occurring around the elbow, accounting for between 10-20% of all elbow fractures[7,8]. Fracture frequently occurs from direct or indirect trauma following a fall from standing height[13,92,226]. The incidence of olecranon fractures has been quoted in one study from Sweden to be 10.8 per 100,000 adult individuals per year, with an incidence of 11.5 per 100,000 adult individuals per year in patients older than 16 years of age[13].

Early studies examining the management of these fractures documented an average age of between 35-45 years and an approximately equal gender ratio[7,17,28]. The only randomised control trial comparing TBW with plate fixation quoting a mean age of 31 years[20]. Recent limited data has suggested some of these fractures should now be considered to be fragility fractures[14,92], particularly in woman. Further work in this area is clearly warranted.

The incidence of associated injuries is unclear, although fractures of the radial head, coronoid and Monteggia fracture-dislocation are documented[9]. Given the subcutaneous location of the proximal ulna, open olecranon fractures are more common than for fractures of the radial head[227].

1.4.2 Diagnosis and Classification

Clinical assessment

Patients present following direct or indirect trauma to the elbow, often following a fall from standing height[13,92,226] with the elbow flexed at about 90 degrees[63]. Patients with a high-energy injury mechanism require a full and careful evaluation of the elbow joint to exclude a more complex injury pattern e.g. Monteggia fracture-dislocation.

The patient will complain of elbow pain, associated swelling and point tenderness over the proximal ulna, with a reduced range of movement in all directions. The patient will likely be unable to actively extend the elbow due to discontinuity in the extensor mechanism. The fracture site can also be palpable. Careful assessment of the skin is necessary to exclude a possible open fracture. Distal neurovascular status should always be tested and documented. Initial and repeated assessments of the arc of motion, forearm rotation, as well as elbow and forearm stability are essential post-operatively.

Imaging

Standard AP and lateral radiographs of the injured elbow are necessary for making the diagnosis (Figure 1.15). These views will aid in determining fracture displacement and comminution, as well as identifying any fractures of the radial head or neck, dislocation of the elbow, and any fractures to the distal humerus.

Figure 1.15: A lateral radiographs demonstrating a displaced comminuted fracture of the olecranon.

Initial images can be limited due to pain and deformity and repeat radiographs once immobilised may be of use[34]. Further imaging modalities are not routinely required for fractures of the olecranon, unless a complex injury is suspected. For such cases, CT with 3D reconstruction can aid with both diagnosis and pre-operative planning. However, the extent of such injuries may not be apparent until theatre[34].

Classification

Although several classification systems exist, one of the most commonly used is the Mayo classification that incorporates displacement, elbow instability and comminution (Figure 1.16)[49]. Mayo type 1 fractures are undisplaced and stable with (1B) or without (1A) comminution. Mayo type 2 fractures are displaced and stable with (2B) or without (2A) comminution. Mayo type 3 fractures are displaced and unstable with (3B) or without (3A) comminution. Karlsson et al documented that 13% of olecranon fractures were undisplaced (<2mm articular displacement) and 22% were comminuted[13]. Other data would suggest that up to 85% of all olecranon fractures are displaced and stable injuries (Mayo type 2)[10,228].

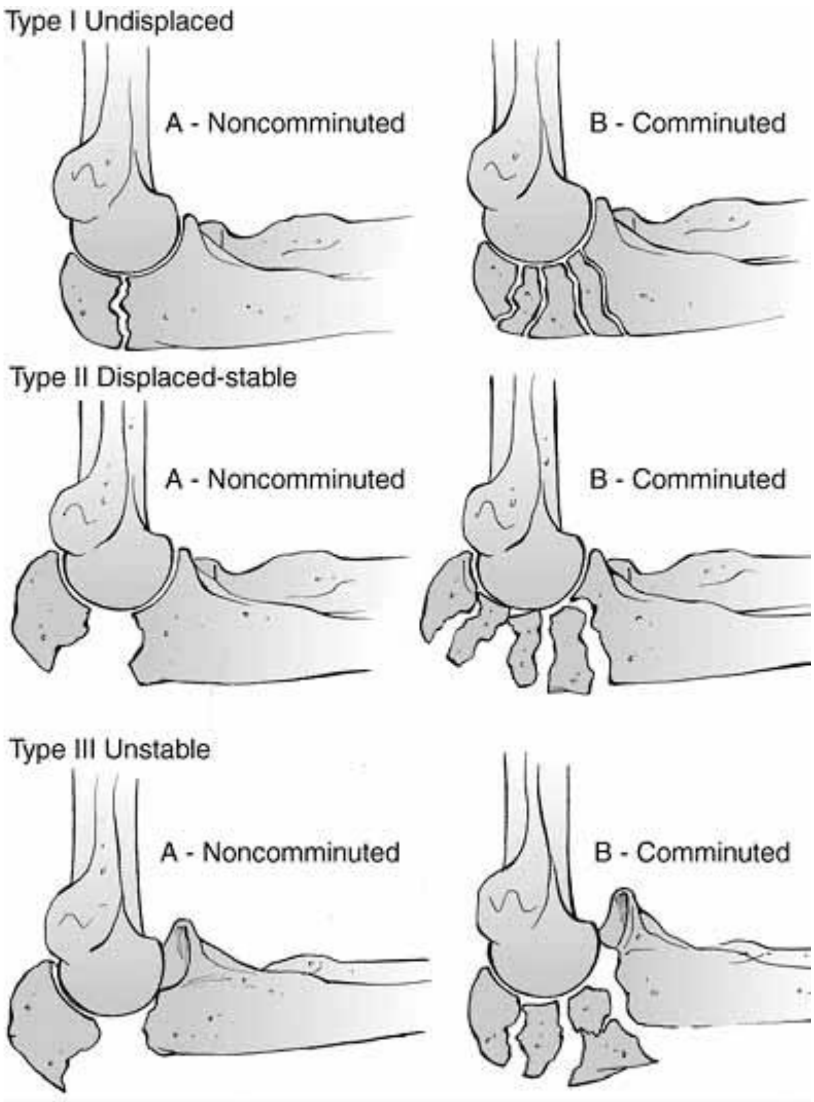


Figure 1.16: The Mayo classification for fractures of the olecranon. (Adapted from Rockwood and Green's Fractures in Adults. 6th ed. Lippincott Williams & Wilkins; 2006)

The other classification systems are summarised in Table 1.3. The Mayo and Schatzker classifications have both been found to be prognostic of outcome, with instability and fracture configuration (oblique and comminuted) predictive of a poorer outcome[7].

Classification		**Description of fracture pattern**
Colton	Type 1	Undisplaced and stable
	Type 2A	Displaced avulsion
	Type 2B	Displaced transverse or oblique
	Type 2C	Displaced comminuted
	Type 2D	Fracture-dislocation
Schatzker	Type A	Simple transverse
	Type B	Transverse impacted
	Type C	Oblique
	Type D	Comminuted
	Type E	Oblique-distal/extra-articular
	Type F	Fracture-dislocation

Table 1.3: The other classification systems for olecranon fractures.

AO-OTA classification

The AO-OTA classification combines proximal forearm fractures under one classification system (Figure 1.10)[134,135]. Type A fractures are extra-articular of either the radius or ulna, type B fractures are intra-articular of the radius or ulna, and type C fractures are intra-articular fractures of both bones. An isolated olecranon fracture is a 21-B1. Like with fractures of the radial head, the AO-OTA classification is comprehensive although difficult to use in day-to-day practice and is felt better suited for research analysis.

Associated injuries

Associated injuries of olecranon fractures are highly variable and need to be assessed and managed on an individual basis. Fractures of the radial head, coronoid, distal humerus and the Monteggia fracture-dislocation (and variants) are seen. Unlike anterior olecranon fracture-dislocations, posterior fracture-dislocations are often associated with radial head and coronoid fractures, as well as an LCL complex injury[143,229].

1.4.3 Management and Complications

The aims of treatment for all olecranon fractures are restoration of function and stability to the elbow joint[7], with minimal associated complications[9,230]. However, consideration of the patient's existing co-morbidities and functional status, as well as the fracture complexity and associated injuries, is essential when determining the optimal treatment. Risks factors associated with a poorer outcome following operative treatment of displaced olecranon fractures are fracture morphology and associated elbow instability or fractures[7,231].

It is agreed that patients with a Mayo type 1 stable undisplaced olecranon fracture can be treated effectively with non-operative management by splinting the elbow in 45-90^{o} of flexion for 3-4 weeks followed by supervised mobilization[9,34]. The acceptable degree of fracture displacement is commonly quoted as <2mm of articular displacement[9,226].

For the Mayo type 2B (comminuted, displaced) and Mayo type 3 (associated with elbow dislocation) fractures, plate fixation is considered to be optimal (Table 1.4), with superior fracture reduction and fixation results, as well as a lower rate of re-operation[9,12,20,21,228,230,232-234]. It is possible that consideration should be given to non-operative management in low-demand and elderly patients with significant co-morbidities for Mayo type 2A and type 2B fractures, although the evidence to data is limited. The other main controversy is regarding the stable and displaced olecranon fractures with minimal or no comminution (type 2A). Tension-band wiring (TBW) is the most recognized and frequently used fixation method for these fractures, although plate fixation and intramedullary screw fixation are noted alternatives[7,9,12-17,228].

Mayo Classification	**Non-operative**	**TBW**	**Plate Fixation**
1A (undisplaced, stable)	√	x	x
1B (undisplaced, stable, comminuted)	√	x	x
2A (displaced, stable)	x	√	√
2B (displaced, stable, comminuted)	x	X	√
3A (displaced, unstable)	x	x	√
3B (displaced, unstable, comminuted)	x	x	√

Table 1.4: Management of olecranon fracture according to the Mayo classification.

Non-operative management

There is very limited evidence regarding the non-operative treatment of displaced olecranon fractures, particularly in elderly patients where co-morbidities, pre-injury functional status, bone quality and potential complications should be considered before determining the optimal treatment. There is conflicting evidence that would suggest the outcome post-surgical fixation of a displaced olecranon fracture is inferior in elderly patients[22,23]. Although there is minimal literature regarding non-operative management, the results are favourable.

Parker et al treated 23 patients (15 men, 7 women), mean age 48 years (range, 13-91), with a displaced olecranon fracture non-operatively using early active motion within 10 days of injury[28]. There were 13 non-comminuted fractures, seven comminuted fractures and three open fractures. Seven patients had fractures to the ipsilateral arm. At a mean follow-up of 26 months 12 patients were rated as good, nine as fair and two as poor (Table 1.5, Table 1.6). Two cases had a loss of flexion arc greater than 30 degrees and three patients had loss of power (MRC Grading +4). Radiological union was achieved in seven cases, with fibrous union achieved in the rest. The authors concluded these results were comparable to operative treatment.

Age (years)	**Good** *Slight pain* *Loss flexion/extension <15°*	**Fair** *Moderate pain* *Loss flexion/extension 15-30°*	**Poor** *Constant pain* *Loss flexion/extension >30°*
<30	5	2	1
31-50	2	2	0
>50	5	5	1

Table 1.5: The breakdown of outcome according to age for the 23 patients managed conservatively for a displaced olecranon fracture by Parker et al[28].

Author (year)	Patients (n)	Mean age yrs (range)	Male/Female	Mean Follow-up (months)	Mean elbow flexion arc Mean forearm rotation arc	Outcome	Complications
Parker et al. (1990)	23	48 (13-91)	15/7	26 (5-96)	- -	12 good, 9 fair, 2 poor 2 loss flexion arc >30 degrees 3 MRC grading 4+ extension 16 fibrous union/non-union	None
Veras del Monte et al. (1998)	13	82 (73-90)	3/9	15 (6-33)	129° 167°	8 good, 3 fair, 1 poor 92% excellent satisfaction 67% pain free 9 fibrous union/non-union	Degenerative arthropathy (n=1) Skin breakdown (n=1)
Bruinsma et al. (2012)	10	59 (21-94)	4/6	17 (3-84)	117° 172°	No angulation or instability Weakness of extension 4/10 100% fibrous union/non-union	Painful non-union (n=2) Ulnar neuropathy (n=1)
	6	58 (21-94)	3/3	22 (5-48)	122° 173°	Mean DASH score 16.8 (n=5) Mean Mayo Elbow score 88 (n=5) Median VAS score 0	

Table 1.6: Studies reporting on the non-operative management of displaced stable olecranon fractures of the olecranon.

In a case series of 13 elderly patients (mean age 81.8 years, >5 mm fracture displacement) treated non-operatively for a displaced olecranon fracture, Veras del Monte et al found patient satisfaction at a mean of 15 months post injury was excellent in 11 patients and poor in only one[11]. According to the criteria of Parker et al eight were good, three were fair and one was poor. Four fractures were noted as being comminuted with displacement ranging from 5-20mm, but with no fractures open or associated with a dislocation. Patients were treated in a splint with the elbow at 90 degrees for a mean of 4 weeks (range, 1-12). At follow-up 67% were pain free, the median elbow flexion arc was 129 degrees and nine patients had a pseudoarthrosis on radiographs. In the one patient with a poor result, this was associated with the development of a degenerative arthropathy. The only other complication noted was a skin sore that healed without concern.

Bruinsma et al reported on 10 patients with a mean age of 59 years (range, 21-94) who presented with a non-union of a displaced olecranon fracture at a mean of 17 months post non-operative management. The mean flexion arc was 117 degrees and all patients were noted to have active elbow extension. Eight patients required no further intervention. Of the two patients who required subsequent surgery, these were both younger patients (21 years and 45 years). One underwent delayed ORIF for an extension weakness and one underwent excision and advancement of triceps for pain with heavy work.

Tension band wiring

Tension band wiring is based on the concept of conversion of the posterior distracting tensile triceps extensor force to a dynamic compression force along the articular surface of the reduced olecranon fracture[9,10,76]. However, the validity of the TBW fixation (Figure 1.17) concept was questioned by Hutchinson et al who cyclically loaded ten cadaveric elbows with simulated transverse fractures of the olecranon[235]. A combination of K-wire, TBW and intramedullary screw constructs were evaluated. They found none of the TBW constructs provided compression at the fracture site and recommended passive exercises only in the post-operative period.

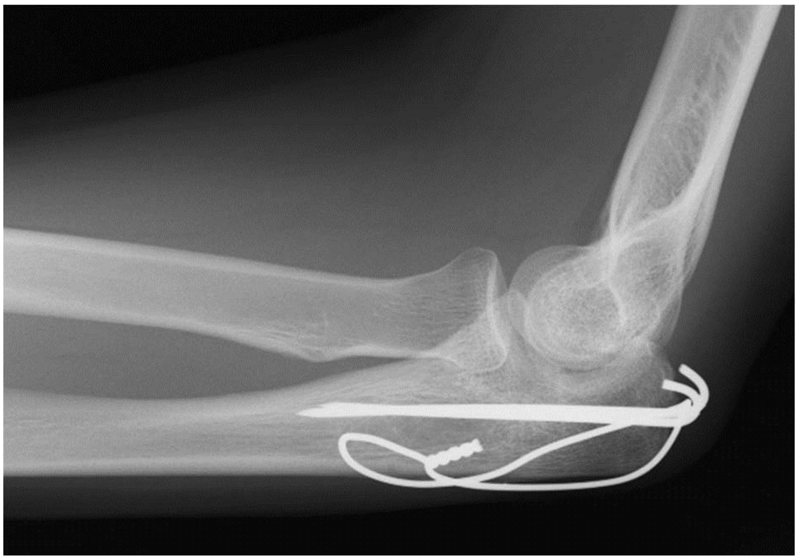


Figure 1.17: TBW of a displaced olecranon fracture.

There is a limited amount of literature reporting on the short and long-term outcome of TBW for isolated displaced fractures of the olecranon. Karlsson et al reviewed 73 patients who had sustained a fracture of the olecranon[13]. Ten (13%)

were displaced ≤2mm and were managed non-operatively. Eight-four per cent were managed with operative fixation, with a figure-of-eight wire used in 40% and a TBW used in 41%. Of these, 65% were simple fractures displaced >2mm and 22% were comminuted. At a mean follow-up of 19 years, 84% of patients had no complaints and 96% achieved a good or excellent outcome. Joint incongruity was found in 33% patients on long-term radiographs. The removal of metalwork rate was 48% and was performed due to localized pain after clinical fracture healing. One patient in this series developed a non-union.

Chalidis et al reviewed the long-term outcome in 62 patients who underwent TBW fixation for a displaced olecranon fracture, of which 40 (64.5%) patients sustained a simple displaced fracture, 13 (21%) a displaced comminuted fracture, and 9 (14.5%, 8 simple, 1 comminuted) cases were associated with elbow instability[14]. At a mean follow-up of 8yrs, 86% patients had a good or excellent outcome according to the MES, with an average satisfaction of 9.3/10. The rate of wound infection in this series was 6.5%, with two of the four patients requiring operative debridement. The rate of non-union was 3.2%. The implant removal rate in all patients was 82.3% and was due to pin prominence, localized pain or on patient request. In this series, no difference was found in the rate of pin loosening and back out whether or not anterior ulnar cortex penetration was achieved.

Among 44 consecutive patients treated with TBW fixation by Villanueva et al, 37 were reviewed at a mean follow-up of 4 years[231]. Of these 37 cases, 20 sustained non-comminuted, displaced fractures with one of these having an associated fracture of the radial head. The mean MES at follow-up was 86 (good), with a mean flexion arc of 126 degrees and a mean DASH of 18.1. The overall implant removal rate was 46%, with the rate in the 20 patient sub-group 45% (n=9), of which three had associated skin breakdown. Overall, there were three cases of heterotopic ossification (HO) that was associated with reduced elbow function.

Rommens et al performed a retrospective analysis of 95 olecranon fractures, with follow-up obtained in 61%[7]. Overall, 95% were managed with some form of TBW and 5% were treated with plate fixation. There were only 20% who sustained a simple displaced fracture, with 29% a displaced comminuted fracture, and 30% (11% simple, 19% comminuted) were associated with elbow instability. At a mean follow-up of 36 months normal radiographs were seen in 60%. In 8.4% of patients implant migration was seen, with 4.2% undergoing subsequent surgery. Overall, the rate of revision surgery was 14.7%, the rate of infection was 2.1% and the rate of delayed union 3.2%. The rate of metalwork removal 12 months post-surgery was 65%.

Complications associated with the TBW technique are wound breakdown, infection, prominent metalwork, malunion and non-union[7,9,14,18-20,236]. The most frequently noted complication is symptomatic metalwork requiring removal. The highest re-operation rate in the literature is 85% and was found by Macko and Szabo who performed a five year retrospective analysis in 20 patients with a variety of displaced olecranon fractures[18]. In 80% (n=16) of patients symptomatic K-wire prominence was the most frequent complication, and was mostly commonly due to inappropriate position at the time of surgery (12/16). However, proximal migration of the K-wire was seen in only 15% (n=3) of all cases. Skin breakdown was seen in 20% (n=4) and infection in only 5% (n=1).

The development of complications has been associated with K-wire positioning. Some authors advocate that the K-wires should penetrate the anterior ulna cortex to prevent pullout[237,238], which has been associated with poor forearm rotation[239]. Huang et al retrospectively reviewed 78 displaced olecranon fractures treated with TBW fixation over a period of 2.76 years[240]. These patients were placed into three groups depending on the placement of the K-wires 1) the proximal ulnar canal, 2) the anterior ulnar cortex or 3) the distal ulnar canal. They found that proximal pin migration and elbow irritation were associated with proximal pin placement and recommended placement of the wires in the distal canal given the complications documented in the literature associated with placement in the anterior cortex. These include iatrogenic neurovascular injury and loss of forearm rotation[241-245].

Plate fixation

There is almost no literature exclusively examining the use of plates for the treatment of isolated displaced olecranon fractures (Figure 1.18). Much of the literature in this area examines the use of plate fixation for comminuted, distal or unstable fractures of the olecranon[9,12,20,21,228,230,232-234].

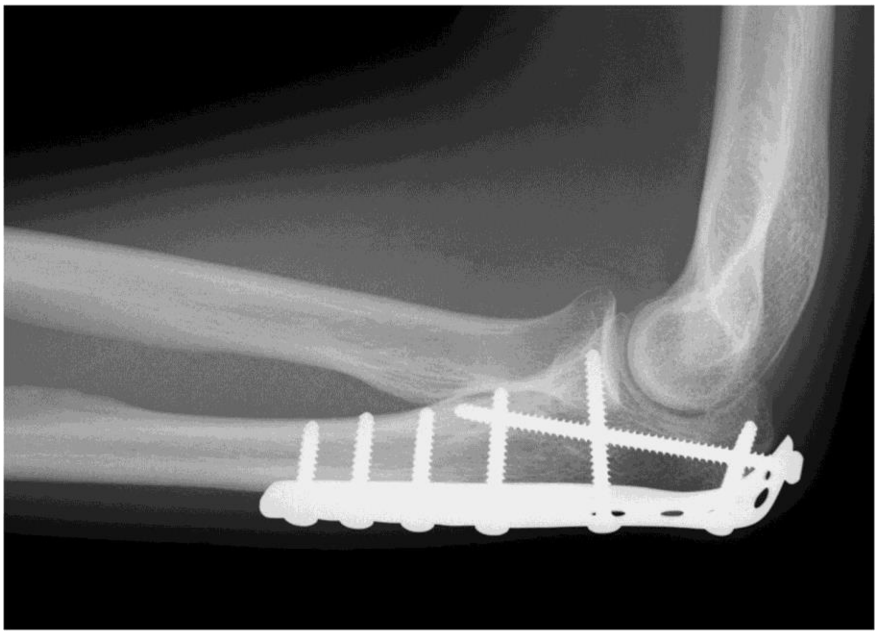


Figure 1.18: Plate fixation of a displaced olecranon fracture.

Bailey et al reviewed 25 patients at an average of 34 months who underwent plate fixation for displaced fractures of the olecranon[21]. An isolated, displaced fracture was seen in 14 patients, of which five were non-comminuted. There were 11 fractures associated with instability, of which 7 were comminuted. Overall, despite a notable reduction in supination compared to the contralateral arm, patient satisfaction was 9.7/10, the mean DASH was 10, and the MES was rated as good or excellent in 23 (92%) patients. Of the five patients in this cohort that had non-comminuted, displaced fractures (Mayo type 2A), the mean MES was 88 with a satisfaction score of 9.8/10. No difference was found between any of the outcome measures when comparing stable and unstable fractures directly. Overall, no infections were seen and in post-operative radiographs an articular step was seen in four patients. Symptomatic prominent metalwork removal occurred in 20%, although two of these patients had concomitant TBW. Two patients developed chronic pain and two patients developed asymptomatic heterotopic ossification (HO).

Anderson et al performed a retrospective study of 32 patients who underwent plate fixation for a displaced olecranon fracture, of which 17 were for non-comminuted displaced fractures[246]. They reported a symptomatic implant removal rate of 12% (n=2) in this sub-group, with a mean MES of 90 and a mean DASH of 22.1 in the 12 patients with follow-up. No difference was seen between the Mayo type 2A fractures and other fractures in terms of MES, DASH or flexion contracture. Furthermore, there was no difference in outcome between comminuted and non-comminuted fractures. As Bailey et al found, no difference in outcome was seen between the stable (Mayo type 2) and unstable (Mayo type 3) fracture patterns.

Hewins et al examined the use of plate fixation following olecranon osteotomies used in 17 consecutive patients who were treated with open reduction internal fixation for an intra-articular distal humeral fracture[247]. In their series all osteotomies united. One patient required an early secondary procedure to shorten a screw that penetrated the proximal radio-ulnar joint. At a mean follow-up of 32 months, only one (6%) patient requested plate removal.

The main perceived complication associated with plate fixation is prominent metalwork given the position of the plate on the dorsal ulna, which has been shown to provide superior strength to the dual medial-lateral plating technique[248]. However, the limited literature would suggest the rates of removal range form 5-20%[9,20,21], which is much lower than that quoted for TBW fixation[14].

TBW versus plate fixation

To date, there is only one prospective randomized trial in the literature comparing TBW and plate fixation for displaced olecranon fractures[20]. Hume and Wiss randomized 41 patients to either TBW (n=19) or plate fixation (n=22) over a one year period. Comminuted and open fractures were included. The major conclusions from this study were that the elbow motion at six months was not significantly different between the two groups, although the post-operative loss of fracture reduction and prominent symptomatic metalwork was more frequently observed after TBW (Table 1.7).

	TBW (%) (n=19)	**Plate Fixation (%) (n=22)**	**p value**
Clinical Outcome			
Good	47	86	
Fair	32	5	NR
Poor	21	9	
Radiological Outcome			
Good	37	64	
Fair	10	27	NR
Poor	53	9	
Symptomatic prominent metalwork	42	5	0.01

Table 1.7: The clinical and radiographic results from the randomized control trial comparing TBW with plate fixation for olecranon fractures[20]. P values are shown where available. (NR = not reported)

The overall clinical outcome was noted to be far superior in the plate fixation group, with 86% obtaining a good result compared to 47% in the TBW group. Twenty-one per cent of the TBW group was defined as having a poor clinical outcome, with 53 % a poor radiological outcome. The radiological outcome in the plate group was defined as good or fair in 91%. Symptomatic metalwork was seen more frequently in the TBW group (42%) than the plate group (5%, p=0.01). All other complications occurred in the TBW group and included infection (n=2), delayed or non-union (n=2), HO (n=1) and ulnar neuropathty (n=1).

Intramedullary screw fixation

There is a lack of clear evidence documenting the efficacy of an intramedullary screw as primary fixation for displaced fractures of the olecranon, with or without associated mini-plate or tension band wire fixation. There have been in vivo biomechanical studies suggesting improved fracture stability with intramedullary screw fixation[235,249-251]. Hutchinson et al concluded that a 7.3-mm screw in conjunction with a tension band wire construct provided superior fixation of a simulated displaced transverse fracture of the olecranon than a tension band wire supplemented with Kirschner wires or the use of a screw alone[235]. However, although it is logical that combining fixation techniques will result in a biomechanically stronger construct, it remains unclear what the optimal construct is to provide stability without leading to associated metalwork complications. Similarly, there are reports on the effective use of an intramedullary screw in repairing the olecranon osteotomy following distal humeral fracture repair[252-254].

A few older studies have advocated the use of the intramedullary screw for fixation of displaced olecranon fractures, with or without a supplementary tension band wire construct, although some have reported an increased loss of fixation with the screw[24,252,255]. There are an increasing number of modern studies reporting good results using a locked intramedullary compression nail for fractures of the olecranon[256-258]. Gehr and Friedl reported on the short-term outcome of 73 (67% comminuted, 33% simple transverse) displaced fractures of the olecranon and reported good or excellent results in 93% of cases.

Some authors advocate the high union rates achieved with intramedullary screw fixation; however, these are comparable to those found with both tension band wire and plate fixation. Furthermore, recent literature has documented that fractures of the olecranon are fragility fractures, with a large number occurring in osteoporotic patients[91]. In such patients it is suggested that it is difficult to achieve adequate reduction and fixation using intramedullary screw fixation without any form of augmentation, therefore, not improving on the outcome in relation to the issues associated with hardware irritation.

Triceps excision and advancement

TBW and plate fixation can be employed in elderly patients, although difficulties associated with fixation in osteoporotic bone, wound breakdown and other complications are reported[11]. In these patients, fracture excision with advancement of the triceps is a viable option if fixation is deemed inappropriate[17,27,259,260]. Some prerequisites for this to be effective are a stable elbow joint (intact coronoid and medial collateral ligament) and a stable forearm (intact interosseous membrane and distal radio-ulnar joint), with the excision limited to less 50% of the trochlear notch[9,230,261]. Much of the literature in this area is in relation to displaced comminuted olecranon fractures.

Gartsman et al performed a retrospective analysis of 107 patients with a displaced isolated olecranon fracture, 53 who were treated with excision and advancement and 54 who were managed with surgical fixation[17]. In the excision group 73% were women and the mean age was 60 years. In the fixation group 47% were women and the mean age was 45 years. There were 63 patients with radiographs available for classification, with 18 cases severely comminuted or an avulsion fracture, with the remaining 45 having non-comminuted displaced fractures. Two part fractures were evenly distributed between the two treatment groups. The rate of complications in the fixation group was 24%, compared with 4% in the excision group. In the fixation group these included infection (n=3), symptomatic metalwork removal (n=2), failure of metalwork (n=1), delayed union (n=1), skin slough (n=1), keloid scar (n=1) and three patients who required excision intra-operatively as the fracture was further comminuted by the fixation method. In the excision group the complications were infection (n=1) and instability (n=1) related to excision of approximately 75% of the particular surface. Only 29 patients underwent long-term follow-up at a mean of 3.6 years. Comparable functional results, including elbow extension, were seen for each group.

Inhofe and Howard reported the results of excision and triceps advancement in 17 patients[25]. In the 12 patients with adequate follow-up, 7 had an excellent result, 4 had a good result and 1 had a poor result. No associated complications were noted.

1.5 Limitations of the evidence and directions for research

There is lack of clear literature examining and defining the epidemiology of proximal forearm fractures and further work is required to determine the characteristics of these injuries. Furthermore, associations with socioeconomic deprivation are unknown. An increased understanding of the epidemiological characteristics of these injuries will potentially have substantial consequences to how we study and manage these fractures.

1.5.1 Radial head fractures

The debate regarding stable isolated fractures of the radial head focuses on the role of operative intervention, with non-operative treatment associated with good results[4,5,77,133,146,153,158,161,165,262]. Symptomatic radiocapitellar arthrosis appears to be rare after a stable isolated fracture of the radial head[133,146,147,175,263], and stable minimally displaced fractures do not create a bony block to elbow flexion and extension. The goal of operative treatment is to address crepitation with forearm rotation or hindrance of forearm motion, both of which are thought to be uncommon[1,3,34,80,133,153]. The most common adverse outcome of a stable isolated fracture is elbow stiffness from capsular contracture, and the most important aspect of treatment is confident stretching exercises to regain motion[68,151].

The evidence to date in relation to these injuries is limited primarily to small retrospective case series, many promoting a specific technique. Some patients with isolated, stable partial articular fractures with 2 millimetres or more displacement have pain, crepitation, or limited motion many months after the fracture. It is not clear if these symptoms will eventually resolve, or if these patients would have had better results with operative treatment, and if so, how to identify these patients from among the majority documented to do well with non-operative treatment.

Large prospective cohort studies and long-term outcome studies of patients with isolated stable fractures of the radial head would help establish the incidence and risk factors for the development of discomfort and dissatisfaction. Validated upper limb patient reported outcome measures (PROMs e.g. DASH or SMFA) should be used as the primary outcome measure, which has not been done in the long-term. Psychological and sociological factors should be taken into account given that they are often the best determinants of symptoms and disability. Given some authors advocate ORIF for stable isolated moderately displaced fractures[158-161], it would suggest the need to demonstrate a benefit over non-operative treatment in a prospective randomized controlled trial[149,262,264]. However, more data is needed to determine the size of such a trial given the low rate of adverse outcomes. Data from prospective and long-term studies may provide enough evidence to negate the need for such a trial.

Diagnosis of unstable injury patterns is generally well agreed, although further data is required to better define the degree of radial shortening that is acceptable in association with the suspected Essex-Lopresti type lesion. The issues regarding management of unstable fractures include which fractures can be repaired and what is the best technique for internal fixation[69,77,158,160,161,166,201,265-270]; which fractures are better off resected and whether partial resection is an option[169-177]; and when to replace a resected head with a prosthesis and what is the best prosthetic design to use[69,182,183,197-200,202,203,205,206]. In most circumstances, the primary goal of operative treatment of unstable fractures of the radial head is to prevent dislocation or subluxation of the elbow and forearm. For unstable fractures that are part of a more complex injury, the imperfections of prosthetic arthroplasty and the uncertain long-term consequences of prosthetic on cartilage raise the issue of how far to take attempts at open reduction and internal fixation before resorting to prosthetic replacement. For unstable fractures, more long-term survival data is needed on prosthetic replacement and more randomized trials comparing both ORIF with prosthetic replacement.

1.5.2 Olecranon fractures

The literature examining the long-term outcome of fractures of the olecranon, as well as the pros and cons of the fixation techniques available for displaced olecranon fractures, is often hindered due to the use of a variety of classification systems, a heterogeneous group of fracture morphologies, as well as the use of different TBW and plate fixation methods. Due to this, it is difficult to determine any meaningful conclusions regarding optimal management.

Studies of displaced olecranon fractures are difficult to interpret due to 1) a mixture of comminuted fractures and fracture-dislocations with non-comminuted fractures; and 2) the use of different TBW and plate fixation methods. In particular, the use of tension band wiring for comminuted fractures is odd, given that the tension band principle requires an intact cortex opposite the tension band, which would mean a simple, non-comminuted articular surface fracture for the olecranon.

It is difficult to interpret implant removal as it is routine in some countries and centres and highly subjective in general. There is little data regarding the ability of specific TBW and plate techniques to limit symptoms related to the implants. The data to date suggests that any technique that can hold the olecranon in place for over a month will lead to union and good function, but they are all prone to bothersome prominence in a subset of patients. The only prospective randomized study available in this area was performed in 1992 with less sophisticated plate systems than are currently available, as well as including complex and open fractures[20]. Despite the findings of Hume and Wiss that would suggest that plate fixation is superior in some respects, TBW is still seen as the gold standard for isolated displaced olecranon fractures[14].

Non-operative treatment is rarely reported in the literature and there is only one long-term study examining the use of non-operative treatment for displaced olecranon fractures in elderly patients[11]. TBW and plate fixation can be employed in elderly patients, although difficulties associated with fixation in osteoporotic bone, wound breakdown and other complications are reported[11]. There is conflicting evidence that would suggest the outcome post-surgical fixation of a displaced olecranon fracture is inferior in elderly patients[22,23]. There is limited evidence regarding the non-operative treatment of displaced olecranon fractures, particularly in elderly patients where co-morbidities, pre-injury functional status, bone quality and potential complications should be considered before determining the optimal treatment. While excision and advancement of the triceps has fewer complications than placing implants, it is not clear that it is superior to no surgery at all. Increasing numbers in the elderly population demand that further work should also look at the outcome of elderly patients managed non-operatively for these injuries with long-term outcome studies, as well as a PRCT comparing this with operative management.

1.5.3 Thesis aims and hypotheses

There is a paucity of robust information in the literature to aid decisions regarding the epidemiology and management of proximal forearm fractures. To address the current limitations of the literature, this thesis will aim to clearly define the individual epidemiological characteristics of fractures of the proximal forearm.

Data from a large prospective study using a pre-defined management protocol for all radial head fractures will aim to provide data regarding the early outcome and complication rate for these injuries. Through retrospective analysis, data will be collected and analysed to determine the long-term outcome for both the non-operative and operative management of radial head and olecranon fractures, using PROMs as the primary outcome measure. Using data from these studies, factors predictive of outcome will be determined and could potentially aid in defining those fractures that can be managed successfully with non-operative intervention.

Finally, two prospective randomized controlled trials (PRCT) will be carried out comparing 1) TBW with plate fixation for isolated displaced olecranon fractures with no or minimal comminution; and 2) Operative vs. nonoperative treatment among low-demand infirm patients. The prospective randomized controlled trial comparing TBW with plate fixation will include all isolated displaced olecranon fractures with no or minimal comminution to help determine the optimal management for these injuries. The second trial comparing non-operative versus operative management for all stable displaced olecranon fractures in elderly patients will be a pilot study given the time constraints of this thesis. The 'cut-off' criteria for these two trials will be determined using data from the preceding epidemiological and retrospective studies. The primary outcome measures for both trials will be an upper limb specific patient orientated outcome disability score (e.g. DASH score), adverse events, patient satisfaction and costs. Radiographic follow-up examining loss of reduction and metalwork failure will be needed, as well as examining complications such as wound breakdown and prominent metalwork requiring removal.

Through this work the aims of this thesis were to test the hypotheses:

1. That non-operative management provides a comparable result to operative intervention for defined fractures of the proximal forearm
2. When operative management is indicated, what is the optimal method and outcome

2 PATIENTS AND METHODS

2.1 Patients and database construction

For all the planned studies, basic demographic data including age, gender, side affected, mechanism of injury, all chronic medical co-morbidities and socioeconomic deprivation category was collected. Fracture classification, including open fracture classification, and associated injuries was determined through a combination of medical note and radiological imaging review where possible, the details of which are found in Section 2.4. Management including details of any surgical management, duration of treatment, the use of physiotherapy, complications and subsequent surgical procedures was also recorded.

2.1.1 The epidemiology of proximal forearm fractures

An existing prospective database of all inpatient and outpatient fractures presenting over a one-year period was used to identify, define and analyse the changing epidemiology of proximal forearm fractures. All fractures were prospectively identified and recorded that presented over a one year period (2007-2008) to the Edinburgh Orthopaedic Trauma Unit (EOTU), which is the only orthopaedic trauma service for the regional adult population (≥13yrs of age). A total of 6872 confirmed fractures presented from 2007-2008.

No other centre in the catchment area provides a musculoskeletal trauma service. The EOTU has a captive population of approximately 514,479, with 270,367 females (52.6%) and 244,112 males (47.4%). Population estimates were used for all adult patients aged 13 or more in the City of Edinburgh, East Lothian and Midlothian[271]. Patients from West Lothian were excluded as outpatient fractures are managed at another institution.

This database was used to identify patients as it contains all fractures that presented over a defined time period. This enabled analysis to both define and contrast the distinct epidemiological characteristics of these injuries. The comprehensive methodology for this section is found in Chapter 3, Section 3.4.

2.1.2 A prospective analysis of radial head fractures

Short-term outcome

A prospective study was performed and a database compiled of consecutive skeletally mature patients who presented to the EOTU with a fracture of the radial head. Inclusion criteria included a closed radial head or neck fracture radiographically confirmed at two weeks, with no other fracture or significant soft tissue injury affecting the skeleton. Patients with an associated ipsilateral elbow dislocation alone, the Mason type 4, are included. Exclusion criteria were a concomitant fracture or significant soft tissue injury affecting the skeleton, including visceral injuries and polytrauma patients.

The primary outcome measures were the surgeon reported Mayo Elbow Score (MES)[272] and the patient reported Short Musculoskeletal Function Assessment

(SMFA)[273,274], which are detailed in Section 2.5. The comprehensive methodology for this section is found in Chapter 4, Section 4.4.

Long-term outcome of non-operative management

For the long-term outcome of the non-operative management of radial head fractures, patients were identified from this prospective study of radial head fractures. All patients who sustained a radiographically confirmed isolated fracture of the radial head or neck (Mason type 1 and type 2), which was managed with primary non-operative intervention, were included. Patients were excluded if they have sustained a complex unstable fracture of the radial head or neck, a concomitant fracture around the ipsilateral elbow, a fracture dislocation of the elbow, or if there was evidence of associated elbow and/or forearm instability. Patients were also excluded if they had moved out with our catchment area and/or were not available or contactable for long-term follow-up, demented patients who were unable to complete follow-up, or if they were deceased.

The primary long-term outcome measure for this study was the patient reported Disabilities of Arm, Shoulder and Hand (DASH) questionnaire[275], which is described in Section 2.5. The comprehensive methodology for this section is found in Chapter 5, Section 5.4.

2.1.3 A retrospective analysis of radial head fractures

A retrospective search of the trauma database held at the EOTU (16 year period) was used to identify all skeletally mature patients who were managed acutely with a primary radial head replacement for an unstable complex fracture of the radial head. This allowed sufficient numbers to be identified and analysed given the relative infrequency of these injuries. Patients were excluded if there was inadequate demographic, fracture characteristic, management or follow-up data including no further record of follow-up at our institution, or if they were from outside our local catchment population.

The primary short-term outcome measure was the surgeon reported rating system of Broberg and Morrey[124,170], which is described in Section 2.5. The primary outcome measure in the long-term was the revision or removal of the radial head prosthesis for any cause. The comprehensive methodology for this section is found in Chapter 7, Section 7.4.

2.1.4 A retrospective analysis of olecranon fractures

Operative

A retrospective search of the epidemiology database described in Section 2.1.1 was used to identify all adult patients who have sustained an isolated displaced fracture of the olecranon, the Mayo type 2 fracture[49], that was managed with primary operative intervention using either TBW of plate fixation. This used a one period from July

2007 until to June 2008. This period allowed sufficient numbers to be identified and analysed, allowing post-operative radiographs to be reviewed, and providing long-term follow-up. The generally accepted criterion of >2mm of displacement of the articular surface on standard radiographs was used as the definition for displacement throughout this thesis[9,226], which is the criterion used within the EOTU to manage patients operatively. Patients were excluded if they have sustained an undisplaced fracture, an open fracture, a concomitant fracture around the ipsilateral elbow, a fracture dislocation of the elbow, or had undergone primary non-operative intervention.

The primary outcome measure in the short-term was the surgeon reported rating system of Broberg and Morrey[124,170]. The primary long-term outcome was the patient reported Disabilities of Arm, Shoulder and Hand (DASH) questionnaire[275]. The comprehensive methodology for this section is found in Chapter 8, Section 8.4.

Non-operative

A retrospective search of the trauma database held at the EOTU was used to identify all adult patients who had sustained an isolated displaced fracture of the olecranon, the Mayo type 2 fracture, which was managed with primary non-operative intervention[49]. A larger search period was used to allow sufficient numbers to be identified and analysed given the relative infrequency of this management technique for these injuries. This limited the ability to review original radiographs. Again, the criteria of >2mm of displacement of the articular surface on standard radiographs was used as the definition of displacement[9,226]. Patients who refused primary surgical intervention, either due to personal preference or due to a late presentation, were also included. Patients were excluded if they had sustained an undisplaced fracture, an open fracture, a concomitant fracture around the ipsilateral elbow or a fracture dislocation of the elbow.

The primary outcome measure in the short-term was the surgeon reported rating system of Broberg and Morrey[124,170]. The primary long-term outcome was the patient reported Disabilities of Arm, Shoulder and Hand (DASH) questionnaire[275]. The comprehensive methodology for this section is found in Chapter 10, Section 10.4.

2.1.5 Prospective randomized controlled trials

TBW vs plate fixation (<75yrs of age)

The study was a registered prospective randomized, single blind, single centre trial in adult patients with a stable displaced fracture of the olecranon. The inclusion criteria were patients less than 75 years of age who had sustained an isolated displaced fracture of the olecranon with no significant comminution of the articular surface (the Mayo type 2A fracture)[49]. Again, the criteria of >2mm of displacement of the articular surface on a standard lateral radiograph of the elbow was used as the definition of displacement[9,226]. Patients were excluded if they have sustained an undisplaced fracture, an open fracture, a concomitant fracture around the ipsilateral elbow or a fracture dislocation of the elbow, pregnant patients with pre-determined treatment, and patients who were demented and/or who were unable to comply with follow-up.

The primary outcome was the patient reported Disabilities of Arm, Shoulder and Hand (DASH) questionnaire at one year[275]. Secondary outcome measures were surgeon reported outcome scores, pain, time to return to work and sports, complications, radiographic assessment and cost of treatment. The two surgeon reported outcome measures were the Mayo Elbow Score (MES)[272] and the Broberg and Morrey Score[124,170]. The comprehensive methodology for this section is found in Chapter 9, Section 9.4.

Non-operative vs operative (≥75yrs of age)

This study was a registered two centre prospective, randomized controlled trial of elderly patients with an isolated displaced fracture of the olecranon. The inclusion criteria were patients greater than or equal to 75 years of age who had sustained an isolated displaced fracture of the olecranon, the Mayo type 2 fracture[49]. The age of 75 years was chosen based on preliminary epidemiological and retrospective data that is subsequently presented in Chapters 3 and 10. Patients were excluded if they had sustained an undisplaced fracture, an open fracture, a concomitant fracture around the ipsilateral elbow or a fracture dislocation of the elbow, if they were demented and/or if they were unable to comply with follow-up.

The primary outcome was the patient reported Disabilities of Arm, Shoulder and Hand (DASH) questionnaire at one year[275]. Secondary outcome measures were as for the younger trial. The comprehensive methodology for this section is found in Chapter 11, Section 11.4.

Power analysis

An initial power analysis was performed to determine the number of patients required for each trial[a]. The DASH score is a continuous variable that follows a normal (Gaussian-shaped) distribution. The figures used are based upon previous studies determining the minimally clinical important difference (MCID) of the DASH for conditions around the elbow and wrist, as well as normative data from the developers of the DASH[276-280]. This study is designed to determine a clinically relevant mean difference of 10 points between the two cohorts at one year after enrolment. A power analysis indicated that a total sample size of 50 (25 in each group) subjects will provide 80% statistical power to detect significant differences (0.05) in DASH scores, assuming an effect size of 0.8 (mean difference of 10 points, standard deviation of 12 points) using an unpaired *t*-test. To account for a possible loss to follow-up of up to 25%, the anticipation was to enrol 35 subjects in each cohort for a total sample size of 70 subjects. Intention to treat analyses were to be performed.

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[a]Thank you to Rob Elton for his assistance with the power calculation.

2.2 Socioeconomic deprivation

The Scottish Index of Multiple Deprivation (SIMD 2009) was used to assess socioeconomic deprivation throughout this body of work[281]. This methodology assesses deprivation using employment, income, crime, housing, health, education, and access to local services as the key factors in calculating socioeconomic status. Areas are divided into data zones that reflect households of similar income using this information[282]. The data zones are ranked in order of decreasing deprivation and each data zone is allocated to 1 of 5 quintiles based on this rank. The first quintile includes the most deprived and the fifth quintile comprises the least deprived on a national level. Each patient is allocated a data zone based on their postal code and thus allocated a deprivation quintile[282]. The population of the catchment area by deprivation quintile (Figure 2.1) was derived from Special Area Population Estimates from the General Records Office[271].

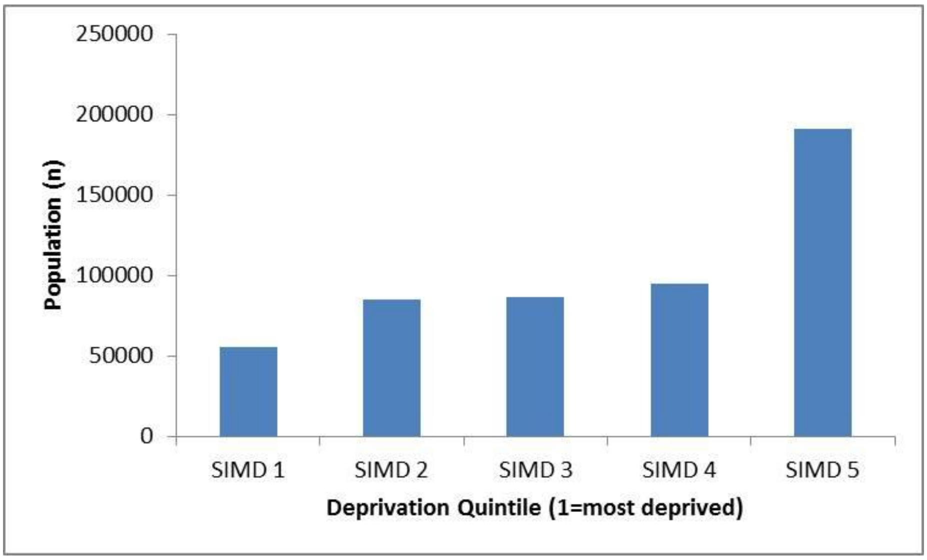


Figure 2.1: Population of hospital catchment area by deprivation quintile.

2.3 Fracture Distribution Curves

Fracture distribution curves were originally set out by Court-Brown and Caesar (Figure 2.2)[91]. They determined that there were eight fracture distribution curves that accounted for the female and male incidence of all fractures, and their use is now recognized within fracture epidemiology[92]. The curves are a measure of the changing incidence (y-axis) with age (x-axis). All curves are associated with peaks in incidence, e.g. unimodal or bimodal.

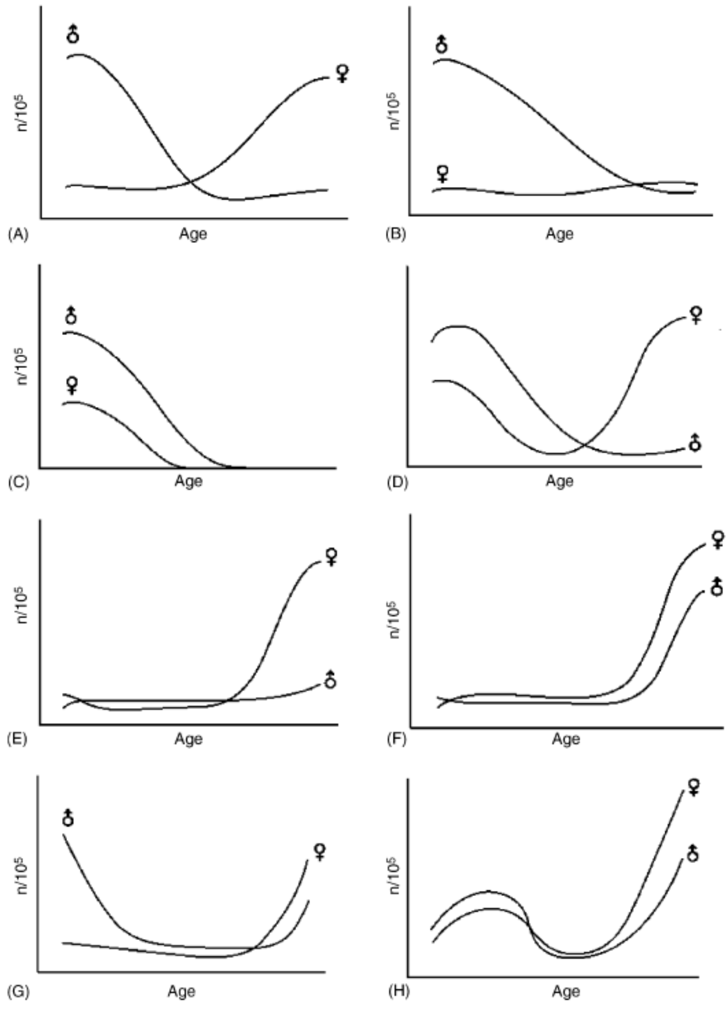


Figure 2.2: Population of hospital catchment area by deprivation quintile. (From Court-Brown C.M., Caesar B. Injury 2006; 37(8):691-7)

2.4 Radiographic Classification

For all the proposed studies, initial injury radiographs were reviewed when available to confirm the fracture classification and the presence of an associated fracture and/or subluxation/dislocation of the elbow. Further imaging was only performed at the discretion of the treating surgeon. Associated injuries were defined as those found on radiographic imaging, or at the time of surgery. This included both osseous and/or ligamentous injuries affecting the ipsilateral elbow, fractures to the ipsilateral upper limb, and/or fractures to the skeleton.

Measurements were carried out in a standardised fashion using calibrated radiographs. This was done using either hard copy radiographs or using the digital PACS radiology system. All classification and measurements were carried out by myself, potentially in conjunction with another registrar level orthopaedic trainee that was acknowledged. All fractures were assessed and classified, with any disagreements resolved by discussion with two experienced orthopaedic trauma surgeons (thesis supervisors MMQ and CCB). Both intra- and inter-observer error is associated with the interpretation of elbow radiographs with regards to classification and measurement (Table 1.1)[126]. This is discussed further within specific chapters.

2.4.1 Radial head fractures

Standard anteroposterior (AP) and lateral radiographs of the elbow from the time of injury were used to classify all fractures of the radial head and neck using both the

AO-OTA fracture classification system (Figure 1.10)[134,135] and the modified Mason (Broberg and Morrey) classification system[124] (Table 1.1, Figure 1.8). Neck fractures with an articular component were defined as head fractures. Broberg and Morrey suggested that to be considered a type 2 fracture, the fragment should be more than 30% of the articular surface and more than 2 millimetres displaced (Figure 2.3). Type 3 fractures are whole head fractures with comminution.

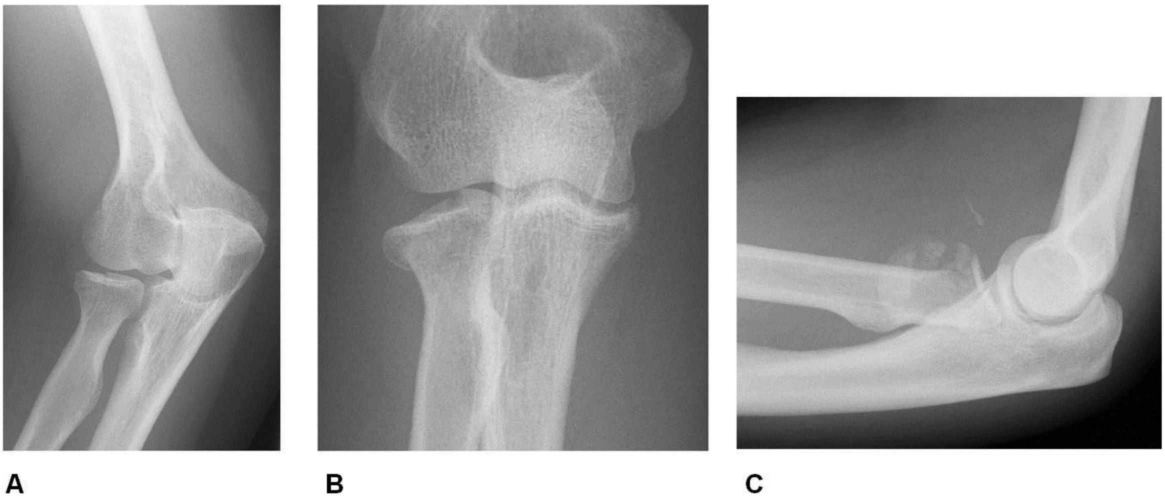
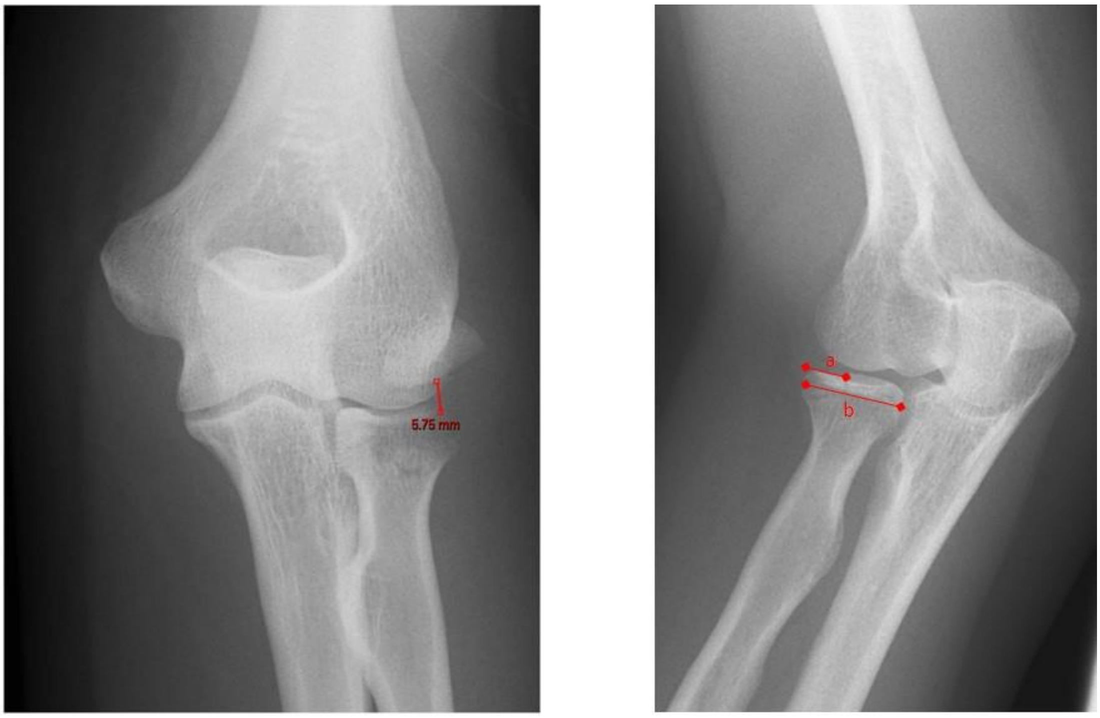


Figure 2.3: Radiographic examples of a Mason type 1 (A; AP view), type 2 (B; AP view) and type 3 (C; lateral view) fractures.

Other parameters recorded when possible were the degree of head involvement, neck angle, comminution and displacement. Degree of head involvement was recorded as a percentage of the total (Figure 2.4), the degree of neck angulation was recorded in degrees, comminution was on a categorical scale (1=mild, 2=moderate, 3=severe), and the degree of maximal displacement was in millimetres on both the AP and lateral views (Figure 2.4).



A B

Figure 2.4: Measurement of radial head fracture displacement on the AP view (A). Measurement of the degree of radial head fracture involvement on the AP view (B), with the reported percentage = (distance a / distance b)*100.

2.4.2 Olecranon fractures

Standard anteroposterior (AP) and lateral radiographs of the elbow from the time of injury were used to classify all olecranon fractures using the AO-OTA fracture classification system (Figure 1.10)[134,135], in addition to the Mayo classification for olecranon fractures[34] (Figure 1.16, Figure 2.5). Mayo type 1 fractures are undisplaced and stable with (1B) or without (1A) comminution. Mayo type 2 fractures are displaced and stable with (2B) or without (2A) comminution. Mayo type 3 fractures are displaced and unstable with (3B) or without (3A) comminution. The Regan and Morrey classification was used for coronoid fractures (Figure 2.6)[283].

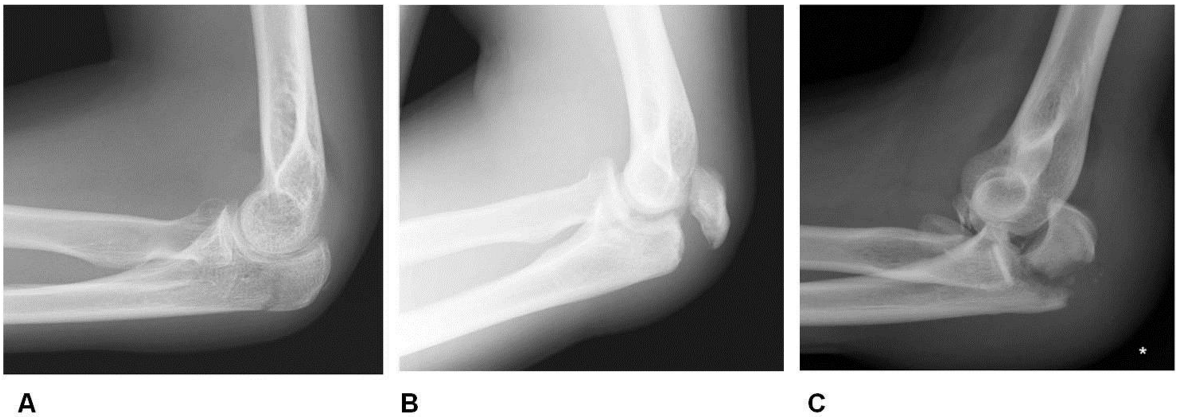


Figure 2.5: Lateral radiographic examples of Mayo type 1 (A), type 2 (B) and type 3 (C) fractures.

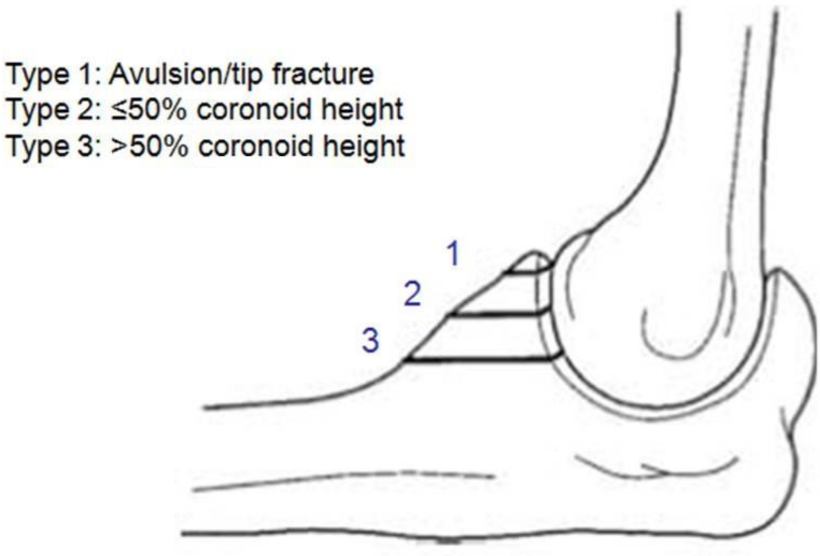


Figure 2.6: Regan and Morrey classification for coronoid fractures.

For fractures of the olecranon displacement was defined as the distance or gap between the articular surface of the fracture, using the lateral radiograph of the elbow at presentation (Figure 2.7)[20]. This view was also used to measure the posterior cortical gap and the distance of the fracture from the point of the olecranon.

A B

Figure 2.7: A: Measurement of articular displacement for fractures of the olecranon on the lateral radiograph. B: Measurement of the distance from the tip of the olecranon to the level of the fracture.

2.5 Outcome Measures

2.5.1 Functional assessment

Full clinical assessment of the affected elbow was performed for all the prospective studies. For retrospective studies, functional assessment was determined by clear documentation in the medical records. If this was not the case, the patient was either excluded from the study or the data was defined as incomplete. For all prospective studies, outcome assessment was completed when possible by a dedicated research physiotherapist not involved with the patient's management. Range of motion in the affected elbow (flexion, extension, supination, pronation; Figure 2.8) was measured often in triplicate using a standard full-circle goniometer, with the mean documented to minimise intra-observer bias.

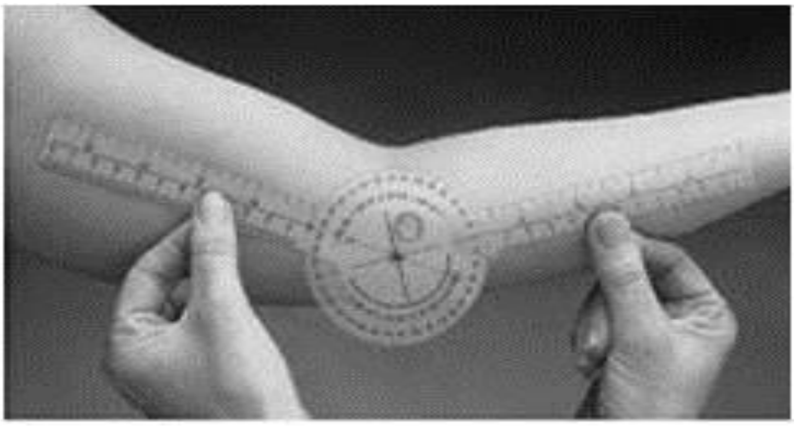


Figure 2.8: Measurement of flexion-extension of the elbow using a full-circle goniometer.

Objective muscle strength assessment (e.g. Biodex©) was not performed. This could have particularly added valuable data on extensor mechanism strength following the non-operative management of displaced olecranon fractures. However, testing is difficult to perform in elderly patients and any loss of muscle strength that affected the patient's day to day activities should be detected in the various patient and surgeon reported outcome measures detailed below.

2.5.2 Patient reported outcome measures (PROMs)

The patient reported outcome measures (PROMs) used were the Short Musculoskeletal Function Assessment (SMFA), the Disabilities of Arm, Shoulder and Hand (DASH) questionnaire and the Oxford Elbow Score (OES). All are validated PROMs that are widely used throughout the literature for the assessment of upper extremity disorders[278,284], with all scores only assessing the patient reported outcome[278,284]. Data supporting the validity, reliability, responsiveness and minimal clinically important difference for these scores are generally available[278,284].

As with all patient reported measures in this area the primary generic issue is the variability in interpreting pain and disability, which is often associated with psychosocial factors and is not routinely accounted for[278,284]. This can lead to an under-estimation of objective improvements in elbow function[285]. Secondly, whilst content validity for use in the trauma patients is assumed, there is a lack of quantitative data in this area[278,284]. Finally, despite upper limb and elbow specific scores being used, the upper limb is often considered as a single functional unit and these scores may identify disability in regions of the limb not being assessed[278,284]. The benefits and limitations of each individual measure is further discussed below

Short Musculoskeletal Function Assessment

The Short Musculoskeletal Function Assessment (SMFA)[273,274] is a validated assessment tool that includes 46 questions used to assess the patient reported outcome for a range of musculoskeletal disorders, including upper limb trauma (Appendix 1). Although the SMFA is a used in the assessment of a wide range of musculoskeletal disorders, over two-thirds of the questions (n=31) are associated with use of the upper limb[278,284]. Questions are categorised as dysfunction (34 items) or bother (12 items), with each question rated by the patient on a scale of one (good function/not bothered) to five (poor function/extremely bothered). The overall score is converted to a final score on a scale of 0-100, with a higher score indicating a poorer outcome.

Disabilities of Arm, Shoulder and Hand

The Disabilities of Arm, Shoulder and Hand (DASH) questionnaire is an upper limb specific validated patient reported outcome measure (Appendix 2)[275]. The DASH is a 30 question upper limb specific validated measure of disability with the outcome score ranging from 0 (no disability) to 100 (maximum disability). Patients answer questions based on their condition in the preceding week. Each question is rated by the patient on a scale of one (no difficulty/no limitation) to five (unable/extreme difficulty or limitation). There are 21 questions related to activities of daily living, five questions related to general symptoms, one question each relating to social activities, work, sleep and confidence.

The DASH was the primary PROM used throughout the thesis as it is the most validated upper limb outcome measure, all 30 questions are related to the upper limb, it can detect subtle and large changes in disability over time, it is relatively simple to use, and it correlates well with joint-specific and general health outcome measures[278,284-287].

There is evidence to support the verbal use of the QuickDASH, with verbal scores correlating well with written scores[288], which gives evidence to support administration through a telephone review. Furthermore, given the normative data from the developers of the DASH and the literature available on the minimally clinical important difference (MCID) for conditions around the elbow, it was the best choice for powering the randomised controlled trials[276-280].

Unique to the DASH is that the patient is instructed to complete the score irrespective of which arm(s) is required to carry out the activity resulting in a composite score for both upper limbs, which could be seen as a potential disadvantage[278,284]. Other limitations of the DASH include the large number of questions, the lack of clear validity in the trauma setting, that use may be limited to those 18-65 years of age, and the strong influence of pain and psychosocial factors on the score[278,284,285,289-291].

Oxford Elbow Score

The Oxford Elbow Score (OES) is a 12 question elbow specific validated outcome (Appendix 3)[292]. The final score ranges from 0 (poor outcome) to 48 (excellent outcome). The three domains of the score include elbow function, pain and social-psychological. Patients answer questions based on their condition in the preceding month. Each question is rated by the patient on a scale of one (no difficulty/no limitation/no pain) to five (impossible to do/all the time/unbearable). There are four questions related to activities of daily living, four questions related to sleep and general well-being, two related to pain and one question each relating to leisure and work. The OES is a validated and responsive elbow specific PROM that is short and easy to use, and has been found to correlate well with both upper limb specific and general health outcome measures[293].

2.5.3 Surgeon reported outcome measures

The surgeon reported outcome measures used were the Mayo Elbow Score (MES) and the Broberg and Morrey score. Both are validated outcome measures that are widely used throughout the literature for the assessment of elbow disorders[278]. Both of these scores combine patient and physician-based rating scores. Along with the issues of patient bias noted above, observer bias on the part of the surgeon is now possible[278,294]. Furthermore, the patient rated aspects do not account for the psychosocial factors of assessing function and there is a lack of quantitative data regarding the content validity of these scores for use in the trauma setting[278]. Both scores have been shown to correlate better with other elbow outcome measures if presented as the raw score rather than the categorical rating[278,289]. As with the DASH score, pain predominates and has been found to have the strongest influence on score variability[278,289].

Mayo Elbow Score (Figure 2.9)

The surgeon reported Mayo Elbow Score (MES) is a validated hundred-point system based upon pain (forty five points), range of motion (twenty points), stability (ten points) and daily function (twenty five points)[272]. The physician rates pain as follows: none (45 points), mild (30 points), moderate (15 points) and severe (0 points). Motion is rated according to flexion arc, with >100 degrees (20 points), 50-100 degrees (15 points), and <50 degrees (5 points). Stability score is determined according to varus-valgus laxity, with no laxity (10 points), <10 degrees of varus-valgus laxity (5 points), and >10 degrees of varus-valgus laxity (0 points). The patient scores for activities of daily living based upon self-feeding, combing hair, hygiene and being able put on a shirt and a pair of shoes. Categorical ratings are assigned as follows: ninety to one hundred points is rated excellent; seventy-five to eighty-nine, good; sixty to seventy-four, fair; and less than sixty points, poor.

Parameter	Finding	Points
Pain	None	45
	Mild	30
	Moderate	15
	Severe	0
Motion	arc>=100º	20
	arc 50-99º	15
	arc<50º	5
Stability	stable (no clinically apparent varus-valgus laxity)	10
	moderate instability (<10º of varus-valgus laxity)	5
	gross instability (>=10º of varus-valgus laxity)	0

Daily Function	Finding	Points
combing hair	able	5
	unable	0
feeding oneself	able	5
	unable	0
hygiene	able	5
	unable	0
putting on shirt	able	5
	unable	0
putting on shoes	able	5
	unable	0

Total =	Min = 0 Max = 100
Index	
>=90	excellent
75-89	good
60-74	fair
< 60	poor

Figure 2.9: The Mayo Elbow Score.

Broberg and Morrey Score (Figure 2.10)

The rating system of Broberg and Morrey[124,170] is a hundred-point system based upon motion (forty points), strength (twenty points), stability (five points) and pain (thirty five points). The surgeon rates pain as none (35 points), mild with activity but requiring no medication (28 points), moderate with or after activity (15 points), or disabling pain that is severe at rest and requires constant medication (0 points). Categorical ratings are assigned according to the score achieved: ninety-five to one hundred points is rated excellent; eighty to ninety-four, good; sixty to seventy-nine, fair; and less than sixty points, poor.

Parameter	Finding	Points
Pain	None	35
	Mild (with activity, no medication)	28
	Moderate (with or after activity)	15
	Severe (at rest, constant medication, disabling)	0
Motion	Flexion (0.2 x arc)	27
	Pronation (0.1 x arc)	6
	Supination (0.1 x arc)	7
Stability	Normal	5
	Mild loss (perceived by patient, no limitation)	4
	Moderate loss (limits some activity)	2
	Severe loss (limits everyday tasks)	0
Strength	Normal	20
	Mild loss (appreciable but not limiting; strength 80% that of contralateral side)	13
	Moderate loss (limits some activity; strength 50% that of contralateral side)	5
	Severe loss (limits everyday tasks, disabling)	0

Total =	Min = 0 Max = 100
Index	
≥ 95	excellent
80-94	good
60-79	fair
< 60	poor

Figure 2.10: The Brobery and Morrey Score.

2.5.4 Subjective outcome measures

Throughout the thesis, subjective measures were used, including pain, stiffness, instability and satisfaction. Stiffness and instability were recorded as dichotomous variables (yes or no). Pain was assessed as both none, mild, moderate or severe, and on a scale of 0-10 (10 being worse). Satisfaction was graded as both yes or no, and on a scale of 0-10 (10 being completely satisfied). Patients were also asked at what stage following injury they returned to work and sports.

2.5.5 Cost analysis

A cost analysis was performed to determine the healthcare costs for each of the planned randomized controlled trials detailed in Section 2.1.5. A cost-benefit analysis was performed, which is a form of economic assessment that compares the estimated monetary costs associated with the interventions under investigation[295]. This includes the costs of any intervention, as well as any associated complications and/or further procedures.

A cost-benefit analysis was performed to compare the cost-benefit of 1) plate fixation with the current standard of TBW fixation in patients >75yrs of age with a displaced olecranon fracture, and 2) current standard surgical treatment (plate or TBW fixation) with non-operative management in patients ≥75yrs of age with a displaced olecranon fracture. The primary outcome for each trial was the estimated difference in cost (pounds) to the health service between the two interventions.

Standardized costings were used taking into account the total number of days in hospital, the cost of the treatment method used, clinical review appointments attended, and the cost of any complications including the cost of subsequent surgeries and antibiotics for infection. Social and productivity costs were not assessed. Figures were taken from standard costings within the National Health Service Lothian. A surgical out-patient consultation was £86, an inpatient stay was £675/day, and a trip to the operating theatre is £1824. Metalwork costs are determined as £12.24 for a standard tension band wire construct, with a plate £505.60 and £5.36 per screw used. The cost of a collar and cuff was determined to be £3 and for an above elbow cast £20. Antibiotic costs were calculated from the current edition of the British National Formulary[296].

3 THE EPIDEMIOLOGY OF PROXIMAL FOREARM FRACTURES

3.1 Hypothesis and Aims

The aims for this chapter were to define the collective and distinctive epidemiological characteristics of proximal forearm fractures, as well as determining if any relationship exists between proximal forearm fracture epidemiology and socioeconomic deprivation.

The hypothesis for this chapter was that proximal forearm fractures have distinct epidemiological characteristics and that an association with socioeconomic deprivation exists.

3.2 Chapter Summary

All patients who sustained either a fracture of the radial head or neck or a proximal ulna fracture over a one year period were identified. Age, gender, socioeconomic deprivation, mechanism of injury, fracture classification, and associated injuries were recorded and analysed.

There were 350 proximal forearm fractures over the one-year period from 2007-2008, accounting for 5% of all fractures. The overall incidence of proximal forearm fractures was 68.0 per 100,000 population, with a type D distribution curve. There were 186 (53%) female patients and the mean age was 46 years (range 13-97, SD 20.3). There were 272 (77.7%) proximal radial fractures, 65 (18.5%) proximal ulna fractures and 13 (3.8%) combined proximal radius and ulna fractures.

No difference in gender incidence was seen for any fracture type. The mean age of males was younger when compared to females for all fracture sub-types ($p<0.05$ for all). Radial head fractures most closely fit a type D distribution curve, with radial neck a type A. Proximal ulna and olecranon fractures were both a type F distribution. Radial head fractures were associated more commonly with complex injuries according to the Mason classification, while associated injuries were related to age, the mechanism of injury, and increasing fracture complexity. There was an unequal distribution of proximal radial fractures according to deprivation and age also varied significantly between the deprivation categories, with the least deprived sustaining their fracture at an older age ($p=0.007$). No association between proximal ulna fractures and socioeconomic deprivation was found.

The epidemiology of proximal forearm fractures are distinct and a variety of characteristics highlight the importance of considering the role of non-operative management for these injuries, with consideration for osteoporosis in a subset of patients potentially necessary. Over 90% of proximal radial fractures are non-complex stable fractures that can potentially be managed non-operatively, although the short-term and long-term patient reported outcome are yet to be defined. Given the association with socioeconomic deprivation, further work is required to determine if deprivation affects both the short and long-term outcome of these injuries. Fractures of the proximal ulna are fragility fractures that occur frequently in elderly patients. Given the number of elderly patients sustaining these injuries, research is needed to determine the role of non-operative treatment for these fractures, particularly in patients with multiple co-morbidities and low functional demands.

3.3 Chapter Introduction

Seventy-five percent of all proximal forearm fractures involve the radial head or neck and frequently follow a fall onto an outstretched hand[1,6]. Previous studies have documented the incidence and associated injuries for radial head fractures, with more recent studies examining the relationship between age, sex, and incidence[8,91,93,94]. However, only limited data specifically defines and contrasts the epidemiology of radial head and neck fractures. There is increasing awareness regarding the relationship of fracture epidemiology and socioeconomic deprivation and its influence on the incidence and severity of upper limb fractures[297-299].

Proximal ulna fractures include fractures of the olecranon, olecranon fracture-dislocations and fractures of the coronoid process. Injury commonly occurs from direct or indirect trauma to the elbow following a fall from standing height[13,92,226]. These fractures can be associated with other injuries around the elbow, including soft tissue trauma secondary to an elbow dislocation and or a fracture of the proximal radius. Fractures of the olecranon account for approximately 20% of all proximal forearm fractures[92] and are predominantly managed using either tension band wiring (TBW) or plate fixation if there is comminution, obliquity or a distal fracture pattern. The coronoid has a major role in elbow stability, with fractures of the coronoid and radial head resulting in an unstable elbow following dislocation[34]. The Regan and Morrey classification is commonly used for coronoid fractures[283]. Despite numerous reports on the management of these injuries, no single study has clearly documented the epidemiology of proximal ulna fractures.

3.4 Patient and Methods

A prospective database of all inpatient and outpatient fractures presenting over a one-year period was used (Section 2.1.1)[b]. A database search identified a subgroup of patients who had sustained a fracture of the proximal forearm. This included all patients who sustained a radial head or neck fracture, and all patients who had suffered a fracture of the proximal ulna. Patients were excluded if they presented and were treated at our centre but resided out with the defined catchment area. Patients under the age of 13 years were also excluded as they are treated at the regional children's hospital.

A database was constructed through collection of demographic data for each patient including age, gender, economic quintile, mechanism of injury, fracture classification, and associated injuries. Associated injuries were defined as a fracture or significant soft tissue injury affecting the ipsilateral limb. Open fractures were noted and classified using the classification of Gustilo and Anderson[300]. The Index of Multiple Deprivation (IMD 2009) was used to assess socioeconomic deprivation[281] (Section 2.2). Fracture distribution curves were generated for all proximal forearm fractures, radial head and neck fractures, and for fractures of the olecranon (Section 2.3).

[b] Thank you to Stuart Aitken and Nick Clement for their work on developing the 2007-2008 trauma database.

3.4.1 Radiographic classification

Standard anteroposterior (AP) and lateral radiographs of the elbow from the time of injury were used to classify all fractures using the AO-OTA fracture classification system[134], in addition to the Mayo classification for olecranon fractures[34] and the Regan and Morrey classification for coronoid fractures[283]. The modified Mason (Broberg and Morrey) classification system was used to classify all proximal radial fractures[124,134]. For neck fractures a type 1 fracture is non-displaced, a type 2 fracture is ≥2mm displaced, a type 3 fracture is a comminuted neck fracture and a type 4 neck fracture is associated with a dislocation of the elbow (Figure 1.8). Please see section 2.4 for details.

3.4.2 Statistical analysis

The fracture distribution curves reflect the incidence of fractures in males and females separately, and do not reflect the actual number of fractures seen in each group. Age was not normally distributed for proximal radial fractures. The Mann-Whitney U test was used to compare non-parametric continuous data between a dichotomous variable (age versus gender and fracture stability), and the Kruskal Wallis test was used to compare non-parametric data where a variable had more than 2 categories (age versus mechanism of injury, IMD and associated injuries). For proximal ulna fractures, age was found to have a non-skewed distribution so the Student t-test was used to compare parametric continuous data and the analysis of variance (ANOVA) test was used to compare parametric data for more than two categorical variables. Chi squared tests were used to compare categorical data. Where the number of cases in a cell was less than 5, the Fisher exact test was used. The Spearman correlation was used to determine the relationship between incidence and deprivation quintile. Two tailed P values were reported throughout and significance was taken to be $P<0.05$.

The "observed proportion" of fractures in each deprivation quintile was calculated by dividing the number of fractures in that quintile by the total number of fractures[c]. The proportion of the population in that quintile was similarly derived. This served as the "expected proportion" in that the null hypothesis was that there was no difference in the proportion of fractures in each quintile. The observed proportion was therefore subtracted from the expected proportion to determine the absolute difference in proportion. This is a basic description of the associated chi-squared statistic.

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[c] Thank you to Paul Jenkins for his assistance with this part of the analysis.

3.5 Results

3.5.1 Proximal forearm fractures

There were 350 proximal forearm fractures over the one-year period from 2007-2008, accounting for 5.1% of all fractures. The overall incidence of proximal forearm fractures was 68.0 per 100,000 population, with a type D distribution curve (Figure 3.1). There is a unimodal young male and bimodal female distribution with an overall peak incidence between 50-59 years. The peak incidence in women is in the eighth decade and the peak incidence in men is the second decade. There were 186 (53%) female patients and the mean age was 46 years (range 13-97, SD 20.3). There were 272 (77.7%) proximal radial fractures, 65 (18.5%) proximal ulna fractures and 13 (3.8%) combined proximal radius and ulna fractures.

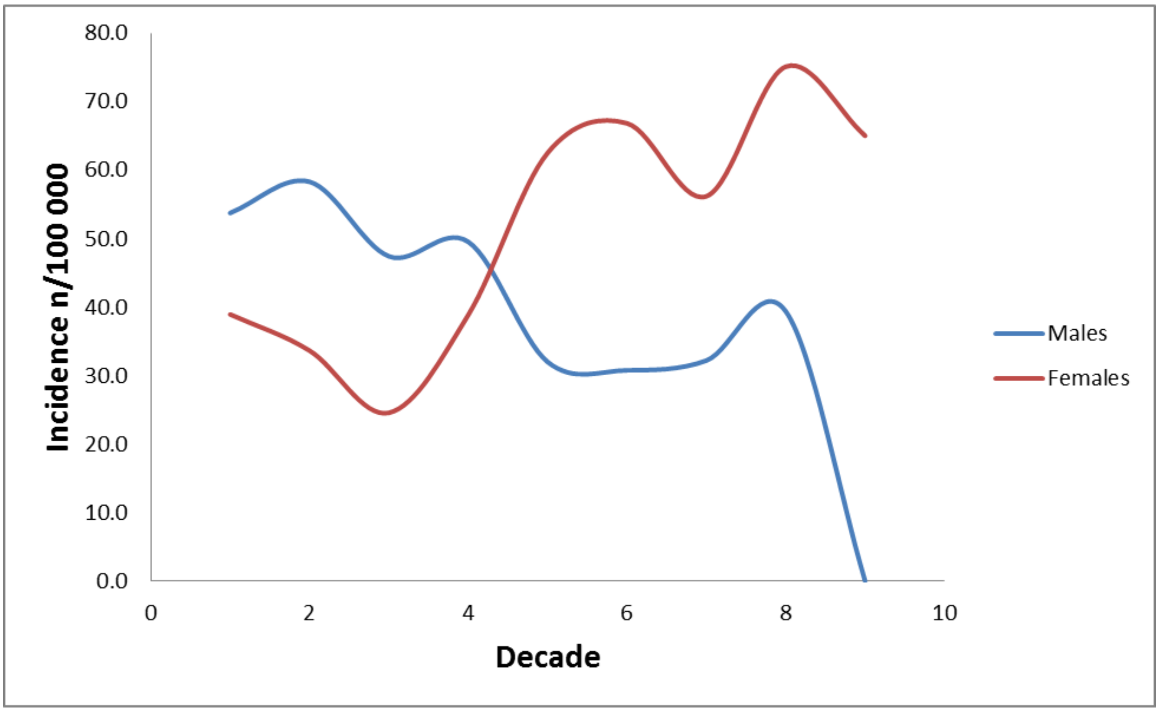

Figure 3.1: The incidence of proximal forearm fractures, categorised by age and gender.

3.5.2 Proximal radial fractures

There were 285 radial head (n=199) or neck fractures (n=86) with a mean age of 44 years (range 13-94, SD 18.9). The overall incidence of radial head and neck fractures was 55.4 per 100,000 population. This was a type D curve with an overall peak incidence between 50-59 years and a unimodal young male and bimodal female distribution (Figure 3.2). The peak incidence in women was in the sixth decade and the peak incidence in men was the fourth decade. There were 151 females (53%), with no gender difference in incidence seen (Table 3.1). The age of injury in males was significantly younger than females (Table 3.1).

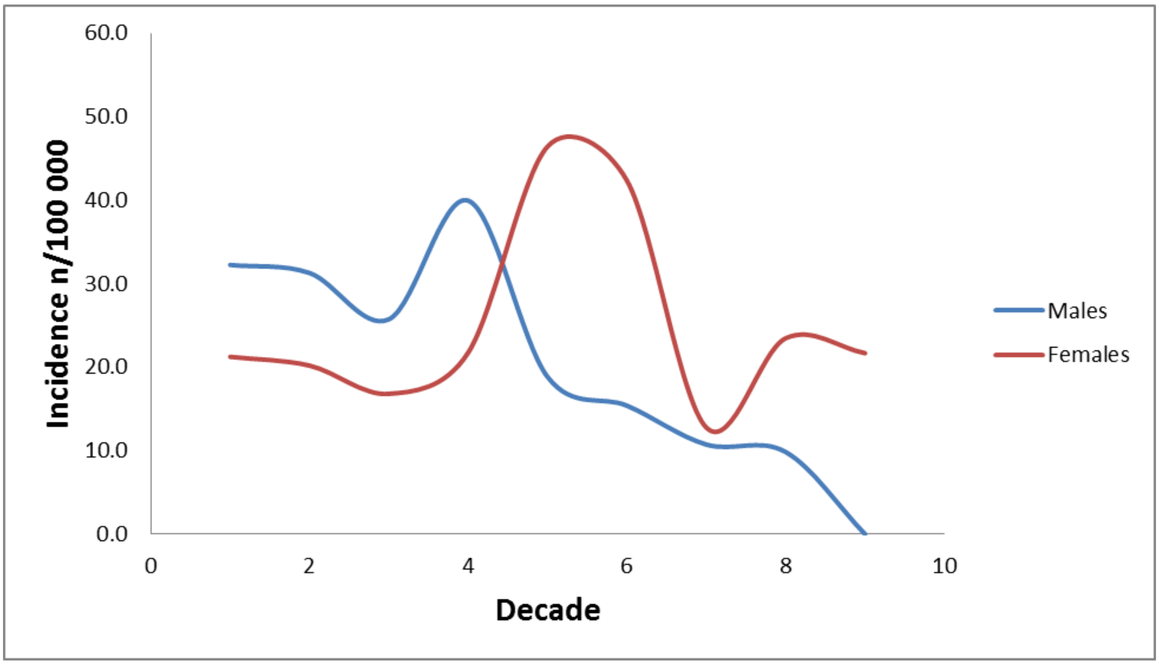

Figure 3.2: The incidence of proximal radial fractures, categorised by age and gender.

Females frequently sustained their fracture following a low energy fall, whereas high energy injuries such as sports and a fall from height were more common in males (Table 3.1, p<0.001). Two open fractures were seen. One was a Gustilo II associated with a Mason type 3 radial head fracture, and the other was a Gustilo I associated with a type 4 radial neck fracture.

	Male (n=134)	**Female (n=151)**	**Total**	**P value**
Incidence (n/100,000/year, 95% CI)	55 (46 to 64)	56 (48 to 65)	55 (49 to 62)	0.885
Mean age (years, range)	38 (15-85)	50 (13-94)	44 (13-94)	**<0.001^{b}**
Age Group (n, % gender)				**<0.001***
<20	14 (10%)	8 (5%)	22 (7.7%)	
20-29	32 (24%)	23 (15%)	55 (19.3%)	
30-39	31 (23%)	16 (11%)	47 (16.5%)	
40-49	29 (22%)	22 (15%)	51 (17.9%)	
50-59	15 (11%)	31 (21%)	46 (16.2%)	
60-69	7 (5%)	29 (19%)	36 (12.6%)	
70-79	3 (2%)	11 (7%)	14 (4.9%)	
80+	3 (2%)	11 (7%)	14 (4.9%)	
MOI				**<0.001***
Simple fall	53 (40%)	110 (73%)	163 (57%)	
Fall from height	20 (15%)	9 (6%)	29 (10%)	
Direct blow	4 (3%)	1 (1%)	5 (2%)	
Sport	33 (25%)	21 (13%)	54 (19%)	
MVC	23 (17%)	11 (7%)	34 (12%)	

Table 3.1: The incidence, distribution, age, sex and mode of injury variations of 285 proximal radial fractures. (MVC = motor vehicle collision. ^{b}Mann-Whitney U, *Chi-squared)

Overall, the most common fracture type was a Mason type 1 (Table 3.2). There was no difference in the distribution of fracture type according to sex or age. The injury severity was influenced by the mechanism of injury (p=0.007). Direct blows (n=7) all resulted in Mason type 1 injuries, whereas falls from height led to 15 (52%) type 1 injuries, 6 (21%) type 2 injuries, and 8 (28%) type 3 injuries. Five (71%) of the type 4 injuries occurred after a simple fall, with 2 occurring (29%) during sport.

	Mason I	**Mason II**	**Mason III**	**Mason IV**	**P value**
Total (n, %)	212 (74)	45 (16)	21 (7)	7 (3)	-
Gender (n, %)					
Males (n=134)	100 (49)	22 (38)	10 (48)	2 (29)	0.795*
Females (n=151)	112 (51)	23 (62)	11 (52)	5 (71)	
Mean age yrs (range)	43 (13-87)	47 (15-86)	52 (20-94)	51 (23-85)	0.123^{Ω}
Associated injuries (n/%)	8 (4)	4 (9)	5 (24)	4 (57)	**<0.001***
Management (n, %)					
Non-operative	212 (100)	42 (93.3)	7 (33.3)	2 (28.6)	
Acute excision	0 (0)	0 (0)	1 (4.8)	0 (0)	**<0.001***
ORIF	0 (0)	0 (0)	1 (4.8)	0 (0)	
Replacement	0 (0)	3 (6.7%)	12 (57.1)	5 (71.4)	

Table 3.2: Distribution, age, sex, associated injuries and management according to the modified Mason classification of the 285 proximal radius fractures. ($^{\Omega}$Kruskal-Wallis test, *Chi-squared)

There were 21 (7%) associated ipsilateral upper limb injuries, with 16 occurring with a radial head fracture and 5 occurring with a radial neck fracture (Table 3.3). An ipsilateral proximal ulna fracture was the most common associated upper limb injury. Of the associated coronoid fractures (n=4), 2 were Regan-Morrey type 1 and 2 were a type 2. Fifteen females sustained associated injuries, with no gender predominance ($p=0.078$). Increasing age ($p=0.011$), high energy mechanism ($p<0.001$), and increasing fracture complexity ($p<0.001$) were risk factors for sustaining an associated injury. Mason type 3 and type 4 fractures were significantly more likely to undergo surgery (Table 3.2). All Mason type 1 fractures and 93.3% of Mason type 2 fractures were managed non-operatively. Only one fracture underwent ORIF (Mason type 3).

Radial head versus neck fractures

Radial head fractures were seen more frequently than radial neck fractures (Table 3.3). Radial head fractures most closely fit a type D distribution curve (unimodal young male, bimodal female), whereas radial neck fractures most closely fit a type A distribution (unimodal young male, unimodal older female), with a peak incidence at ≥80 years but with a peak incidence in women at ≥80yrs and a peak incidence in men <20 years.

No difference in sex incidence was seen for either fracture (Table 3.3). There was no significant difference in the median age of head and neck fractures, but the median age of injury in males was significantly younger when compared to females for both fracture types (both $p<0.001$). A simple fall from standing height was the most common mechanism of injury for both fractures. Radial head fractures were more commonly associated with more complex injuries according to the Mason classification (p<0.001). Associated injuries were seen with both radial head and neck fractures (p=0.509).

	Radial Head	Radial Neck	P value
Total (n, %)	199 (70)	86 (30)	-
Incidence (n/100,000 per year)	38.8 (34-44)	16.7 (13-21)	-
Males/Females (%)	95/104 (48/52)	39/47 (45/55)	0.711*
Mean age years (range)	44 (13-94)	45 (13-87)	0.797^{b}
Males	39 (16-81)	36 (15-85)	0.240^{b}
Female	49 (13-94)	52 (13-87)	0.273^{b}
Mode of injury			
Simple fall	119	44	
Fall from height	23	6	
Direct blow	4	1	0.187*
Sports	33	21	
MVC	20	14	
Mason Classification (n, %)			
Mason I	129 (65)	83 (97)	
Mason II	43 (21)	2 (2)	**<0.001***
Mason III	21 (11)	0 (0)	
Mason IV	6 (3)	1 (1)	
Associated injuries (n=21)	16	5	
Distal radius fracture	1	2	
Proximal ulna fracture	7	2	
Elbow soft tissue (MCL/LCL)	2	0	0.509*
Scaphoid fracture	1	1	
Coronoid fracture	4	0	
Capitellum fracture	1	0	

Table 3.3: A comparison of radial head and neck fractures. Incidences are expressed with 95% confidence intervals. (MVC = motor vehicle collision, IQR = interquartile range, ^{b}Mann-Whitney U-test, *Chi-squared)

3.5.3 Proximal ulna fractures

There were 78 patients who presented with a fracture of the proximal ulna over the one year period, of which 43 (55%) were female and the mean age was 57 years (range 15-97, SD 23.3). The overall prevalence of proximal ulna fractures was 1.1% and accounted for 21% of all proximal forearm fractures. The incidence of proximal ulna fractures was 15 per 100,000 population.

The mean age of fracture in males was 51 years (range 16-90), significantly younger when compared with 62 years (range 15-97) in females (p=0.04). No gender predominance was seen (p=0.37). The incidence in both male and female patients increased in the seventh decade and peaked in the ninth decade, demonstrating a curve that most closely fit a type-F distribution[91] with a unimodal older male and a unimodal older female (Figure 3.3).

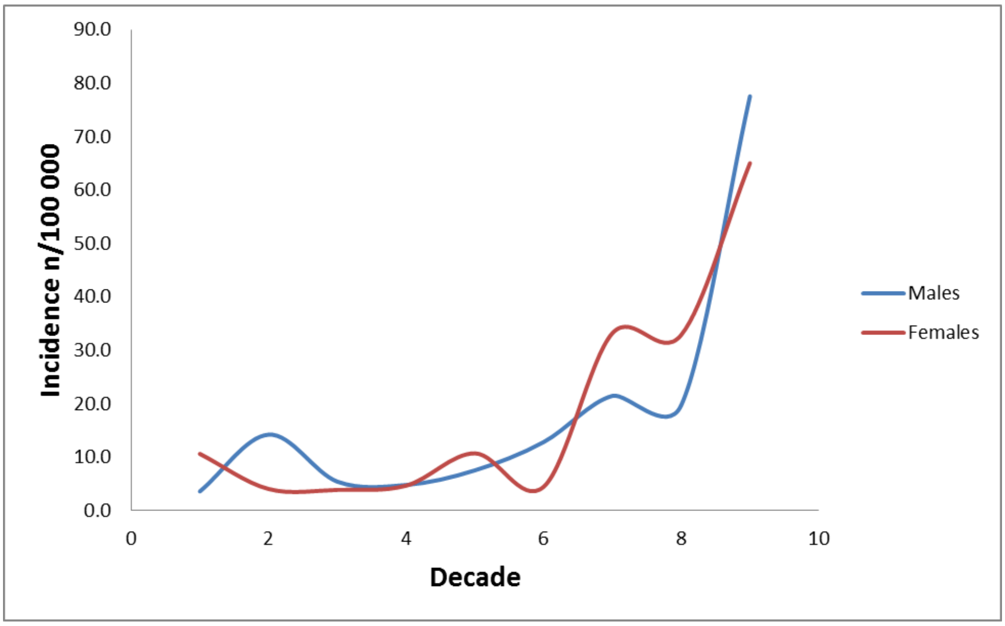

Figure 3.3: The incidence of proximal ulna fractures, categorised by age and gender.

A fall from a standing height or less accounted for the largest number of fractures (n=52, 67%), with a fall from height comprising the next most common cause (n=11, 14%). High energy injuries including motor vehicle collision (MVC), sports and a fall from height, accounted for 27% (n=21) of all fractures. Patients who sustained their injury during sports or a MVC were significantly younger than those patients who sustained their fracture following a low energy fall ($p<0.001$).

According to the AO-OTA classification, B type fractures were most frequently seen (n=67, 85.9%), followed by C type (n=7, 9.0%) and A type injuries (n=4, 5.1%). There were 17 (22%) patients who sustained an associated ipsilateral upper limb injury. There were thirteen patients with an associated fracture of the radial head or neck, four of which were associated with an elbow dislocation and one that was associated with a fracture of the distal humerus. According to the modified Mason classification there were two type 1, three type 2, four type 3 and four type 4 fractures. Two patients had an associated distal radius fractures, one a proximal humerus fracture and one an isolated elbow dislocation. There was no difference in the mean age between those with or without an associated injury ($p=0.662$). There was also no association with gender ($p=0.449$) or mechanism of injury ($p=0.213$). Five (6.4%) patients had an open fracture, two had a Gustilo grade I and three had a Gustilo grade II.

Olecranon fractures

Sixty-four (82%) patients presented with a fracture of the olecranon, of which 35 (55%) were female and the mean age was 57 years (range 15-97, SD 23.5).

Olecranon fractures accounted for 18% of all proximal forearm fractures and the overall incidence was 12 per 100,000 population. The mean age of fracture in males (50yrs) was significantly younger when compared to females (63yrs; p=0.03). No gender predominance was seen (p=0.45) and the fracture distribution was again a type-F curve (Figure 3.4). A fall from standing height or less accounted for the largest proportion of injuries (n=45, 70%), with a fall from height the next most frequent mode (n=7, 11%). As with proximal ulna fractures, high energy injuries such as sports or a MVC occurred in significantly younger patients than those who sustained their fracture following a low energy fall (p<0.001).

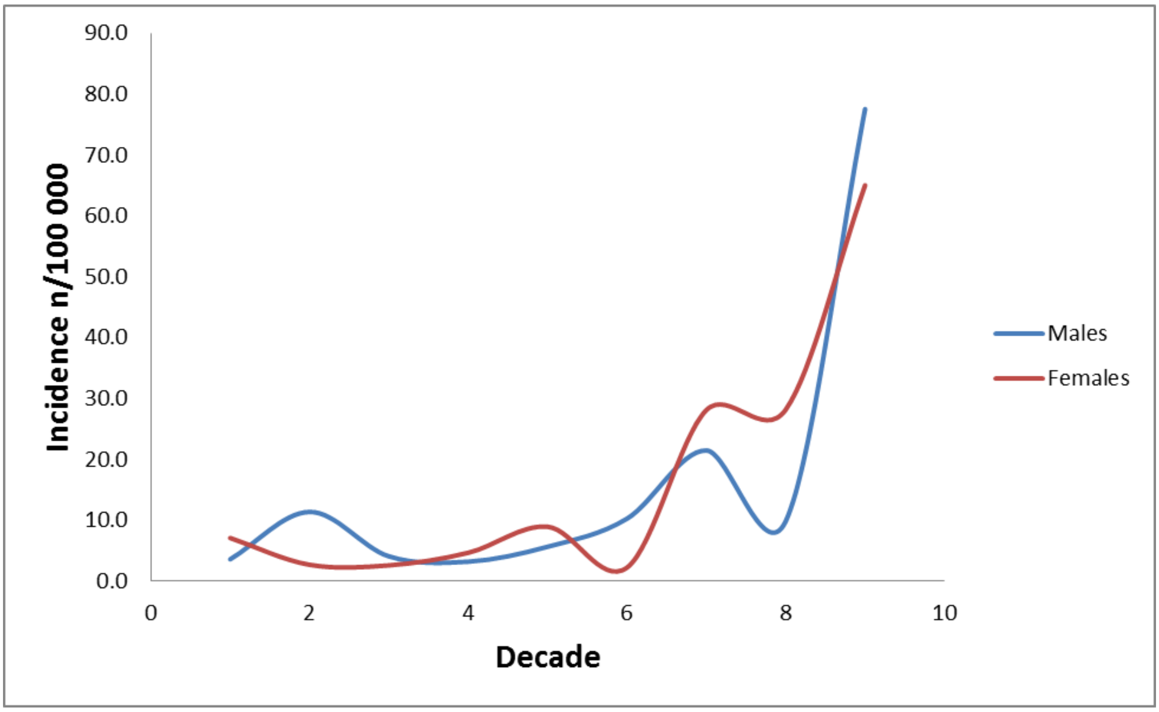

Figure 3.4: The incidence of olecranon fractures, categorised by age and gender.

The most frequent injury according to the AO-OTA fracture classification was the 21-B1.1 type (n=57), with a simple isolated displaced olecranon fracture (type 2A) most common according to the Mayo classification (Table 3.4). TBW was the most commonly used management technique (n=42, 66%) and was employed predominantly for the Mayo type 2A fracture. Conservative management was used in 14 fractures, with plate fixation used in the eight patients (Table 3.4). The mean age of those treated conservatively for a Mayo type 2 fracture was 71 years (range, 47-90).

	Conservative	Plate Fixation	TBW	Total (%)
Mayo				
1A	8	0	0	8 (12.5)
2A	5	1	41	47 (73.5)
2B	1	3	1	5 (7.8)
3A	0	2	0	2 (3.1)
3B	0	2	0	2 (3.1)

Table 3.4: The classification and management of 64 fractures of the olecranon

Coronoid fractures

Eleven (14%) patient sustained a fracture of the coronoid with three (27%) isolated fractures (all type 1). Two fractures were associated with a fracture of the olecranon, one which was also associated with a fracture of the ipsilateral distal radius. Three fractures were associated with a dislocation of the elbow, with two of these fractures associated with a fracture of the proximal radius, a ‘terrible triad’ injury pattern. The remaining three fractures were associated with a fracture of the proximal radius alone. Overall, the mean age was 47 years (range, 18-78) and seven were male. Six were a Regan and Morrey type 1, with four fractures being a type 2 and one a type 3.

3.5.4 Socioeconomic deprivation

There was an unequal distribution of proximal radial fractures according to deprivation (Table 3.5, Figure 3.5) with a statistical trend towards a declining incidence with decreasing deprivation (p=0.1, Spearman correlation coefficient -0.8). In the most deprived category the difference between observed and expected proportions was 1% (95% CI 0.7 to 1.3) more than expected, and in the least deprived group it was 1.2% (95% CI 0.9 to 1.5) less than expected.

Age varied significantly between the deprivation categories with the least deprived sustaining their fracture at an older age (Kruskal Wallis p=0.021, Spearman p=0.007). There was no association between IMD and gender (p=0.994), mechanism of injury (p=0.440), head or neck fracture type (p=0.844), the Mason classification (p=0.478), or associated injuries (p=0.687). No associations were found between the epidemiological characteristics of proximal ulna fractures and socioeconomic deprivation (all $p \geq 0.05$; Table 3.5).

Deprivation Quintile	Total n (%)	Incidence (n/100,000 per year)	*P value*
Proximal radial fractures			
1	33 (12)	59	
2	55 (19)	64	
3	50 (18)	57	0.10*
4	46 (16)	48	
5	101 (35)	53	
Proximal ulna fractures			
1	15 (19)	27	
2	14 (18)	16	
3	11 (14)	13	0.20
4	10 (12)	10	
5	29 (37)	15	

Table 3.5: The association between proximal forearm fracture incidence and deprivation quintile. (*Spearman correlation coefficient -0.8)

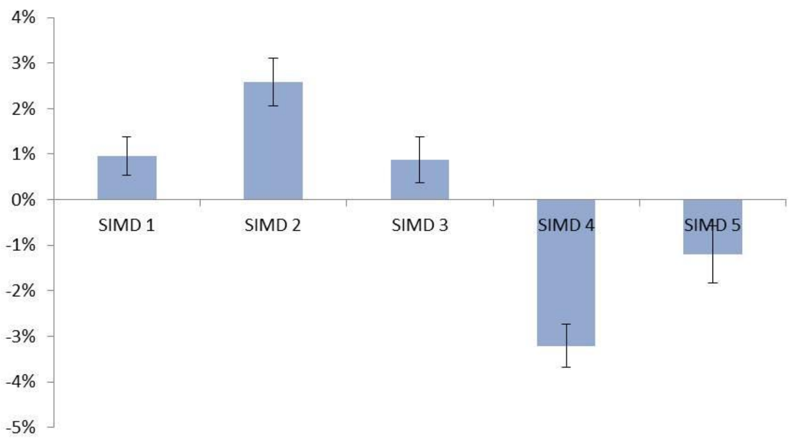

Figure 3.5: The percentage difference (+/- standard error of mean) between observed and expected proportion of fractures by deprivation quintile (1=most deprived).

3.6 Chapter Discussion

This chapter has documented the distinct epidemiological characteristics of proximal forearm fractures. There are several findings from this chapter that highlight the importance of investigating the role of non-operative management for defined fractures of the proximal forearm.

Proximal ulna fractures appear to be predominantly fragility fractures as they follow low energy falls, and demonstrate a type F fracture distribution curve with an increase in incidence after the seventh decade for both males and females[91,92]. Olecranon fractures were found to be the most common injury of the proximal ulna and frequently occur following a fall from standing height[13,92,226]. Early studies examining the treatment of these fractures documented an average age of approximately 45 years[7,17,28], with the only randomised control trial comparing TBW with plate fixation quoting a mean age of 31 years. The documented mean age at the time of injury from this data is approaching 60 years, with the mean age in females significantly older than that of males[92,231]. The increase in mean age over time may be related to the changing demographics of the population, particularly given many of these original studies were performed over a decade ago.

For proximal radius fractures, these results demonstrate a significantly lower mean age of males when compared to females for both head and neck fractures but with a type D distribution for radial head fractures and a type A distribution for radial neck fractures[8,91,93,94]. Differences were also found with regards to age distribution and the Mason classification. The mean age of radial head and neck fractures ranges from 39 years to 48 years in the literature, which is comparable to these results, but with figures noted to have increased over the past five years[8,93-95]. Furthermore, 99% of radial neck fractures were Mason type 1 or type 2 injuries. These findings suggest that proximal radial fractures, particularly radial neck fractures, are frequently low energy fragility fractures associated with osteoporosis[91,94].

Given these potential links with osteoporosis, potential further work would be to determine if consideration for investigating bone quality is appropriate and whether it would be beneficial to routinely investigate (e.g. with DEXA scanning) for osteoporosis in post-menopausal women who sustain a fracture of the proximal forearm, particularly given the significantly higher age at which they sustain their injury. A case-control study analysing women aged over 50 years with a fracture radial head fracture found that patients with a radial head fracture had an increased risk of osteoporosis (odds ratio 3.4) when compared to a control group[301]. As with distal radius fractures, some fractures of the proximal forearm may be a ‘primary fracture’ in signalling poor bone quality when early intervention with preventative therapy may reduce the risk of subsequent fragility fractures in the future. However, the clear limitation from this data is the uncertainty as to whether this was the first fragility fracture the patient has sustained, which would be necessary for a proximal forearm fracture to be used an indicator for bone density screening.

The reported incidence of radial head fractures ranges from 25-30 per 100,000 adults[93,94]. The higher incidence we found is likely due to the captive nature of our trauma centre and the inclusion of adolescents between 13 and 16 years of age. However, all the fractures in this study were extraphyseal adult type injuries with closed physes and as such warrant inclusion. Karlsson et al quoted an incidence of 11.5 per 100,000 person years for olecranon fractures, which is comparable to our findings[13].

This study has found an approximately equivalent gender ratio, as with other fractures of the proximal forearm[92,94], and has found open fractures of the proximal ulna to be rare. An approximately equal sex ratio for both radial head and neck fractures was found, although the literature reports a wide variation with either male or female predominance [8,91,93-96]. These findings do corroborate that fractures of the radial head and neck commonly result from a fall on the outstretched hand[1,8,99] and that open proximal radial fractures are rare. Radial head fractures were found to be almost twice as common as radial neck fractures, compatible with limited data stating radial head fractures account for 56% and radial neck fractures 20% of all proximal forearm fractures[8]. Despite the distinct characteristics of these injuries as described above, given radial neck fractures are predominantly stable fractures, analysis with head fractures is not contraindicated.

The distribution of proximal radial fractures for this patient population according to the Mason classification is similar to previous reports[8,94,174]. The association found between increasing fracture complexity according to the Mason classification and the presence of associated injuries has been noted by Kaas et al[94]. This is not surprising given the further association found between the mechanism of injury, i.e. the higher the force, and the more complex proximal radial fracture being associated with other ipsilateral upper limb injuries.

The distribution of proximal ulna fractures according to the AO-OTA, Mayo, and Regan and Morrey classifications has not previously been clearly documented in the literature. AO-OTA type B and Mayo 2A fractures account for the vast majority of proximal ulna fractures. Despite limited evidence, the perception is that fractures of the coronoid frequently occur in conjunction with other injuries around the elbow[302]. This work demonstrated that only a quarter of all coronoid fractures are isolated type 1 injuries, with 75% of coronoid fractures occurring in association with another significant fracture or soft tissue injury.

The incidence of associated ipsilateral upper limb injuries with radial head fractures is comparable to that reported, although with a higher number of associated proximal ulnar fractures[93,94]. Furthermore, almost a quarter of patients with a fracture of the proximal ulna sustained a concomitant injury to the ipsilateral limb, with a fracture of the proximal radius most commonly observed. This rate of associated injuries is notably higher than the rate quoted for fractures of the proximal radius[93-95]. Given these findings, a high index of suspicion is necessary for these injuries and a full assessment is recommended in all patients. This is particularly important when concomitant elbow or forearm instability is suspected[1,96,303].

3.6.1 Deprivation

A trend towards deprivation influencing the population incidence of radial head and neck fractures was observed, with no association found for proximal ulna fractures. It is possible the relationship with proximal radial fractures would be significant with larger study numbers. This finding is in keeping with previous papers looking at the effect of social deprivation upon the incidence, severity, and management of other fractures[297-299,304]. Patients from the most deprived category were younger than those in the least deprived category. One explanation for this variant is behavioural differences, with the younger socially-deprived patients sustaining their fractures during sporting activities and assaults, which has been demonstrated for other fractures[298,304]. Those in the least-deprived category incur their fracture at an older age and thus again may be defined as having a fragility fracture, which has been suggested by Court-Brown and Caeser[91]. A further explanation for this finding is that the least deprived patients have a better bone quality at a comparable age, thus resulting in fewer fragility fractures at a younger age. Factors associated with socioeconomic status that may influence fracture incidence are physical inactivity, nutrition, alcohol, smoking, and education[305,306]. It is possible that these correlations with deprivation could influence the outcome of these fractures, and further work in this area is needed. Advancing age predicts a poorer outcome for these injuries, while deprivation and ethnicity influence the outcome after hip arthroplasty and distal radius fractures[307,308].

3.6.2 Strengths and limitations

The main strength of this chapter is that it represents prospectively collected data on a large series of patients with radiologically-confirmed proximal forearm fractures in a well-demarcated population. The EOTU is the only centre providing a musculoskeletal trauma service for the local catchment population and this allows us to define accurately the prevalence and incidence of these injuries.

An inherent weakness of the study is the intra- and inter-observer error associated with the classification and interpretation of elbow radiographs[126]. This could be of particular importance with regards to the presence of comminution on plain radiographs for olecranon fractures, which may explain the high proportion of Mayo type 2A fractures. Recent literature has reported that the intra-observer and inter-observer agreement for the Mayo olecranon fracture classification system is superior to that of the Schatzker and Colton classification systems[309].

Larger numbers may have demonstrated statistically significant correlations with deprivation, particularly those correlations that approached significance, e.g. incidence. This work used a methodology of categorizing deprivation that has been employed in many orthopaedic and trauma studies from multiple countries[297,306,310,311]. Yet it may be difficult to generalize our results because there is no collectively-agreed standard for measuring socioeconomic status. However, the IMD is a universally applicable tool given that the factors used to determine deprivation are attributable to any developed population.

4 A PROSPECTIVE ANALYSIS OF RADIAL HEAD FRACTURES: SHORT-TERM OUTCOME

4.1 Hypothesis and Aims

The aims for this chapter were to describe the natural history of radial head and neck fractures, and determine the short-term functional results and outcome predictors for these injuries. In particular, the aim was to determine the short-term patient and surgeon reported outcomes following primary non-operative management of these injuries. The relationship between socioeconomic deprivation and short-tern outcome will be analysed given the findings of Chapter 3 that found an association between deprivation and the epidemiology of these injuries.

The hypothesis for this chapter was that for defined isolated fractures of the radial head, non-operative management resulted in a satisfactory short-term patient and surgeon reported outcome.

4.2 Chapter Summary

A prospective study was carried out of consecutive patients who sustained an isolated radiographically confirmed radial head or neck fracture over an eighteen-month period. Demographic and fracture details were recorded prospectively and the Index of Multiple Deprivation (IMD) was used to quantify deprivation. Follow-up was carried out over a one-year period using clinical and radiological assessment. The primary outcome measures were the surgeon reported Mayo Elbow Score (MES) and the patient reported Short Musculoskeletal Function Assessment (SMFA).

There were 201 patients in the study cohort with a mean age of 44yrs (range, 16-83). A fall from standing height accounted for 60% of all injuries, with one or more co-morbidities in 35% of patients. There were 103 (51%) Mason type 1 fractures, 82 (41%) Mason type 2, 11 (5.5%) Mason type 3 and five (2.5%) Mason type 4. At a mean of six months post injury, 187 (93%) patients achieved an excellent or good MES. The mean MES was excellent (92; range, 45-100), with 14 patients having a fair or poor final MESs. The final median SMFA score was 0.54, with a mean score of 4.98 (range, 0-55.43). The mean flexion arc was 138 degrees (range, 0-160) and the mean forearm rotation arc was 177 degrees (range, 90-190). The mean MES for Mason type-I (n=103) and type-II (n=82) fractures was excellent, with only two patients requiring surgical intervention for a mechanical block to forearm rotation. On multivariate analysis a worse surgeon reported MES score was associated with older patients, increasing fracture classification severity and compensation (all $p<0.05$). For the SMFA, compensation and increasing deprivation were the only independent predictors of a worse SMFA score (all $p<0.05$), with fracture classification approaching significance.

The majority of isolated Mason type 1 and type 2 radial head fractures can be treated non-operatively, achieving excellent or good functional results. This work has identified key factors associated with the short-term outcome of these injuries, as well as the contrasting predictors for surgeon and patient reported outcome measures. Future work needs to determine the long-term outcome of these injuries following non-operative intervention, in particular the patient reported outcome using validated upper limb scores. Furthermore, work is required to determine if the influence of deprivation on the patient reported outcome persists in the longer-term.

4.3 Chapter Introduction

Although there are minimal data in the literature, there is a consensus that conservative treatment with early mobilisation for non-displaced radial head fractures (Mason type 1) produces good or excellent results in the vast majority of patients[4,5,147]. For minimal or moderately displaced fractures (Mason type 2) favourable results have been demonstrated for both non-operative and operative management[4,77,133,146,153,312].

Factors regularly quoted as influencing treatment choice are functional status and demand of the patient, bone quality, instability, comminution, displacement, impaction, a block to elbow motion and other associated injuries[1,3]. There is very limited data regarding predictors of outcome following a proximal radial fracture, which could potentially improve the management of these injuries.

The importance of socioeconomic status in health has been found for both chronic diseases and in trauma patients[313-316], with recent data suggesting the most deprived spend a significant amount of their lives with illness or disability[317]. There is now increasing literature examining the correlation between fractures and deprivation, with influences on incidence, severity and management already reported[297,299,304,318,319]. However, the influence of socioeconomic deprivation on fracture outcome has not been clearly documented in the literature before, with no study incorporating the influence of demographic and fracture characteristics on outcome. This is of particular interest given the relationship between proximal radial fracture epidemiology and socioeconomic deprivation detailed in Chapter 3.

4.4 Patients and Methods

4.4.1 Patients and database construction

Over an 18-month period from September 2003 to February 2005 a prospective study was performed and a database compiled of consecutive skeletally mature patients aged 15 years or older who presented to the EOTU with a fracture of the radial head[d]. Inclusion criteria included a closed radial head or neck fracture radiographically confirmed at two weeks, with no other fracture or significant soft tissue injury affecting the skeleton. Patients with an associated ipsilateral elbow dislocation alone, the Mason type 4, were included. Exclusion criteria were a concomitant fracture or significant soft tissue injury affecting the skeleton, including visceral injuries and polytrauma patients. Patients unable to comply with follow-up were also excluded. Using these criteria 237 patients were identified over an eighteen month period. There were 113 (48%) males and 124 females (52%) with a mean age of 44yrs (range, 16-91yrs; SD 17.7). This included 156 radial head fractures and 81 radial neck fractures.

Demographic data was documented at initial presentation including age, gender, co-morbidity, smoking, mechanism of injury and injury dominance. Employment was recorded and categorised (1=office work, 2=light manual, 3=heavy manual, 4=unemployed, 5=retired), as was self-employment. The Index of Multiple Deprivation (IMD 2009) was used to assess socioeconomic deprivation[281], which is described in Section 2.2.

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[d] Thank you to Phil Walmsley, Brad Petrisor and Bruce Watson for their assistance with developing this database.

4.4.2 Radiographic classification

All fractures were assessed at the time of presentation using standard anteroposterior (AP) and lateral radiographs of the injured elbow. Fractures were classified according to the modified Mason (Broberg and Morrey) and AO-OTA classification systems (Section 2.4)[124,134]. Other parameters recorded were degree of head involvement, neck angle, comminution and displacement. Degree of head involvement was recorded as a percentage of the total, the degree of neck angulation was recorded in degrees, comminution was recorded on a categorical scale (1=mild, 2=moderate, 3=severe), and displacement was defined by the degree of maximal displacement in millimetres (Section 2.4). Measurements were carried out in a standardised fashion with a calibrated radiograph. All radiographs were independently assessed and classified for each fracture, with any disagreements resolved by discussion with two experienced orthopaedic trauma surgeons (thesis supervisors MMQ and CCB).

4.4.3 Management protocol

Management, duration of treatment, the use of physiotherapy, complications and subsequent surgeries were documented. Treatment was over seen by the supervising consultant, all of whom were orthopaedic trauma surgeons. The routine protocol for non-operative management was immobilisation in a collar and cuff for a maximum of one week, with early active mobilisation and physiotherapy as indicated. Three patients managed non-operatively were placed in a cast for approximately two weeks: one for an associated elbow dislocation (Mason type 4), one for an associated small coronoid fracture (Mason type 2), and one because primary treatment was initiated in another centre (Mason type 2). The indication for physiotherapy was a persistent residual functional deficit and/or elbow stiffness. Referral would regularly take place at six weeks for strengthening and range of motion exercises, followed by functional activities.

Relative indications for operative intervention were a mechanical block to forearm rotation, severe displacement and/or comminution. Replacement was performed if the fracture was too comminuted to be reconstructed using open reduction and internal fixation (ORIF). All patients underwent their primary surgery within the first two weeks following the date of injury. Five patients were treated with ORIF; screw fixation alone was used in three cases, with plate and screw fixation employed in the remaining two. Five patients underwent radial head replacement. One patient had primary acute radial head excision. One patient underwent open reduction alone, with an above elbow cast placed for approximately two weeks.

4.4.4 Outcome assessment

Eight patients were lost to follow-up after their initial presentation. Twenty-eight patients, of which 25 sustained a Mason type 1 fracture, were lost at the two-week point. All of these patients were managed non-operatively. This left 201 (84.8%) patients that made up the study cohort for analysis, of which 107 (53%) were female and the mean age was 44 years (range, 16-83; SD, 17.3). There was no difference in age (p=0.240), gender (p=0.506), co-morbidities (p=0.619) or fracture classification (p=0.209) between the final and the lost cohort.

Patients were reviewed prospectively at two weeks, six weeks, twelve weeks, six months and one-year post injury. A full clinical assessment of the affected elbow and ipsilateral limb was performed. Patients were reviewed prospectively in clinic until they had attained a satisfactory outcome according to functional and radiographic assessment as standard. Patients who attained a good or excellent outcome prior to this point were discharged, along with any patient who refused follow-up as they were happy with their outcome. All patients managed operatively were followed-up for one year.

At each follow-up visit, clinical and radiographic follow-up was carried out by the supervising consultants (MMQ and CCB). Request for compensation related to the patient's injury was also recorded. A full outcome assessment was then completed by a dedicated research physiotherapist not involved with the patient's management[e]. Range of motion in the affected elbow (flexion, extension, supination,

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[e] Thank you to Elizabeth Will for her assessment of the patients.

pronation) was measured in triplicate using a standard full-circle goniometer, with the mean documented to minimise intra-observer bias.

The primary outcome measures were the surgeon reported Mayo Elbow Score (MES) and the patient reported Short Musculoskeletal Function Assessment (SMFA), which are detailed in Section 2.5.

4.4.5 Statistical analysis

Age was found to be normally distributed. The SMFA and the MES were found to have a skewed distribution. Variables were analysed to determine significant patient and fracture characteristics that were predictive of outcome according the MES and SMFA score. A Student's unpaired t-test was used to analyse parametric continuous data from two groups. The Mann-Whitney U-test was used to analyse non-parametric continuous data from two groups. Categorical binary data were analysed using either the chi-square test ($n>5$) or Fisher's exact test ($n\leq5$). The analysis of variance (ANOVA) test was used for parametric continuous data where a variable had more than two categories, with the Kruskal-Wallis test used for non-parametric continuous data. Spearman's correlation was used to analyse the correlation between two continuous variables. Regression analysis was to use to analyse the correlation between deprivation and outcome, with further analysis performed to determine the age and gender adjusted means[f]. Loess with Kernel (Cauchy) analysis was used for assessing the correlation between SMFA and fracture displacement. Unlike standard bivariate correlation, this methodology uses locally weighted polynomial regression that produces a trend line based on subset data points that are calculated through the weighting of local data points. Weighting is greatest for data closest to the point of estimation. Two tailed p-values were reported and statistical significance was set at $p<0.05$, with 95% confidence intervals (95% CI) presented.

Variables were examined using univariate analysis to determine predictors of outcome according to both the primary outcome measure, the surgeon orientated MES, as well as the patient orientated outcome (SMFA). Factors found to be significant or near-significant ($p<0.10$) on univariate analysis were incorporated and underwent multivariate linear regression analysis to determine independent predictors of outcome when controlled for age, gender and co-morbidities.

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[f] Thank you to Nick Clement and Rob Elton for their statistical advice.

4.5 Results

There were 201 patients in the study cohort with a mean age of 44yrs (range, 16-83; SD 17.3) and 107 (53%) were female (Table 4.1). The mean age of females was 51yrs (16-83, SD 17.4), which was significantly older (p<0.001) than the mean age of males (36yrs, 17-76, SD 13.2) at the time of injury. The dominant side was affected in 94 (47%) cases. One or more co-morbidities were documented in 35% (n=70) of patients, with the distribution by deprivation quintile found in Table 4.1.

The most frequent mechanism of injury (Figure 4.1) was a fall from standing height (n=120, 60%), followed by sports (n=43, 21%), fall down stairs (n=13, 6.5%), fall from height (n=13, 6.5%) direct blow (n=5, 2.5%) and a motor vehicle collision (n=2, 2%). Females most commonly sustained their fractures following a fall from standing height, whilst males sustained sports injuries as commonly (Table 4.1, p<0.001).

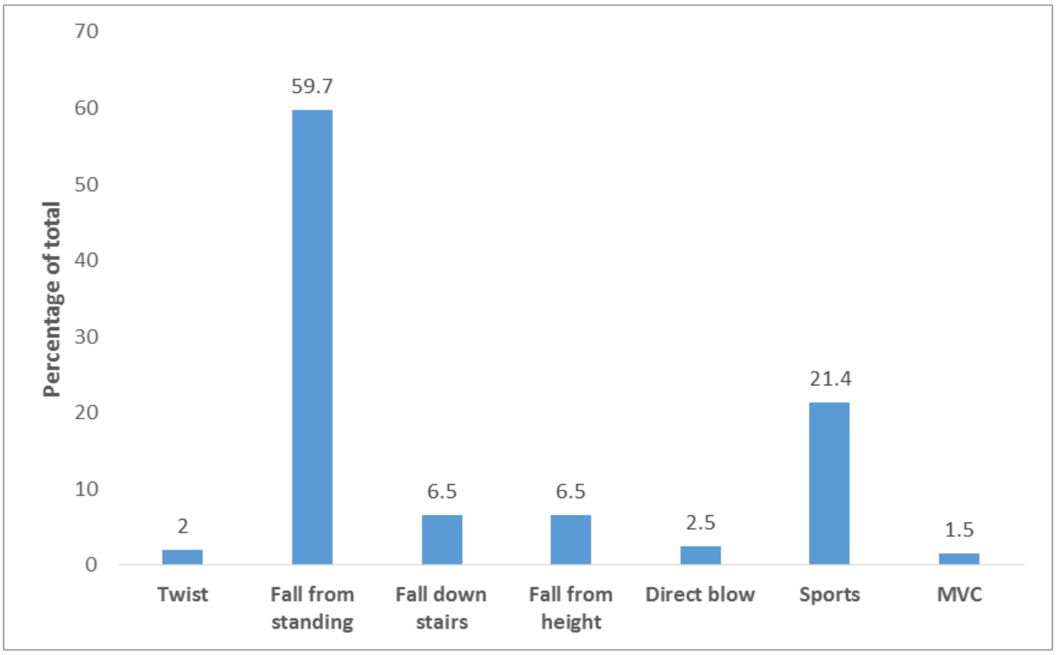

Figure 4.1: The mechanism of injury for 201 radial head and neck fractures.

		Male n (%)	Female n (%)	p value
Total		94 (47)	107 (53)	NA
Mean age (range, SD, 95% CI)		36 (17-76, 13.2, 34-39)	51 (16-83, 17.4, 48-55)	**<0.001[a]**
Mechanism of injury				
	Fall from standing height	36 (38.3)	84 (78.5)	
	Sports	37 (39.4)	6 (5.6)	
	Fall down stairs	6 (6.4)	7 (6.5)	**<0.001***
	Fall from height	10 (10.6)	3 (2.8)	
	MVC	1 (1.1)	2 (1.9)	
	Direct blow	1 (1.1)	4 (3.7)	
	Twist	3 (3.2)	1 (0.9)	
Occupation Code	Office Work	52 (55.3)	36 (33.6)	
	Light manual	27 (28.7)	35 (32.7)	
	Heavy manual	4 (4.3)	0 (0)	
	Unemployed	6 (6.4)	4 (3.7)	**<0.001***
	Retired	5 (5.3)	32 (29.9)	
Compensation proceedings		3 (3.2)	6 (5.6)	0.506¶
Index of Multiple Deprivation				
	1 (n=19)	8 (8.5)	11 (10.3)	
	2 (n=33)	18 (19.1)	15 (14.0)	
	3 (n=42)	19 (20.2)	23 (21.5)	0.902*
	4 (n=37)	17 (18.1)	20 (18.7)	
	5 (n=70)	32 (34.0)	38 (35.5)	
Mason classification	Type 1 (n=103)	45 (47.9)	58 (54.2)	
	Type 2 (n=82)	43 (45.7)	39 (36.4)	0.323*
	Type 3 (n=11)	3 (3.2)	8 (7.5)	
	Type 4 (n=5)	3 (3.2)	2 (1.9)	
AO-OTA	A2.1 (n=1)	0 (0)	1 (0.9)	
	A2.2 (n=67)	28 (29.8)	39 (36.4)	
	B2.1 (n=107)	55 (58.5)	52 (48.6)	0.667*
	B2.2 (n=12)	6 (6.4)	6 (5.6)	
	B2.3 (n=11)	4 (4.3)	7 (6.5)	
	C2.3 (n=3)	1 (1.1)	2 (1.9)	
Radial head (n=133)		66 (70.2)	67 (62.6)	
Radial neck (n=68)		28 (29.8)	40 (37.4)	0.256*

Table 4.1: Patient demographics and fracture characteristics. ([a] Student's t-test, * Chi-squared, ¶ Fisher's exact test)

There were 133 (66%) radial head fractures and 68 (34%) radial neck fractures. The median fracture displacement was 1.5mm (range, 0-10mm) and the median percentage head involvement was 20% (range, 0-100%). There were 103 (51%) patients classified as a Mason type 1 fracture (radial head n=39, radial neck n=64), 82 (41%) a Mason type 2 (radial head n=78, radial neck n=4), 11 (5.5%) a Mason type 3 and 5 (2.5%) a Mason type 4. There were no radial neck fractures seen in the Mason type 3 or type 4 categories. Of the five Mason type 4 fractures, three were associated minor coronoid flake avulsion injuries (Regan and Morrey type 1), one was associated with a Mason type 2 fracture and two with a Mason type 3. The distribution of fractures according to the AO-OTA classification is found in Table 4.1. The median fracture displacement categorised by fracture classification is found in Table 4.2.

All Mason type 1 and type 2 fractures were managed with primary non-operative intervention as described above. Two patients with a Mason type 2 fracture underwent ORIF within the first two weeks following injury for a persistent confirmed mechanical block to forearm rotation. Of the remaining 10 patients that underwent operative intervention, two were for a confirmed mechanical block to forearm rotation (one Mason type 3, one Mason type 4) and the remainder were due to a significant degree of radiographic comminution and/or displacement (n=8; seven Mason type 3, one Mason type 4). The remaining Mason type 3 and 4 fractures underwent non-operative intervention.

Classification	Median fracture displacement mm (range)
Mason	
Type 1 (n=103)	0 (0-2)
Type 2 (n=82)	2 (2-5)
Type 3 (n=11)	7 (3-10)
Type 4 (n=5)	4 (0.5-7.0)

Table 4.2: Fracture displacement categorised by fracture Mason classification.

No significant association was found between age (p=0.525), gender (p=0.902) or mechanism of injury (0.684) and the deprivation quintiles. Patients in the most deprived quintiles were more likely to have associated medical co-morbidities than those in the least deprived (p=0.001). No association was found between deprivation quintile and occupation (p=0.124) or compensation proceedings (p=0.600). A difference was seen with the classification of fractures according to the Mason classification and the deprivation quintile (p=0.034), although there was no difference in the distribution of fractures according to head or neck location (p=0.143) or the AO-OTA classification (p=0.238). The distribution of operative and non-operative treatment was not different across the quintiles (p=0.805).

4.5.1 Short-term outcome

At a mean of six months (range, 1.5-12) post injury, the mean MES was excellent at 92 (range, 45-100; SD 10.1), with 14 patients having a fair or poor final MESs. The median SMFA score was 0.54, with a mean score of 4.98 (range, 0-55.43; SD 9.5)

(Table 4.3). There were 187 (93%) patients who achieved an excellent or good result on the MES, with 155 (77%) achieving this by six weeks. The mean flexion arc was 138 degrees (range, 0-160; SD, 17.6) and the mean forearm rotation arc was 177 degrees (range, 90-190; SD, 11.4).

Classification	**Mean Flexion Arc (range, SD, 95% CI)**	**Mean Rotation Arc (range, SD, 95% CI)**	**Mean MES (range, SD, 95% CI)**	**Mean SMFA (range, SD, 95% CI)**
Mason				
1 (n=103)	141 (88-160, 12, 88-157)	179 (120-190, 6.5, 178-180)	93 (70-100, 8.8, 91-94)	4.0 (0-44.6, 7.8, 2.5-5.6)
Head (n=39)	138 (88-160, 15, 133-143)	180 (175-180, 1.1, 179-180)	90 (75-100, 7.9, 88-93)	4.6 (0-44.6, 9.1, 1.6-7.6)
Neck (n=64)	142 (112-160, 10, 140-145)	179 (120-190, 8.2, 176-181)	94 (70-100, 9.1, 92-96)	3.7 (0-34.2, 6.9, 1.-5.4)
2 (n=82)	139 (88-157, 12, 137-142)	179 (155-180, 3.8, 178-180)	94 (70-100, 8.6, 92-95)	4.6 (0-55.4, 10, 2.4-6.8)
Head (n=78)	139 (88-157, 12, 136-141)	179 (155-180, 3.9, 178-180)	93 (70-100, 8.7, 91-95)	4.8 (0-55.4, 10.2, 2.5-7.1)
Neck (n=4)	149 (145-155, 4.5, 142-156)	180 (all)	100 (all)	0 (all)
3 (n=11)	103 (0-145, 40, 76-130)	156 (90-180, 34, 127-185)	77 (45-100, 17.1, 65-88)	18 (0-37.5, 12.8, 9-27)
4 (n=5)	121 (73-140, 28, 86-156)	161 (90-180, 40, 111-210)	91 (70-100, 13.4, 74-108)	2.4 (0-10.9, 4.8, -3.5-8.3)

Table 4.3: The outcome scores of all radial head and neck fractures, categorized according to the modified Mason classification. All Mason type 3 and type 4 fractures were radial head fractures.

There was one (0.5%) non-union and one loss of fracture position. Seven patients undertook compensation proceedings within the first six weeks post injury, one within three months and one within six months. No complications were associated with non-operative treatment. Post-operative complications in the Mason type 3 and type 4 fractures included dislocation of the radial head prosthesis (with subsequent exchange replacement required), radial head subluxation post ORIF and one episode of recurrent post-operative wound infection requiring repeated courses of antibiotics to treat.

Mason type 1 and type 2 fractures

Primary non-operative intervention was used for all type 1 and type 2 fractures (n=185), with 96% achieving an excellent or good outcome (Table 4.3). The mean MES was excellent at 100 (range, 70-100; SD 8.7) and the median SMFA score of 0.54 (range, 0-55.43; mean 4.3). Two patients required operative intervention due to a mechanical block to forearm rotation, achieving good and excellent outcome scores respectively.

Five patients attained fair scores, all radial neck fractures. One patient had a final flexion arc of 140 degrees with a rotational arc of 180 degrees but still had elbow pain. One patient developed post-traumatic ipsilateral DeQuervain's tenosynovitis. Two patients had minor discomfort at their distal radio-ulnar joint but with no frank evidence of an Essex-Lopresti lesion. One of these patients developed a post-traumatic ipsilateral shoulder capsulitis and the other developed some mild elbow stiffness.

Three patients with a Mason type 2 radial head fractures had a poor outcome, all treated non-operatively. Head involvement was 50%, 95% and 95% respectively, although displacement was only 2mm in all cases. At one year follow-up the patient with 50% involvement had a good functional result (flexion arc 120 degrees, forearm rotation arc 180 degrees) but with elbow pain. One patient with 95% head involvement was complaining of elbow locking at one year post injury, with symptoms progressing. The final patient had a good functional result with a flexion arc of 143 degrees and a forearm rotation arc of 180 degrees but had persistent elbow pain.

Mason type 3 and 4 fractures

Overall, the Mason type 3 fractures achieved the lowest mean MES (77; Table 4.3), with five of eleven patients graded as fair or poor. Two patients with fair or poor score were treated non-operatively. One elderly patient with 100% head involvement was the only fracture that lost position after initial presentation. This patient was offered surgery at six weeks but declined due to the ill health of a relative. Three patients, with a fair or poor score, were managed operatively with a radial head replacement. All three had poor flexion and rotation arcs at one year, with two patients planned for prosthesis removal (one with arthrolysis).

The Mason type 4 fractures achieved a mean excellent outcome score (91; Table 4.3), with three of the five patients managed non-operatively. One patient in this group had a fair final MES who underwent ORIF and was awaiting radial head excision. The flexion arc, MES and SMFA for the patients managed non-operatively for Mason type 3 and type 4 injuries were not significantly different (all $p \geq 0.05$) to those patients who were managed operatively (Table 4.4).

Mason type 3 and type 4	**Non-operative (n=6)** (range, SD, 95% CI)	**Operative (n=10)** (range, SD, 95% CI)	**p value***
Mean Flexion Arc	128 (105-145, 15, 112-143)	98 (0-140, 42, 67-128)	0.128
Mean Rotation Arc	177 (170-180, 5.2, 171-182)	142 (90-178, 42, 103-181)	**0.041**
Mean MES	85 (55-100, 19, 55-105)	79 (45-100, 16, 67-91)	0.511
Mean SMFA	11.3 (0-37.5, 16, -5.4-28)	14.2 (0-37.5, 12, 5.7-23)	0.434

Table 4.4: The outcome scores of all Mason type 3 (n=11) and type 4 fractures (n=5), categorized according to treatment modality. (*Mann-Whitney U test)

4.5.2 Predictors of short-term outcome

Surgeon reported outcome measure (MES)

Age (p=0.011), the Mason (p=0.002) and AO-OTA (p=0.001) classifications, head or neck location (p=0.017) and percentage head involvement (p=0.002) were the only predictors of the short-term MES. Compensation proceedings were approaching significance (p=0.061). A lower (worse) MES score was found in older patients, Mason type 3, AO-OTA type B2.3 fractures, those patients who sustained a radial head fracture and increasing percentage head involvement.

Gender (p=0.282), co-morbidities (p=0.563), deprivation quintile (p=0.155), mechanism of injury (p=0.140), hand injury dominance (p=0.635), smoking (p=0.748), self-employment (p=0.588), employment code (p=0.422) and degree of fracture displacement (p=0.113) were not associated with the short-term MES.

Regarding fracture classification, Table 4.3 demonstrates the lower MES associated with Mason type 3 fractures. With regards to the AO-OTA classification, it was the B2.3 fractures that were associated with a poorer MES (Table 4.5). The outcome for the AO-OTA A2.2, B2.1 and B2.2 fracture sub-types (n=186) was excellent, with the B2.3 fractures achieving the lowest mean MES (76, good).

Classification	**Mean Flexion Arc (range, SD, 95% CI)**	**Mean Rotation Arc (range, SD, 95% CI)**	**Mean MES (range, SD, 95% CI)**	**Mean SMFA (range, SD, 95% CI)**
A2.1 (n=1)	143 (N/A)	180 (N/A)	85 (N/A)	2.17 (NA)
A2.2 (n=67)	143 (112-160, 10.0, 140-145)	179 (120-190, 8.1, 177-181)	94 (70-100, 9.0, 92-97)	3.5 (0-34.2, 6.8, 1.8-5.1)
B2.1 (n=107)	139 (88-160, 12.0, 137-141)	179 (165-180, 2.2, 179-180)	93 (70-100, 8.0, 91-94)	4.2 (0-55.4, 8.9, 2.5-5.9)
B2.2 (n=12)	136 (110-155, 13.6, 128-145)	179 (170-180, 2.9, 177-181)	91 (70-100, 11.9, 84-99)	8.8 (0-43.5, 15.3, -0.9-19)
B2.3 (n=11)	99 (0-156, 42.3, 70-127)	148 (90-180, 39, 118-177)	76 (45-100, 16.9, 65-88)	14.6 (0-37.5, 12.0, 6.5-23)
C2.3 (n=3)	117 (101-128, 14.4, 82-153)	173 (170-180, 5.8, 159-188)	85 (70-100, 15.0, 48-122)	16.9 (1.6-37.5, 18.5, -29-63)

Table 4.5: The outcome scores of all radial head fractures (n=201), categorized according to the AO-OTA classification.

On further analysis of fracture location, the flexion arc, forearm rotation arc, MES and SMFA were all significantly better (all $p<0.05$) for radial neck fractures (Table 4.6).

	Radial Head (n=133)	**Radial Neck (n=68)**	**p value***
Mean Flexion Arc (range, SD, 95% CI)	135 (0-160, 20.0, 131-138)	143 (112-160, 9.9, 140-145)	**0.004**
Mean Rotation Arc (range, SD, 95% CI)	177 (90-180, 12.9, 175-179)	179 (120-190, 8.0, 177-181)	**0.049**
Mean MES (range, SD, 95% CI)	91 (45-100, 10.4, 89-93)	94 (70-100, 9.0, 92-96)	**0.017**
Mean SMFA (range, SD, 95% CI)	5.76 (0-55.4, 10.6, 3.9-7.6)	3.46 (0-34.2, 6.8, 1.8-5.1)	**0.021**

Table 4.6: The outcome of all patients (n=201), categorized according to head or neck fracture site. (*Mann-Whitney U test)

Using multivariate regression analysis controlling for age, gender and co-morbidities, independently significant predictors of a worse MES were increasing age, the AO-OTA fracture classification (fracture type B2.3) and those patients who pursued compensation in relation to their injury (Table 4.7).

Variable	**Regression Coefficient**	**95% Confidence Limits**	**p-value**
Age	-0.095	-0.190 to 0	**0.049**
Gender	-0.011	-2.940 to 2.919	0.994
Co-morbidities	-1.284	-4.368 to 1.799	0.412
AO-OTA Classification	-4.796	-7.960 to -1.632	**0.003**
Mason Classification	1.856	-0.765 to 4.478	0.164
Fracture location	3.172	-0.929 to 7.273	0.129
% Head involvement	-0.039	-0.118 to 0.040	0.330
Compensation	6.559	0.187 to 12.931	**0.044**

Table 4.7: Multivariate linear regression analysis documenting independent predictors of outcome according to the MES.

Patient reported outcome measure (SMFA)

Age (p=0.007), gender (p=0.009), co-morbidities (p=0.009), deprivation (p=0.013), Mason (p=0.001) and AO-OTA (p=0.003) classifications, head or neck location (p=0.021), degree of fracture displacement (p=0.007) and percentage head involvement (p=0.001) were the predictors of the short-term SMFA. Compensation proceedings were approaching significance (p=0.070). A higher (worse) SMFA score was found in older patients, female gender, patients with one or more co-morbidities, increasing deprivation, Mason type 3 fractures (Table 4.3), AO-OTA type B2.3 and C2.3 fractures (Table 4.5), those patients who sustained a radial head fracture (Table 4.6) and increasing fracture displacement and percentage head involvement.

Mechanism of injury (p=0.150), hand injury dominance (p=0.463), smoking (p=0.529), self-employment (p=0.572) and employment code (p=0.100) were not associated with the short-term SMFA.

The deprivation quintile significantly influenced the SMFA score (Table 4.8; R=-0.18, p=0.013,). Further analysis adjusting for age and gender, revealed patients in the most deprived quintile had a SMFA score 5.2 points (95% CI 0.6 to 9.7) higher than the least deprived, and those in the second most deprived group had an SMFA score 4.9 points (95% CI 1.1 to 8.7) higher than the least deprived (Table 4.8, Figure 4.2). Quintiles 3 and 4 did not have a significant difference in SMFA score compared with the least deprived group.

Deprivation Quintile	Median SMFA Score (Range)	Adjusted Mean SMFA (95% CI)
1 (most deprived)	3.3 (0 to 44.6)	8.3 (4.2 to 12.3)
2	2.2 (0 to 55.4)	8.0 (4.9 to 11.1)
3	0.5 (0 to 30.4)	3.4 (0.7 to 6.1)
4	0.5 (0 to 38.6)	6.0 (3.1 to 8.9)
5 (least deprived)	0 (0 to 34.8)	3.1 (1.0 to 5.2)

Table 4.8: SMFA outcome scores categorised by IMD quintiles. A mean SMFA adjusted for injury severity, age and gender is also presented.

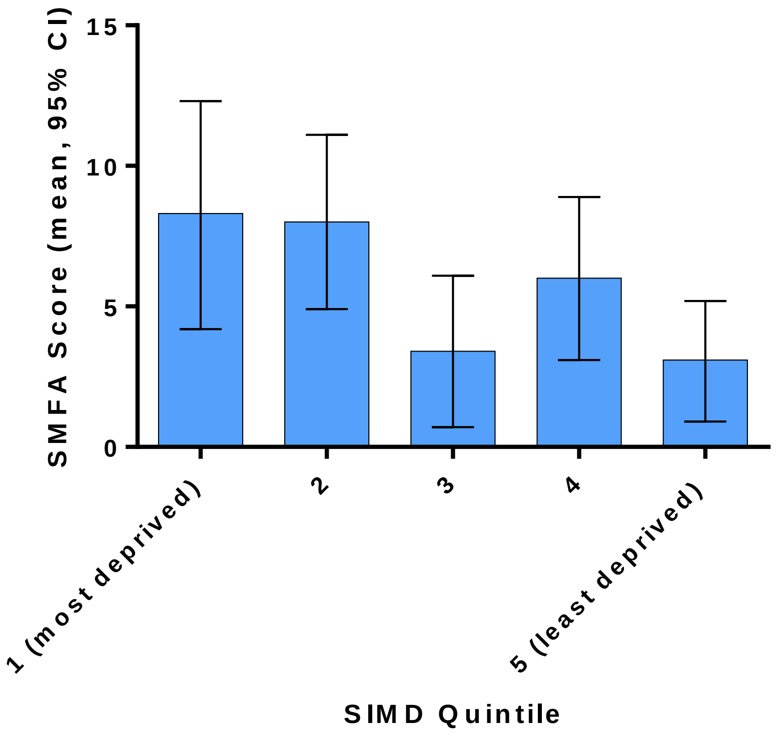

Figure 4.2: The mean adjusted SMFA score categorised by deprivation quintile.

There was a significant correlation between the degree of fracture displacement and the SMFA score (Table 4.9; R=0.19, p=0.007), with increasing displacement resulting in a greater (worse) SMFA score (Figure 4.3 and Figure 4.4). Using a Loess with Kernel (Cauchy) analysis for smoothness of fit for SMFA against displacement, an increase in the SMFA is seen at 4.5mm of displacement. On further analysis, there was a significantly worse SMFA score for fractures displaced 5mm or more (4.4 verses 13.9, p=0.001).

Displacement category (mm)	**Mean SMFA (range, SD, 95% CI)**
0-0.9 (n=84)	3.96 (0-44.6, 8.3, 2.2-5.8)
1-1.9 (n=20)	4.16 (0-14.1, 5.2, 1.7-6.6)
2.0-2.9 (n=65)	4.48 (0-55.4, 10.3, 1.9-7.0)
3.0-3.9 (n=13)	6.1 (0-30.4, 10.4,-0.2-12.4)
4.0-4.9 (n=5)	1.74 (0-4.9, 2.4, -1.3-4.7)
5.0-5.9 (n=4)	19.4 (1.1-37.5, 20.9, -14-53)
6.0-6.9 (n=2)	6.5 (0-13.0, 9.2, -76-78)
7.0-7.9 (n=5)	14.2 (0-26.1, 10.4, 1.3-27)
>8.0 (n=3)	14.9 (4.89-24.2, 9.7, -9.1-39)

Table 4.9: SMFA scores categorised by displacement category.

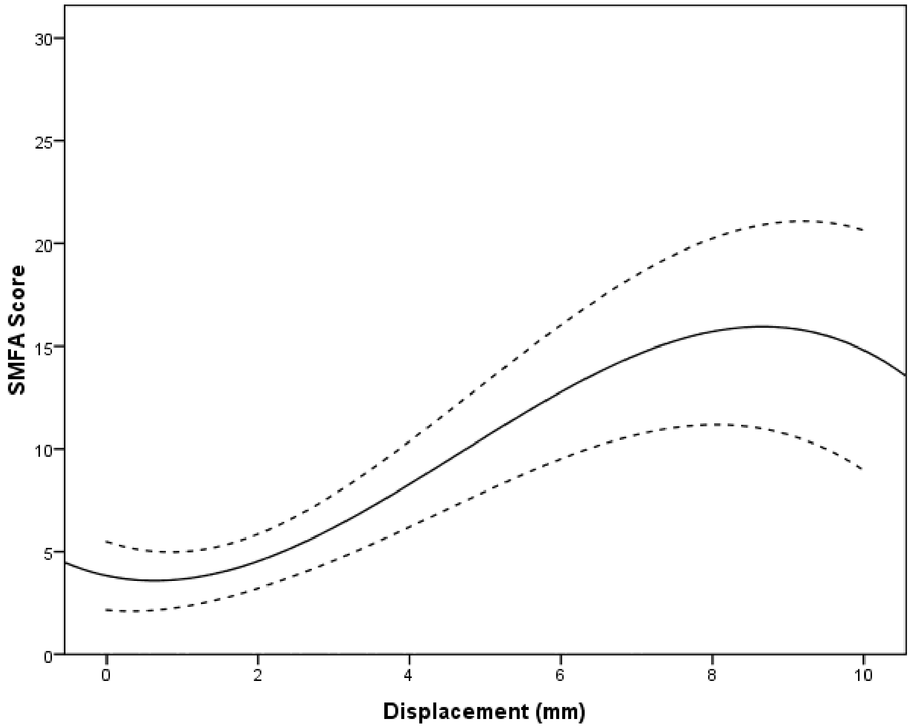

Figure 4.3: Cubic correlation curve of fracture displacement against SMFA score with 95% confidence intervals shown (dashed lines). (R=0.265)

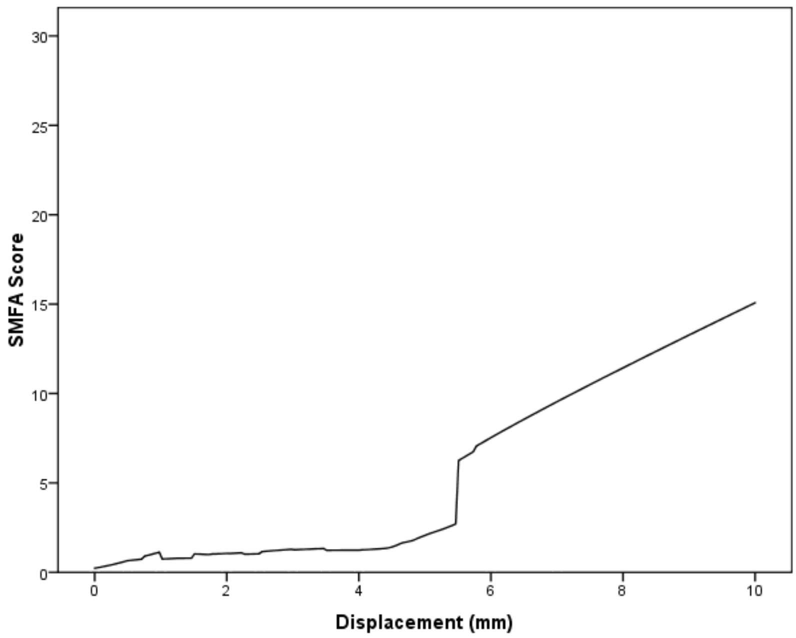

Figure 4.4: Loess with Kernel (Cauchy) analysis for smoothness of fit for SMFA against displacement.

Using multivariate regression analysis controlling for age, gender and co-morbidities, independently significant predictors of a worse SMFA were increasing deprivation and those patients who pursued compensation in relation to their injury (Table 4.10), with the AO-OTA fracture classification (fracture type B2.3) approaching significance.

Variable	**Regression Coefficient**	**95% Confidence Limits**	**p-value**
Age	0.017	-0.072 to 0.107	0.703
Gender	1.425	-1.357 to 4.207	0.314
Co-morbidities	-0.930	-3.971 to 2.112	0.547
Deprivation	-0.967	-1.930 to -0.003	**0.049**
AO-OTA Classification	3.243	-0.068 to 6.553	***0.055***
Mason Classification	-1.830	-4.898 to 1.237	0.241
Fracture location	-3.355	-7.314 to 0.604	0.096
Displacement	0.423	-0.873 to 1.719	0.521
% Head involvement	0.051	-0.025 to 0.126	0.187
Compensation	-6.135	-12.191 to -0.079	**0.047**

Table 4.10: Multivariate linear regression analysis documenting independent predictors of outcome according to the SMFA.

4.6 Chapter Discussion

This is the largest series in the literature documenting both the patient and surgeon reported outcome for isolated fractures of the radial head, and to date, the only prospective study. With 95% of patients managed conservatively and over 90% achieving an excellent or good result, these results show that the vast majority of radial head and neck fractures can be appropriately managed with primary non-operative intervention. In approximately 75% of cases a good or excellent result will be achieved within six weeks. Data from this chapter demonstrates that a non-union is rare as previously reported[146], and that the incidence of radiographic instability is rare with only one fracture losing position after initial presentation.

Our results confirm the general consensus, despite minimal published evidence, that conservative treatment for Mason type 1 radial head fractures produces good or excellent results[4,5,147]. None of our Mason type 1 injuries were treated operatively, 95% achieving excellent or good outcome scores with no significant complications encountered. The five patients who did not achieve this all sustained radial neck fractures. This is of doubtful significance and is most probably related to the ipsilateral complications experienced by these patients.

Radial neck fractures were associated with a statistically superior outcome when compared with radial head fractures, which could potentially be explained by the fact that as with results from Chapter 3, the vast majority of these are non- or minimally displaced isolated fractures. However, neck fracture location was not predictive of either the surgeon or patient reported outcome on multi-variate analysis and the significant differences found on univariate analysis were actually small and probably of limited clinical significance.

The evidence in the literature regarding the Mason type 2-4 radial head fractures is controversial. Struijs et al performed a systematic review that compared the results of conservative treatment with a range of surgical interventions for radial head fractures[5]. They found that there was inadequate data to draw definitive conclusions on the optimal treatment of Mason type 2-4 radial head fractures. This is the first prospective data to support a few smaller long-term retrospective cohort studies favouring non-operative management of isolated displaced Mason type 2 radial head and neck fractures, with an excellent or good result attained in 96% of cases managed non-operatively[4,133,146,153,312]. These results would advocate that the only absolute indication for primary operative intervention of Mason type 2 fractures is a mechanical block to forearm rotation, an established indication for all proximal radial fractures[1,3,34,80,133,153]. However, it is important to be aware of the difficulty of making a confident diagnosis of a mechanical block as forearm rotation can be inhibited by pain. These results also provide short-term evidence to suggest that 2mm or more of fracture displacement is not an indication for surgery, with good patient reported outcomes reported following non-operative management in fractures with less than 5mm of displacement in this series.

Yoon et al have recently reported a retrospective comparative mid-term review of 60 patients with an isolated displaced (2-4.9mm) fracture of the radial head[320]. There were 30 patients managed with ORIF (mean follow-up 4.5 years) and 30 patients treated non-operatively (mean follow-up 3 years). Using a combination of surgeon and patient reported outcome measures, superior outcomes were found in favour of non-operative management according to the MES, the SF-12 physical and overall rate of complications. The MES (93 vs 93; % good or excellent 93% vs 96%) and range of movement reported in the non-operative group were comparable to those found in this series of patients. Prospective long-term data is needed in this area using validated patient reported outcome measures.

Much of the literature for the Mason type 3 and type 4 injury compares and contrasts the various operative methods employed for these injuries as they are routinely part of a more complex injury pattern. Authors have demonstrated good long term results with open reduction internal fixation (ORIF), early or delayed radial head excision and radial head replacement[169,170,172,174,175,182,197,267]. There is limited data in the literature regarding the conservative treatment of these fracture sub-types[4,5,146,174]. The number of patients within these fracture sub-types was too small to make any definitive conclusions with regards optimal management. However, there was no statistically significant advantage of operative management over conservative treatment, with a delay in recovery, for the 'isolated' Mason type 3 and type 4 fractures in this series. Non-operative treatment of these fractures, especially in older patients, with delayed radial head excision or intra-articular osteotomy could be an acceptable option if the long-term result is not acceptable[133,170,321]. However, this must be tempered with the requirement for intervention when the fracture is associated with elbow and/or forearm instability e.g. the terrible triad injury.

4.6.1 Predictors of outcome

Knowledge of outcome predictors following a fracture of the radial head or neck can be invaluable when determining the optimal management for the patient, as well as discussing the expected recovery time and course. This study is the first to use multivariate analysis to predict both the patient and surgeon reported short-term outcome following a fracture of the radial head.

The AO-OTA fracture classification that combines proximal forearm fractures under one system, was a predictor of outcome for the MES, whilst approaching significance for the SMFA. Given the AO-OTA classification has been found to influence both the patient and surgeon reported outcome scores for these injuries, it may provide a suitable alternative for assessment and analysis in future studies[77,134]. However, the regular use of the AO-OTA classification in clinical practice is infrequent due to its complexity and poor intra- and inter- observer reliability[127]. The reliability of this finding is also limited by the small number of patients in the more complex fracture categories (e.g. fracture type B2.3) of the classification. Furthermore, the AO-OTA classification system is interlinked with the Mason classification. The Mason classification[123], in particular the Broberg and Morrey modification[124], is routinely used to classify these types of injuries in the literature with an excellent intra-observer agreement and a moderate inter-observer agreement[126].

The relationship between age and the surgeon reported outcome is likely associated with the inevitable decline in function with advancing age[322]. Although age was predictive on univariate analysis for both outcome measures, it was only independently predictive on multivariate analysis of the surgeon reported MES.

The other predictor of both outcome scores was compensation, which has been shown in previous studies to influence pain and outcome following orthopaedic trauma[323,324]. A recognised issue regarding compensation is timing, with a poor result or slow progress for the patient potentially prompting a decision to seek compensation. Alternatively, if compensation is sought at a very early stage post injury, this is more strongly suggestive of being associated with a poor outcome. The reliability of this finding is limited by the overall small number of patients in the series undertaking compensation proceedings related to their injury (n=9).

Deprivation

This is the first data to document a clear relationship between socioeconomic deprivation and fracture outcome. Most notable is the effect of deprivation once other significant demographic and fracture characteristics have been accounted for, with the fracture classification and compensation the only other predictive factors found on multivariate analysis. The importance of deprivation in medicine is become increasingly clear with effects on cancer survival rates, the rates of diabetes and obesity, as well as the incidence, severity and treatment of fractures already proven[297,299,304,313,315,319]. In relation to orthopaedic trauma, differences in outcome according to ethnicity following distal radial fractures has been shown using multivariate analysis[307], however, in terms of a proven relationship between socioeconomic deprivation and outcome the literature is sparse with no analysis using multivariate regression. Jenkins et al found an association between deprivation and outcome following total hip arthropasty[311], whilst Horton et al found an association with the self-reported physical outcome following hand fractures and soft tissue trauma[297]. In keeping with these findings, both studies found the more deprived reporting poorer functional outcome scores.

This study has found a higher rate of co-morbidities in the most deprived, which also has been found in patients with hip fractures[306]. Factors related to deprivation that have been proposed to influence fracture incidence and outcome are nutrition, alcohol, smoking, physical inactivity, education, employment, marital status, compliance, access to local services and life expectancy[305,306]. These have all been related to the incidence of fractures, in particular osteoporotic proximal femoral fractures, in the most deprived[325-329]. These factors could be associated with reduced bone quality and healing in these patients, as well as poor access to resources and support, thus hindering their recovery. Risk factors such as smoking and employment had no effect on outcome in our analysis, whilst age was not significant on multivariate regression. Further work is needed in this area to determine the aspects of deprivation that could be targeted and potentially modified in the most deprived quintiles e.g. e.g. IMD quintiles 1 and 2 from our work, in order to improve the outcome for these patients. However, it is possible that there are some socio-economic factors that determine outcome in the more deprived patients that are not modifiable. Furthermore, the more deprived patients may have a higher baseline disability and thus pre-injury SMFA scores may be beneficial to determine if the association with deprivation is seen prior to injury. However, there is an obvious difficult and inaccuracy with trying to attain these.

Analysis of data from this study revealed there was no association between the MES and deprivation quintile; however, the SMFA was predictive and is a recognised patient reported outcome score used for musculoskeletal disorders, including upper limb trauma, as well as being recommended by the American Academy of Orthopaedic Surgeons[273,274,284,330,331]. The only other predictor of the SMFA on multi-variate analysis was compensation. Patient reported outcome measures (PROMs), such as the SFMA, have been found to have a good correlation with surgeon completed outcome scores[332,333]. However, one study has shown a discrepancy between SMFA and DASH outcome scores in upper limb trauma patients[334]. Furthermore, the two previous orthopaedic studies that found a correlation between outcome and deprivation used a patient-orientated outcome score[297,311]. To date, no correlation has been shown with a surgeon completed score. The potential inconsistency between these two types of outcome measure, as well as the association seen with deprivation, need to be considered when planning and interpreting future orthopaedic trauma studies. Further work in this area may use a limb specific patient outcome score, such as the DASH, to see if comparable results are seen.

4.6.2 Strengths and limitations

The main strength of this chapter is that it represents a large series of patients with the prospective collection of demographic and follow-up data. The variable follow-up times are a limitation and it has only examined the short-term outcome of these patients, with long-term problems such as pain and stiffness potentially not accounted for. However, as the EOTU is the only primary acute musculoskeletal trauma service for the local adult population, it could be argued that the majority of these patients did not attend as they were happy with their outcome. As has already been mentioned regarding the AO-OTA and Mason classification systems, there is an unavoidable intra- and inter-observer error when interpreting the radiographs.

The methodology used for categorising deprivation is recognised and has been examined in international studies as well as previous trauma literature[297,310]. Although some data was collected on deprivation factors such as co-morbidities and employment, a limitation is the lack of additional data on confounding variables such as alcohol, ethnicity and treatment compliance, which may potentially explain the differences found in outcome according to deprivation. Pre-injury SMFA scores would have been beneficial to determine if the association with deprivation was seen prior to injury and future work in this area would be valuable. It is also possible that the variations in outcome according to deprivation we have found may not be significant in the long term.

5 A PROSPECTIVE ANALYSIS OF RADIAL HEAD FRACTURES: LONG-TERM OUTCOME OF NON-OPERATIVE MANAGEMENT

5.1 Hypothesis and Aims

The aim of this chapter was to define the long-term outcome following primary non-operative management of stable isolated fractures of the radial head and neck (Mason type 1 and type 2 injuries). The aim was also to determine what factors predict the long-term outcome of these injuries and how these correspond with the short-term predictors defined in Chapter 4.

The hypothesis was that for stable isolated fractures of the radial head, non-operative management results in a satisfactory long-term patient reported outcome that is comparable to operative management for defined fractures.

5.2 Chapter Summary

There is evidence to support the primary non-operative management of isolated stable fractures of the radial head. However, the long-term outcome of these fractures remains unclear. From the prospective proximal radial fracture database reported in chapter 4, all patients with a confirmed isolated stable fracture of the proximal radius (Mason type 1 or type 2 fracture of the radial head or neck) that were primarily managed non-operatively were identified. The primary long-term outcome measure was the DASH score.

There were 100 patients in the study cohort with a mean age of 46yrs (range, 17-79). A fall from standing height accounted for 69% of all injuries, with one or more co-morbidities in 35% of patients. There were 57 (57%) Mason type 1 and 43 (43%) Mason type 2 fractures. At a mean of 10yrs (range, 8.8-10.2) post injury, the mean DASH score was 5.8 (range, 0-67.2) and the mean Oxford Elbow Score was 46 (range, 14-48). 92% of patients were satisfied and the median satisfaction score was 10 (range, 3-10). Fourteen (14%) patients reported stiffness and 24 (24%) some degree of pain. A worse DASH was associated with older patients ($p=0.002$), ≥1 co-morbidities ($p=0.008$), increasing deprivation ($p=0.026$), increasing fracture displacement ($p=0.041$), and compensation ($p=0.006$).

The findings of this chapter support the routine primary non-operative treatment of stable fractures of the radial head and neck, providing a satisfactory outcome in the vast majority of patients.

5.3 Chapter Introduction

The vast majority of fractures of the radial head are stable isolated non-displaced or minimally displaced fractures of the radial neck or the anterolateral portion of the radial head (Mason type 1 and type 2)[34,72,136]. Stable fractures are characterised by preservation of radiocapitellar contact with no associated elbow or forearm instability and no clinically relevant associated injuries[97,98,137]. Primary non-operative management of Mason type 1 and type 2 fractures is associated with good short (within one year) to mid-term results, with post-injury stiffness the primary concern[4,5,153]. There are advocates for primary operative management of displaced partial articular fractures (Mason type 2)[158,161,165], although the only generally agreed absolute indication for operative intervention is crepitus on forearm rotation or an established block to forearm rotation, which are rare[1,3,34,80,133,153].

There are minimal data documenting the long-term outcome following non-operative management of isolated stable fractures of the radial head. There are some case series reporting favourable long-term results, although none have used validated patient reported outcome measures, with the incidence of pain, stiffness and re-intervention remaining unclear[133,146,147,312,335]. It is acknowledged that further work is needed to determine the patient reported long-term outcome following these fractures, as well as the rates of persistent stiffness and pain[34,262].

5.4 Patients and Methods

5.4.1 Patients and database construction

Of the original 237 patients reported in Chapter 4, those patients were identified who had sustained a radiographically confirmed isolated stable fracture of the radial head or neck (Mason type 1 and type 2), which was managed with primary non-operative intervention. Patients were excluded if they had sustained a complex unstable fracture of the radial head or neck, a concomitant fracture around the ipsilateral elbow, a fracture dislocation of the elbow, or if there was evidence of associated elbow and/or forearm instability. Patients were also excluded if they had moved out with the catchment area and/or were not available or contactable for long-term follow-up, demented patients who could not complete follow-up, or if they were deceased.

Using these criteria 142 patients were identified of which 82 (57.7%) were female, the mean age was 44yrs (range, 16-79yrs, SD 15.5) and 84 (59.2%) were a Mason type 1 fracture. Of the original 142 patients identified, 42 did not respond and were lost to follow-up, leaving 100 (70%) patients that made up our study cohort for analysis. The mean age was 46yrs (range, 17-79yrs; SD 15.4; 95% CI 43-49), 59 (59%) were female and 57 (57%) were a Mason type 1 fracture. As would be expected, patients had a mean younger age (38yrs; SD, 14.5; 95% CI 34-43) in the lost cohort (p=0.006). There was no difference in gender (p=0.641), co-morbidities (p=0.457) or fracture classification (p=0.420) between the final and the lost cohorts**.**

5.4.2 Radiographic classification

All fractures were assessed as described in Section 4.4.2.

5.4.3 Management protocol

Management, duration of treatment and the use of physiotherapy were described in Section 4.5.2. For this patient group, delayed operative intervention was considered for a confirmed mechanical block to forearm rotation, with delayed excision if the patient developed chronic symptoms.

5.4.4 Outcome assessment

Long-term follow-up was by means of a telephone and questionnaire review using two upper limb specific validated patient reported outcome measures – the Oxford Elbow Score (OES)[292] and the Disabilities of Arm, Shoulder and Hand (DASH)[275] (Section 2.5)[g]. There is evidence to support the verbal use of the QuickDASH, with verbal scores correlating well with written scores[288]. The DASH was the primary outcome measure for this study.

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[g] Thank you to Neil Wickramasinghe for his assistance with the telephone follow-up.

Patients were asked to confirm if they had undergone further surgery for a persistent problem associated with their initial injury. For this patient group, delayed operative intervention was considered for a confirmed mechanical block to forearm rotation, with delayed excision if the patient developed chronic symptoms. Along with the OES, other secondary outcome measures included subjective pain, stiffness, instability and satisfaction (Section 2.5.4). Stiffness and instability were recorded as a dichotomous response (yes or no). Instability was defined as the current subjective impression of the patient that the elbow felt unstable on activity. Pain was assessed as both none, mild, moderate or severe, and on a scale of 0-10 (10 being worse). Satisfaction was graded as both yes or no, and on a scale of 0-10 (10 being completely satisfied). All patients were asked at what stage following injury they returned to work and sports.

5.4.5 Statistical analysis

Age was found to be normally distributed, with the OES and the DASH scores having a skewed distribution. A Student's unpaired t-test was used to analyse parametric continuous data (age), with the Mann-Whitney U-test used for non-parametric data (OES and DASH). The Kruskal-Wallis test was used for non-parametric continuous data where a variable had more than two categories. Categorical binary data were analysed using either the chi-square test (all observed frequencies in each cell >5) or the Fisher's exact test (one cell had an observed frequency of ≤5). Spearman's correlation was used to analyse the correlation between two continuous variables (e.g. age vs DASH). Regression analysis was to use to analyse the correlation between deprivation and outcome. Polynomial regression analysis was used to analyse the correlation between fracture displacement and outcome. This methodology analyses the outcome data to determine which curve most closely fits the distribution of the data, which is defined by the greatest R^2 value (Figure 5.1). Two tailed p-values were reported and statistical significance was set at p<0.05, with 95% confidence intervals (95% CI) presented.

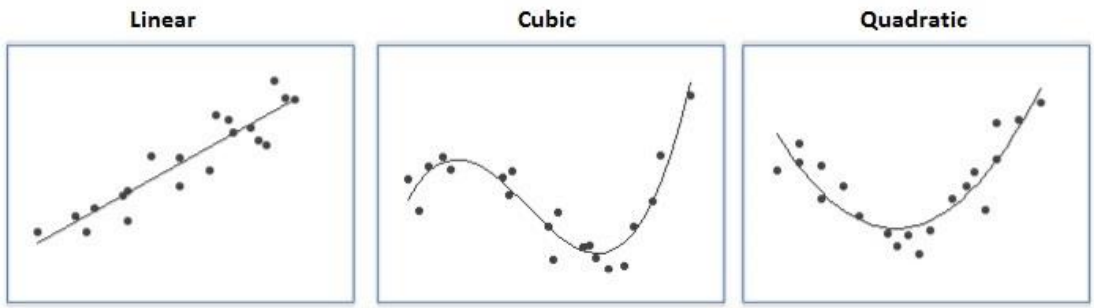

Figure 5.1: Linear, cubic and quadratic correlation curves.

5.5 Results

There were 100 patients in the study cohort with a mean age of 46yrs (range, 17-79; SD 15.4) and 59 (59%) were female (Table 5.1). The mean age of females was 52yrs (17-79, SD 15.6), which was significantly older (p<0.001) than the mean age of males (38yrs, 20-65, SD 11.2) at the time of injury. The dominant side was affected in 43 (43%) cases. One or more co-morbidities were documented in 35% (n=35) of patients, with the distribution according to deprivation quintile found in Table 5.1.

No significant association was found between age (p=0.998), gender (p=0.231), mechanism of injury (p=0.739), employment (p=0.749), fracture classification (p=0.505) or location (p=0.282), and the deprivation quintiles. The most frequent mechanism of injury was a fall from standing height (n=69, 69%), followed by sports (n=20, 20%), fall down stairs (n=4, 4%), fall from height (n=3, 3%) direct blow (n=2, 2%) and finally a motor vehicle collision (n=2, 2%). Females most commonly sustained their fractures following a fall from standing height, whilst males sustained sports injuries just as commonly (Table 5.1, p<0.001).

	Male n (%)	**Female n (%)**	**p value**
Total	41 (41)	59 (59)	NA
Mean age (range, SD, 95% CI)	38 (20-65, 11.2, 34-41)	52 (17-79, 15.6, 48-56)	**<0.001[a]**
Mechanism of injury			
Fall from standing height	18 (43.9)	51 (86.4)	
Sports	18 (43.9)	2 (3.4)	
Fall down stairs	0 (0)	4 (6.8)	**<0.001***
Fall from height	3 (7.3)	0 (0)	
MVC	0 (0)	2 (3.4)	
Direct blow	2 (4.9)	0 (0)	
Occupation Code			
Office Work	21 (51.2)	20 (33.9)	
Light manual	13 (31.7)	20 (33.9)	
Heavy manual	1 (2.4)	2 (3.4)	0.175*
Unemployed	2 (4.9)	1 (1.7)	
Retired	4 (9.8)	16 (27.1)	
Compensation proceedings	0 (0)	4 (6.8)	0.142¶
Index of Multiple Deprivation			
1 (n=8)	4 (9.8)	4 (6.8)	
2 (n=15)	10 (24.4)	5 (8.5)	
3 (n=22)	8 (19.5)	14 (23.7)	0.231*
4 (n=13)	4 (9.8)	9 (15.3)	
5 (n=42)	15 (36.6)	27 (45.8)	
Mason classification			
Type 1	23 (56.1)	34 (57.6)	0.879*
Type 2	18 (43.9)	25 (42.4)	
AO-OTA			
A2.2	10 (24.4)	20 (33.9)	
B2.1	29 (70.7)	37 (62.7)	0.577*
B2.2	2 (4.9)	2 (3.4)	
Radial head	31 (75.6)	39 (66.1)	
Radial neck	10 (24.4)	20 (33.9)	0.308*

Table 5.1: Patient demographics and fracture characteristics. ([a] Student's t-test, * Chi-squared, ¶ Fisher's exact test)

There were 70 (70%) radial head fractures and 30 (30%) radial neck fractures, with the median fracture displacement 1mm (range, 0-5mm) and the median percentage head involvement 30% (range, 0-70%). There were 57 (57%) patients classified as a Mason type 1 fracture (radial head n=27, radial neck n=30) and 43 (43%) a Mason type 2 (radial head n=43, radial neck n=0). The median fracture displacement for Mason type 1 fractures was 0mm (range, 0-1.5mm), and was 2.5mm (range, 2-5mm) for Mason type 2 fractures. According to the AO-OTA classification there were 30 (30%) A2.2 fractures, 66 (66%) B2.1 fractures and 4 (4%) B2.2 fractures.

5.5.1 Long-term outcome

At a mean of ten years (range, 8.8-10.2) post injury, the mean DASH score was 5.8 (range, 0-67.2; SD 12.9) and the mean Oxford Elbow Score was 46 (range, 14-48; SD 5.02) (Table 5.2). 92% of patients were satisfied and the median satisfaction was score 10 (range, 3-10). The median time to return to work was 2 weeks (range, 0-36; n=73), with a median time to return to sports 6 weeks (range 1-24; n=72).

Fourteen (14%) patients noted some subjective stiffness and four (4%) a feeling of subjective instability. There were 24 (24%) patients complaining of some degree of pain with 17 mild, five moderate and two severe. The overall median pain score was 0 (range, 0-8). Two (2%) patients underwent further surgery. One patient (Mason type 2 radial head) underwent ORIF at ten days following injury for a persistent mechanical block to forearm rotation. The other patient (Mason type 1 radial head fracture) had persistent pain and clicking, undergoing radial head excision 8 years post injury.

Classification	Mean OES (range, SD, 95% CI)	Mean DASH (range, SD, 95% CI)
Mason		
I (n=57)	46.2 (26-48, 4.4, 45-47)	5.8 (0-65, 13.7, 2.2-9.4)
Head (n=27)	45.8 (27-48, 4.6, 44-48)	5.8 (0-53, 13.1, 0.6-11.0)
Neck (n=30)	46.6 (26-48, 4.1, 45-48)	5.9 (0-65, 14.5, 0.5-11.3)
II (n=43)	45.5 (14-48, 5.8, 44-47)	6.1 (0-67, 11.8, 2.5-9.7)
Head (n=43)		

Table 5.2: Long-term OES and DASH scores.

5.5.2 Predictors of long-term outcome

Age (p=0.002), co-morbidities (p=0.008), deprivation (p=0.026), degree of fracture displacement (p=0.041) and compensation proceedings (p=0.006) were the only predictors of the long-term DASH score. An increased (worse) DASH score was found in older patients, patients with one or more co-morbidities, increasing deprivation, increasing fracture displacement, and those patients who pursued compensation in relation to their injury.

There was a significant correlation between the degree of fracture displacement and the DASH score (Table 5.3; R=0.21, p=0.041), with increasing displacement resulting in a greater (worse) DASH score (Figure 5.2).

Displacement category (mm)	Mean DASH (range, SD, 95% CI)
0-0.9 (n=40)	6.0 (0-64.7, 14.9, 1.27 to 10.8)
1-1.9 (n=17)	5.3 (0-41.1, 11.1, -0.35 to 11.0)
2.0-2.9 (n=23)	3.4 (0-24.1, 5.89, 0.87 to 5.96)
3.0-3.9 (n=12)	6.2 (0-28.4, 8.62, 0.72 to 11.7)
4.0-4.9 (n=5)	16.4 (0-67.2, 28.9, -19.6 to 52.3)
5.0-5.9 (n=3)	9.4 (0-19.2, 9.6, -14.5 to 33.2)

Table 5.3: DASH scores categorised by displacement category.

There was a trend towards a significantly worse DASH for fractures displaced 4mm or more (5.2 verses 13.7, $p=0.07$).

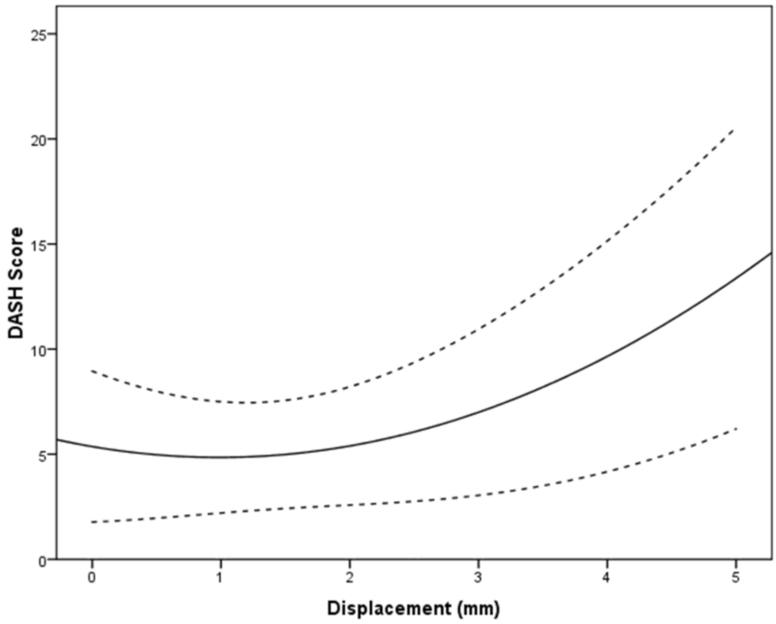

Figure 5.2: Quadratic correlation curve of fracture displacement against DASH score with 95% confidence intervals shown (dashed lines).

Further analysis of deprivation adjusting for age, gender and fracture classification demonstrated that patients in the most deprived quintile had a mean DASH score 13.3 points higher than the least deprived (Table 5.4).

Deprivation Quintile	Mean DASH (range, SD, 95% CI)	Adjusted mean DASH (95% CI)
1 (n=8)	16.7 (0-64.7, 23.7, -3.0 to 36.5)	16.8 (8.4 to 25.3)
2 (n=15)	4.5 (0-35.2, 9.7, -0.9 to 9.9)	4.9 (-1.5 to 11.2)
3 (n=22)	9.6 (0-67.2, 16.7, 2.2-17.0)	9.7 (4.6 to 14.9)
4 (n=13)	1.9 (0-10.3, 3.5, -0.2 to 4.1)	1.8 (-4.8 to 8.4)
5 (n=42)	3.7 (0-53.4, 9.3, 0.9 to 6.6)	3.5 (-0.16 to 7.3)

Table 5.4: DASH scores categorised by deprivation quintiles. Increased deprivation was associated with a poorer DASH score (p=0.04). A mean DASH adjusted for age, gender and fracture classification is presented.

Gender (p=0.056), mechanism of injury (p=0.281), injury dominance (p=0.186), the Mason classification (p=0.132) or the AO-OTA classification (p=0.624), head or neck location (p=0.334) and percentage of head involvement (p=0.401) were not predictive of long-term outcome according to the DASH score. No difference in any of the secondary outcome measures was seen when comparing Mason type 1 and type 2 fractures or when comparing head and neck fractures directly (Table 5.5).

	Mason type 1 **n (%)**	**Mason type 2** **n (%)**	**p value**	**Radial head** **n (%)**	**Radial neck** **n (%)**	**p value**
Total	57 (57)	43 (43)	NA	70 (70)	30 (30)	NA
Mean age (range, SD, 95%CI)	46 (23-78, 15.2, 42-50)	47 (17-79, 15.9, 42-51)	0.856[a]	46 (17-79, 14.7, 43-50)	47 (23-78. 17.3, 40-53)	0.859[a]
Gender						
Male	23 (40.4)	18 (41.9)	0.879*	31 (44.3)	10 (33.3)	0.308*
Female	34 (59.6)	25 (58.1)		39 (55.7)	20 (66.7)	
MOI						
Fall standing height	39 (68.4)	30 (69.8)		48 (68.6)	21 (70)	
Sports	12 (21.1)	8 (18.6)		13 (18.6)	7 (23.3)	
Fall down stairs	2 (3.5)	2 (4.7)	0.209*	2 (2.9)	2 (6.7)	0.549*
Fall from height	0 (0)	3 (7.0)		3 (4.3)	0 (0)	
MVC	2 (3.5)	0 (0)		2 (2.9)	0 (0)	
Direct blow	2 (3.5)	0 (0)		2 (2.9)	0 (0)	
Pain						
Median score	0 (0-5)	0 (0-8)	0.225[b]	0 (0-8)	0 (0-5)	0.298[b]
None	46 (80.7)	30 (69.8)		51 (72.9)	25 (83.3)	
Mild	8 (14.0)	9 (20.9)		14 (20)	3 (10)	
Moderate	3 (5.3)	2 (4.7)	0.291*	3 (4.3)	2 (6.7)	0.452*
Severe	0 (0)	2 (4.7)		2 (2.9)	0 (0)	
Stiffness	10 (17.5)	4 (9.3)	0.383¶	7 (10)	7 (23.3)	0.078¶
Instability	1 (1.8)	3 (7.0)	0.312¶	3 (4.3)	1 (3.3)	1.000¶
Satisfaction						
Median score (range)	10 (4-10)	10 (3-10)	0.429[b]	10 (3-10)	10 (7-10)	0.343[b]
Yes	53 (93)	39 (90.7)	0.722¶	63 (90)	29 (96.7)	0.429¶
No	4 (7)	4 (9.3)		7 (10)	1 (3.3)	
Median return to work (weeks; range)	2 (0-10)	4.5 (0-36)	0.147[b]	3.5 (0-36)	2 (0-10)	0.441[b]
Median return to sports (weeks; range)	6 (1-24)	6 (2-24)	0.944[b]	6 (2-24)	6 (1-24)	0.556[b]
Mean OES (range, SD, 95% CI)	46.2 (26-48, 4.4, 45-47)	45.5 (14-48, 5.8, 44-47)	0.126[b]	45.6 (14-48, 5.3, 44-47)	46.6 (26-48, 4.1, 45-48)	0.067[b]
Mean DASH (range, SD, 95% CI)	5.8 (0-64, 13.7, 2.2-9.4)	6.1 (0-67, 11.8, 2.5-9.7)	0.132[b]	6.0 (0-67, 12.2, 3.1-8.9)	5.9 (0-64, 14.5, 0.5-11.3)	0.334[b]

Table 5.5: Fracture characteristics and outcome. ([a] Student's t-test, [b] Mann-Whitney test, * Chi-squared, ¶ Fisher's exact test)

5.6 Chapter Discussion

This is the largest series in the current literature documenting the subjective long-term outcome of patients treated with primary non-operative intervention for an isolated stable fracture of the radial head. The data would suggest that conservative management of these injuries is a reliable treatment option, yielding an excellent or good long-term result in the majority of cases. Despite a small number of patients reporting persistent pain and stiffness, patient satisfaction is high, the need for secondary intervention is negligible, and patients routinely return early to work and sports.

Overall, 92% of patients are satisfied with their long-term outcome following non-operative management of an isolated stable radial head fracture. Forearm rotation crepitus or block in the short-term and symptomatic radiocapitellar arthrosis in the long-term are felt to be rare following an isolated stable fracture of the radial head[34,80,133,146,147,263], with only 2% of patients requiring re-intervention in this series. The predominant adverse outcome commonly reported is persistent elbow stiffness, with a long-term rate of 14% found in this series. Patients should be counselled regarding the risk of persisting pain and stiffness following these injuries and managed appropriately. Elbow stiffness is often secondary to capsular contracture and data would suggest that persistent stiffness is best managed with positive stretching exercises[68,151]. This study found a median time to return to work of two weeks, with the median time to return to sports six weeks. This data is consistent with reports on patients who have sustained a variety of upper limb injuries following soccer or rugby, with nine weeks the median time to return to soccer[336] and 86% of patients returning to rugby by 3 months[337].

The aims of non-operative management following an isolated stable fracture of the radial head are to allow early mobilisation of the elbow and to meet the long-term demands of the patient, whilst producing minimal complications and the need for secondary intervention. These results are in keeping with the short-term data from chapter 4 and the limited available literature on the mid to long-term outcome of these injuries, with non-operative management routinely providing a satisfactory outcome[4,133,146,147]. In a study of 32 Mason type 1 fractures evaluated at a mean of 21 years post injury, no objective impairment was found in any patient and only three patients reported occasional pain[147]. This is consistent with these findings that found 93% of patients who sustained a Mason type 1 fracture were satisfied with their outcome. Long-term data reporting the outcome of 49 patients that were managed conservatively for isolated Mason type 2 fractures demonstrated that 82% had no subjective complaints[133], which is comparable to a satisfaction rate of 91% in this group. However, 12% underwent delayed radial head excision within the first six months post injury, which was higher than in this series where one patient required early ORIF and one delayed radial head excision[133].

Although there is a consensus regarding the non-operative management of Mason type 1 fractures, type 2 fractures are more open to debate. These findings provide long-term data to support the findings in Chapter 4 that that the only clear indication for surgery for isolated stable displaced fractures of the radial head or neck is a persistent mechanical block to forearm rotation[1,3,34,80,133,153].

A systematic review of nine case series on the management of stable Mason type 2 radial head fractures concluded there was insufficient evidence to determine whether conservative or operative treatment was superior[149]. Despite retrospective data reporting positive results for ORIF of displaced partial radial head fractures[158,161,164,165], there are no prospective studies and few clearly demonstrate a superior outcome for ORIF over non-operative management. Operative fixation can be associated with an anaesthetic risk, poor fixation in osteoporotic bone, as well as the potential for further surgery to remove metalwork or carry out excision or replacement of the radial head. In a small retrospective case series of 16 patients managed with ORIF for an isolated Mason type 2 fracture, long-term results of operative treatment gave no appreciable advantage over non-operative management with an increased complication rate[153]. At a mean of 22 years following surgery the authors reported an inferior DASH score (12 vs 6) and complication rate (44% vs 0%), which is comparable to what has been found in this series of patients.

Although further work to compare operative and non-operative management for stable displaced partial radial head fractures has been recommended by some authors[149,262,264], with the long-term results reported here there is a now strong body of evidence to support the non-operative management of these injuries and such a trial would require large numbers due to the low rate of complications. Caveats to employing non-operative management for Mason type 2 fractures are 1) fractures with a clinically relevant associated injury pattern and/or elbow/forearm instability; and 2) the patient who has sustained a high-energy injury with an apparently stable and isolated fracture, which subsequently may be found to be an unstable fracture and part of a complex injury pattern[34,105].

5.6.1 Predictors of outcome

This is the first data to document the predictors of long-term outcome following the non-operative management of stable isolated fractures of the radial head. Predictors of short-term outcome identified in Chapter 4 included increasing age, increasing deprivation, fracture classification and compensation[1,77]. Increasing fracture displacement was the only injury characteristic that was predictive of long-term outcome in our study, potentially suggesting that above a certain degree of displacement surgery might be indicated.

From both Chapter 4 and the findings here, it would seem that fractures displaced less than 5mm are associated with a satisfactory patient reported outcome and that operative intervention would not confer a superior outcome. This would be in keeping with many studies on Mason type 2 isolated partial displaced radial head fractures that use an arbitrary 5mm displacement cut-off point for inclusion[133,320,338]. There have been mid-term studies that have reported no association between fracture displacement and patient reported outcome (PREE and DASH), with one of these studies reporting a weak correlation between greater fragment displacement and a poorer MES.

The difficulty with drawing firm conclusions from these studies and the findings presented here is the small sample size, particularly of fractures displaced more than 5mm, and the inevitable degree of intra- and inter-observer variability associated with measuring fracture displacement. Furthermore, it is not certain that surgery would necessarily provide a superior outcome over non-operative treatment for these cases.

Increasing age, co-morbidities, socioeconomic deprivation and compensation were the other factors associated with of a poorer long-term outcome. The association between age and outcome in the short-term reported in Chapter 4, persists in the longer-term and again is not surprising given the inevitable decline in function that is well represented in most patient reported outcome scores and has been found for both radial head fractures and a multitude of other injuries[320,322]. Intrinsically related to co-morbidities is socioeconomic deprivation.

As has already been discussed in Chapter 4, deprivation is known to influence all aspects of medicine including orthopaedics[297,299,304,307,311,313,315,319,339], as well as predicting the short-term outcome of these injuries. The results of this chapter build on this to document an association between deprivation and the long-term outcome. Worsening deprivation is routinely associated with an increasing incidence of disease and a poorer outcome, but it is unclear which contributing factors of deprivation influence the outcome. Proposed contributing factors include co-morbidities, alcohol, smoking, nutrition, physical exercise, education, employment, compliance, access to health services, and life expectancy[305,306]. As was suggested before, the outcome in the more deprived quintiles could be improved by targeted care and investment, although it is possible that some of these factors are not easily modified.

5.6.2 Strengths and limitations

The main strength of this chapter is that it includes a large series of patients with prospective demographic and fracture characteristic data collection, as well as documenting the long-term follow-up from a defined population with only one centre providing an acute musculoskeletal trauma service. Strict and recognised inclusion and exclusion criteria have been employed with all radiographs available to confirm the diagnosis.

This is the first data to report on the long-term outcome and satisfaction of these patients with the use of validated upper limb patient reported outcome scores. This study has also clearly defined the incidence of pain and stiffness following these injuries, providing useful prognostic data for both the treating clinician and the patient. However, the lack of long-term radiographic follow-up is a limitation as no comment regarding post-traumatic osteoarthritic change and outcome can be made.

Undoubtedly, the primary limitation of this chapter is the retrospective design that resulted in a loss to follow-up rate of 30%. This could potentially lead to under-estimation of the incidence of adverse outcomes and re-intervention. It is also hinders the recall of patients, particularly when considering the time to return to work and sports following their initial injury. However, a degree of this is inevitable with longer follow up times and is comparable to other published studies reporting on the long-term outcome following fracture. Furthermore, there were no significant differences in the demographics between those lost to follow-up cohort and the study cohort except for age.

As discussed above, the small study sample size and the intra- and inter-observer variability associated with measuring fracture displacement for these injuries mean that conclusions regarding long-term prognostic indicators are limited.

6 A PROSPECTIVE ANALYSIS OF RADIAL HEAD FRACTURES: DIAGNOSING THE ESSEX-LOPRESTI INJURY

6.1 Hypothesis and Aims

This chapter developed as a consequence of an observation from Chapter 4 regarding patients that presented with ipsilateral wrist pain following a fracture of the proximal radius. The aim for this chapter is to describe the prevalence of wrist pain following a fracture of the radial head and the range of radial shortening that may occur. Using data from Chapter 4 and Chapter 5, the aim was to document the short-term and long-term outcome in these patients.

The hypothesis was that a spectrum of injury to the forearm exists following a fracture of the radial head, for which non-operative management provides a satisfactory outcome in a majority of patients.

6.2 Chapter Summary

The Essex-Lopresti lesion is thought to be rare, with a varying degree of disruption to forearm stability probable. From the data collected in Chapter 4, patients noted to have ipsilateral wrist pain at initial presentation underwent bilateral wrist radiographs to determine whether there was disruption of the distal radio-ulnar joint suggestive of an Essex-Lopresti lesion. The primary short-term outcome measures were the Mayo elbow score (MES) and the short musculoskeletal function assessment (SMFA) questionnaire. The primary long-term outcome measure was the DASH score.

Sixty patients had ipsilateral wrist pain at the initial assessment of 237 proximal radial fractures. Radial shortening of ≥2mm (range, 2–4) was seen in 22 patients. The mean age was 48 years (range, 19-79) and 16 (73%) were female. There were 21 fractures classified as a Mason type 1 or type 2 injury, all of which were managed non-operatively. One Mason type 3 fracture underwent acute radial head replacement. Short-term outcome was assessed in 21 patients. At a mean of six months post injury, 18 (86%) patients achieved an excellent or good MES. The mean MES was excellent (90; range, 70-100). The final median SMFA score was 1.63, with a mean score of 4.79 (range, 0-26.09). At a mean of 10yrs (range, 9.1-10.1; n=9) post injury, the mean DASH score was 15.3 (range, 0-67.2) and the mean Oxford Elbow Score was 43 (range, 14-48).

The incidence of the Essex-Lopresti lesion type is possibly under-reported as there is a spectrum of injuries, and subtle disruptions often go unidentified. A full assessment of all patients with a proximal radial fracture is required in order to identify these injuries, and the index of suspicion is raised with higher energy injuries and as the complexity of the fracture increases.

6.3 Chapter Introduction

The Essex-Lopresti lesion is the eponym given to radio-ulnar instability caused by sequential injury to the distal radio-ulnar joint, the interosseous membrane and fracture of the proximal radius[139]. The original paper by Essex-Lopresti suggested that this is a rare injury, with subsequent literature indicating the lesion is present in approximately 1% of all radial head fractures[139,340]. A varying degree of force, in order to sustain such an injury, has been reported[341,342]. A recent study looking at all types of radial head fractures has shown that the incidence of associated injuries is high on MRI[98], with another study finding subtle lesions of the distal IOM on forearm MRI following low energy Mason type 1 radial head fractures[343]. A clear knowledge of the range of radial shortening, suggestive of an Essex-Lopresti type lesion, would aid in the optimal assessment and management of these lesions.

The diagnosis and treatment are often challenging, with further imaging often employed when an unstable lesion is suspected[118,120]. Although the diagnosis may manifest acutely, it is not unusual for it be subtle and delayed, with subsequent sequelae most notably affecting the wrist[113,114,140,340]. When there is instability, ORIF or radial head replacement with added longitudinal stabilization of the forearm bones is recommended[140,344,345]. Caution is necessary with ORIF as many chronic Essex-Lopresti lesions are the results of failed fixation and subsequent resection of the radial head[140,340,344-346].

6.4 Patients and Methods

6.4.1 Patients and database construction

This section of the thesis came from an observation from the prospective study on all radial head fractures (Chapter 4). It includes a sub-group of patients from the prospective study of radial head fractures who presented with a closed proximal radial fracture and persistent ipsilateral wrist pain within two weeks following injury. Patients were included if they had radial shortening of ≥2mm when compared to the contralateral wrist. Patients were excluded from the analysis if they had ipsilateral wrist pain but with a radiologically confirmed injury to the wrist. A total of 60 patients had ipsilateral wrist pain at the initial assessment of 237 proximal radial fractures. Radial shortening of ≥2mm (range, 2–4mm) was seen in 22 patients, with a mean age of 48 years (range, 19-79) and 16 (73%) were female.

6.4.2 Radiographic classification

All patients underwent radiographic assessment used standard anteroposterior (AP) and lateral radiographs of the elbow, which were classified as described in Section 4.4.2. Where the patient had wrist pain or tenderness, neutral PA and lateral radiographs of the affected wrist were performed to screen for the presence of any distal radial-ulnar joint abnormality. Radiographs of the unaffected contralateral wrist were performed for comparison. If there was 2mm or more of ipsilateral radial shortening compared to the contralateral side, this was considered suggestive of an

Essex-Lopresti type lesion (Figure 6.1). Two trauma trained fellows independently assessed and classified each injury with any discrepancies resolved by consensus with the senior authors. All diagnoses were made within 2 weeks of injury.

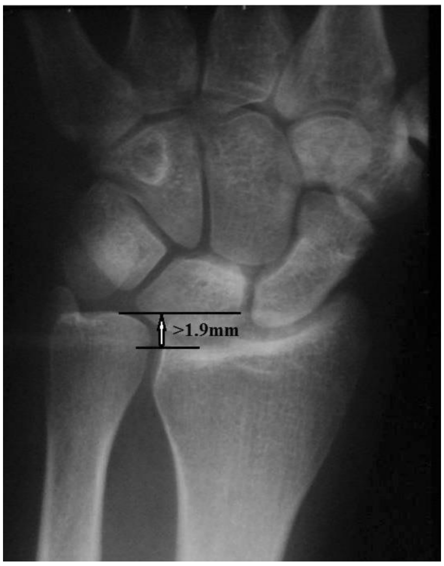

Figure 6.1: An Essex Lopresti lesion was diagnosed in this patient's radiographs, which demonstrated greater than 2 mm of shortening of the ipsilateral radius when compared to the contralateral side.

6.4.3 Management protocol

The management protocol of these patients was described in Section 4.4.3.

6.4.4 Outcome assessment

The short-term and long outcome assessment of these patients was described in Sections 4.4.4 and 5.4.4 respectively.

6.4.5 Statistical analysis

The Mann-Whitney U-test was used to analyze non-parametric continuous data. The Kruskal–Wallis one-way analysis of variance test was used to analyze data for several groups. Significance was determined as a p value of <0.05 in all analyses, with 95% confidence intervals (CI) set.

The kappa value was used to determine the inter-observer reliability of diagnosing an Essex-Lopresti type injury as 2 mm or more of ipsilateral radial shortening compared to the contralateral side, with an associated grading assigned: slight agreement (0.00-0.20), fair agreement (0.21-0.40), moderate agreement (0.41-0.60), substantial agreement (0.61-0.80) and very good agreement ($\geq$0.81)[347]. The 95% CI for the kappa value was calculated using the standard formula, which was kappa value $\pm$ 1.96 x standard error (0.026).

6.5 Results

There were 60 patients noted to have ipsilateral wrist pain at the initial assessment of 237 proximal radial fractures. Radial shortening of ≥2mm (mean, 2.5; range, 2-4; SD 0.6) was seen in 22 patients (9%, 95% CI 6-14). There were two disagreements regarding the diagnosis of radial shortening between the two observers, giving a Kappa value 0.96 (95% CI 0.9-1), with the strength of agreement considered to be 'very good'.

Of the original 22 patients, the mean age was 48 years (median 50; range, 19-79; SD 17.7) and 16 (73%) were female. The dominant side was affected in 9 (41%) cases. One or more co-morbidities were documented in 45.5% (n=10) of patients. The most frequent mechanism of injury was a fall from standing height (n=11, 50%), followed by sports (n=6, 27.3%), fall down stairs (n=3, 13.6%) and finally a direct blow (n=2, 9.1%).

There were 10 (46%) radial head fractures and 12 (54%) radial neck fractures, with the median fracture displacement 0.25mm (range, 0-7mm) and the median percentage head involvement 0% (range, 0-100%). There were 13 (59%) patients classified as a Mason type 1 fracture (radial head n=1, radial neck n=12), 8 (36%) a Mason type 2 (radial head n=8), and 1 (5%) Mason type 3 radial head fracture. According to the AO-OTA classification there were 12 (54.5%) A2.2 fractures, 8 (36.4%) B2.1 fractures, 1 (4.5%) B2.2 fracture, and 1 B2.3 (5%) fracture. There were no fractures associated with a dislocation of the elbow. There were no significant concomitant injuries. No patients had a past medical history of major trauma to the ipsilateral elbow, forearm or wrist. The degree of radial shortening varied ($p=0.036$) with increasing fracture severity (Table 6.1).

Mason Classification	**Median radial shortening mm (range)**	**Median fracture displacement mm (range)**
Type 1 (n=13)	2.0 (2-3)	0 (0-1)
Type 2 (n=8)	2.5 (2-3.5)	2 (2-4)
Type 3 (n=1)	4 (NA)	7 (NA)

Table 6.1: The degree of radial shortening measured on bilateral wrist radiographs, categorized by fracture complexity according to the Mason classification.

Non-operative management was employed in 21 (95%) patients. Operative management was employed in 1 (5%) patient due to substantial comminution and displacement of the radial head, the one Mason type 3 fracture with suspected forearm instability when assessed intra-operatively. This patient underwent acute radial head replacement with no complication.

6.5.1 Short-term outcome

Of the 22 patients diagnosed with ≥2 mm radial shortening suggestive of an Essex-Lopresti type lesion, 21 attended for short-term review (10 radial head, 11 radial neck; 12 Mason type 1, 8 Mason type 2, 1 Mason type 3). The mean age was 49 years (median 50; range, 19-79; SD 17.7) and 16 (76%) were female. At a mean of six months (range, 1.5-12) post injury, the mean MES was excellent at 90 (range, 70-100; SD 11.0), and the median SMFA score was 1.63 with a mean score of 4.79

(range, 0-26.09; SD 7.2). Eighteen patients achieved excellent or good functional results measured on the MES. The mean flexion arc was 136 degrees (range, 90-154; SD, 14.9) and the mean forearm rotation arc was 175 degrees (range, 90-180; SD, 19.7).

Of the three patients who did not achieve excellent or good functional results, all had MESs of 70, with two patients treated non-operatively. One patient had mild elbow stiffness but with a good flexion arc of 144 degrees and a rotation arc of 180 degrees. One patient developed shoulder capsulitis secondary to the injury, delaying recovery. The patient who underwent operative intervention with radial head replacement had a final MES of 70 with notable elbow stiffness.

6.5.2 Long term outcome

There were nine patients (four Mason type 1 neck fracture and five Mason type 2 head fractures) with long-term follow-up data from Chapter 5. The Mason type 3 fracture was not contactable. At a mean of ten years (range, 9.1-10.1) post injury, the mean DASH score was 15.3 (range, 0-67.2) and the mean Oxford Elbow Score was 43 (range, 14-48). Only 67% of patients were satisfied and the median satisfaction was score 10 (range, 3-10). The median time to return to work was 6 weeks (range, 0-36; n=6), with a median time to return to sports 8 weeks (range 1-12; n=5). One (4.5%) patient noted some subjective stiffness and one (4.5%) a feeling of subjective instability. There were 3 (33.3%) patients complaining of some degree of pain with one mild, one moderate and one severe. The overall median pain score was 0 (range, 0-8). No patients underwent further surgery.

6.6 Chapter Discussion

This chapter describes a range of radial shortening suggestive of an Essex-Lopresti lesion following an ipsilateral fracture of the radial head or neck. Due to the small numbers in the series, the degree of radial shortening found on radiographs indicative of an unstable Essex-Lopresti lesion cannot be clearly determined. However, all patients treated as a stable lesion had less than 4 mm of radial shortening. The results in both the short and long-term indicate that stable lesions need no treatment, with satisfactory results attained. For the unstable Essex-Lopresti injuries, the treatment algorithm described by Edwards and Jupiter is commonly used[140].

Edwards and Jupiter classified Essex-Lopresti injuries into three sub-types with an aim to determine treatment[140] (Table 6.2). This data suggests the Essex-Lopresti is a spectrum, with a varying degree of injury to the interosseous membrane and disruption to the distal radio-ulnar joint seen. A number of the injuries presented are probably best described as a ‘type 1a’. This is a proximal radial fracture with minimal comminution or displacement (Mason type 1 and 2) and minimal disruption of the ‘forearm joint’, which may be amenable to primary non-operative intervention.

Type	Description
Type 1	Large displaced radial head fracture fragments with minimal or no comminution.
Type 2	Severe radial head comminution requiring replacement to maintain radial length.
Type 3	Chronic/old injuries with irreducible proximal migration of the radius.

Table 6.2: The Essex-Lopresti injury classification as set out by Edwards and Jupiter in 1988[140].

Although just under a third of all proximal radial fractures are neck fractures (Chapter 3), over half of the patients in this series sustained a radial neck fracture. There are only a small number of cases in the literature where an Essex-Lopresti lesion is associated with a radial neck fracture[116,348]. Rodriguez-Martin et al recently described an Essex-Lopresti injury with a radial neck fracture and interosseous ligament injury but normal wrist radiographs. Malik et al described two cases of an elbow dislocation with ipsilateral radial neck fractures and an associated DRUJ dislocation[349]. One of Malik and colleagues' cases featured an impacted angulated fracture, but the other two of these three patients had displaced fractures. Another distinction is that our patients had longitudinal instability rather than DRUJ dislocation. Together with this data, these cases demonstrate the variation in Essex-Lopresti injuries with radial neck fractures.

The Essex-Lopresti lesion is defined as radio-ulnar instability secondary to disruption of the distal radio-ulnar joint, the interosseous membrane and a fracture of the proximal radius[139]. This leads to proximal migration of the radius and a positive ulnar variance at the wrist, particularly in the presence of comminution or displacement of the proximal radial fracture. Recent studies have examined a potential association between less complex fractures of the proximal radius and the Essex-Lopresti lesion[105,343]. A study examining low energy Mason type 1 radial head fractures with MRI of the forearm revealed partial ruptures of the distal interosseous membrane without disruption to the interosseous ligament[343]. However, they reported that none of their patients had abnormalities on wrist examination or imaging diagnostic of an Essex-Lopresti lesion, which was present in all of these patients. Furthermore, Essex-Lopresti injuries have been described with a minimally displaced partial fractures (Mason type 2) of the proximal radius[105]. This data has found that as fracture complexity increases the degree of radial shortening increases, therefore, the index of suspicion for instability should increase.

As with isolated proximal radial fractures, the most common mechanism of injury was a fall onto an outstretched arm with no association found between mechanism of injury and the degree of radial shortening. The original paper by Essex-Lopresti suggested that the injury was sustained following a 'violent longitudinal compression force in the long axis of the radius', with the mechanism of injury and the force required to cause it the focus of many studies since[139,350]. Essex-Lopresti lesions are often suspected following high-energy falls onto an outstretched hand e.g. a fall from height[114,346]. However, in the literature, a varying degree of force is quoted to be required to disrupt the triangular fibrocartilage complex, the interosseous ligament and fracture the radial head[341,342]. It has been suggested that the wide range of forces quoted could be related to the position of the forearm at the time of injury[351-353]. Irrespective of the mechanism of injury, it is essential to perform a full assessment of the forearm to exclude the presence of an Essex-Lopresti lesion.

Radiographs are the first line investigation and should include a true lateral of the wrist, as well as a posterior-anterior film in neutral rotation, to determine whether there is subluxation or dislocation of the DRUJ[140,344]. Bilateral wrist radiographs enable assessment of the individual's DRUJ index. To determine the integrity of the interosseous membrane and congruency of the DRUJ ultrasound, computerized tomography and MR have been shown to be useful and might be considered in high energy injuries or patients with wrist or forearm tenderness and ecchymosis[117,118,342,344,354,355].

6.6.1 Strengths and limitations

The main strength of this chapter is that it represents an unselected large series of patients with a proximal radial fracture with prospective data collection. The short-term follow-up, with some patients not completing a full year follow-up, is a drawback along with the small numbers.

Despite reporting good inter-observer reliability using plain radiographs for the diagnosis of an Essex-Lopresti lesion, the measurement of displacement is inevitably subject to a degree of intra- and inter-observer variability. At the study centre, MRI is not routinely performed unless instability is suspected. The lack of MRI to confirm the diagnosis could be criticized, however, in some institutions such imaging can be of limited supply and may cause delay in the diagnosis and treatment of the patient.

7 A RETROSPECTIVE ANALYSIS OF RADIAL HEAD FRACTURES: LONG-TERM OUTCOME OF OPERATIVE MANAGEMENT

7.1 Hypothesis and Aims

This work follows on from Chapter 4 that looked at a small number of radial head replacements for Mason type 3 fractures, with an inferior outcome found. From the work in Chapter 3, it is clear that a spectrum of associated injuries occurs with these complex fractures and the aim was to document the outcome following radial head replacement for this spectrum of injuries. The aims for this chapter were to determine the rate and risk factors for removal or revision following radial head replacement for acute complex unstable fractures in the long-term. A further aim was to document the short-term functional outcome following these injuries in a larger number of patients.

The hypothesis was that for acute complex unstable fractures of the radial head, radial head replacement provides a satisfactory outcome in all patients with these injuries.

7.2 Chapter Summary

From a retrospective review of a prospective trauma database, all patients over a 16-year period managed acutely for an unstable complex fracture of the radial head with primary radial head replacement were identified[h]. Of the 119 patients, 105 (88%) met the inclusion criteria with a mean age of 50 years (range, 16–93 years) and 57 (54%) were female. All implants were uncemented monopolar prostheses, of which 86% were metallic and 14% were silastic. The primary short-term outcome measure was the Broberg and Morrey elbow score. The primary long-term outcome measure was failure of the radial head replacement, defined by revision or removal of the prosthesis for any cause.

There were 29 patients (27%) who had undergone revision (n = 3) or removal (n = 26) of the prosthesis at a mean of 7 years (range, 2–18 years) after injury. Independent risk factors for prosthesis removal or revision were silastic implant type and lower age. At a mean of 1.1 years (range, 0.3–5.5 years) after surgery, the mean Broberg and Morrey score was 80 (range, 40–99).

This chapter demonstrated a high rate of removal or revision following radial head replacement for acute unstable complex fractures, with lower age and silastic implants independent risk factors. Younger patients should be counselled regarding the increased risk of requiring further surgery following radial head replacement.

[h] Thank you to Neil Wickramasinghe and Nick Clement for their assistance with the search.

7.3 Chapter Introduction

Unstable fractures of the radial head commonly occur as part of a complex injury pattern, have fragments that are detached and mobile with little or no soft tissue attachments, and are associated with osseous and ligamentous injuries to the elbow or forearm. The primary goal of treatment is to prevent dislocation or subluxation of the elbow and forearm, with restoration of the radiocapitellar contact essential for alignment and stability[69,107]. When these fractures are not associated with elbow or forearm instability, partial or complete radial head excision is an option[170-172,175,176], although in most cases when instability is present, other options include internal fixation[77,158,161,201,268] or prosthetic replacement[182,183,197,198,202,205,206].

Two recent prospective randomized trials have demonstrated superior results for replacement over open reduction and internal fixation (ORIF) for unstable complex fractures[200,205], with several studies finding ORIF to be associated with increased rates of early failure and nonunion, with one study determining that 3 fracture fragments was the cut-off point for progressing to replacement[77,96,166,168]. A variety of replacement designs are available, with comparable short- to mid-term clinical results documented for cemented bipolar implants and loose spacers [182,198,202,210]. However, the frequency of and risk factors associated with further surgery for removal and/or revision after this procedure remain incompletely characterized [217].

7.4 Patients and Methods

7.4.1 Patients and database construction

A retrospective search of a prospective trauma database held at the EOTU was used to identify all skeletally mature patients who were managed acutely with a primary radial head replacement for an unstable complex fracture of the radial head over a 16-year period between September 1994 and September 2010. A total of 119 patients were identified, of which there were 63 females (53%) and 56 males (47%), with a mean age of 50 years (range, 15–93 years; SD, 19 years).

Patients were excluded if there was inadequate demographic, fracture characteristic, management or follow-up data including no further record of follow-up at our institution (n=8), or if they were from outside our local catchment population (n=6). Fourteen patients did not meet the inclusion criteria and were excluded, leaving 105 (88%) patients who were defined as our study cohort for analysis (Figure 7.1). There were no differences between the included and excluded cohorts in terms of age ($p = 0.99$), sex ($p = 0.42$), mechanism of injury ($p = 0.18$), comorbidities ($p = 0.30$), fracture classification ($p = 0.34$), or fracture location ($p = 0.22$).

Medical case notes and the trauma database were retrospectively reviewed to document demographic data including age, gender, mechanism of injury, and medical comorbidities. Diagnosis and associated injuries were recorded through medical record and radiographic review. The details of operative management, complications, and subsequent surgical procedures were recorded.

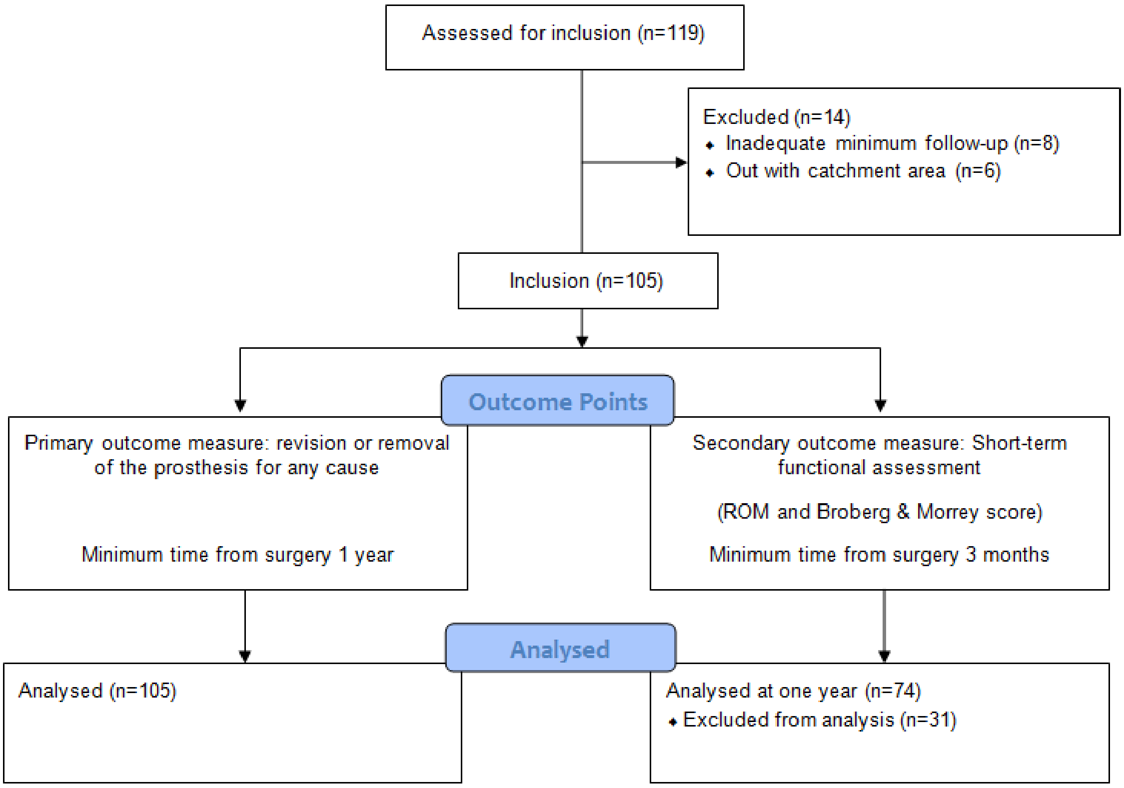

Figure 7.1: A flowchart that demonstrates the patient selection process.

7.4.2 Radiographic classification

Initial radiographs were reviewed where available (n = 66, 63%) to confirm fracture classification and the presence of an associated fracture and/or subluxation/dislocation of the elbow. All fractures were assessed using standard AP and lateral radiographs of the injured elbow and were subsequently classified according to the modified Mason fracture classification system (Section 2.4)[124]. Further imaging was performed at the discretion of the treating surgeon. Associated injuries were defined as those found on radiographic imaging or at the time of surgery requiring repair.

7.4.3 Management protocol

Initial management, surgical technique, and postoperative rehabilitation were determined in all cases by the supervising surgeon, all of whom were experienced consultant orthopaedic trauma surgeons. During the period of study, multiple surgeons were involved in the care of these patients and the absolute indications for surgery did vary. However, the general indications for operative intervention were a confirmed mechanical block to forearm rotation, or severe displacement or comminution of the fracture associated with instability of the elbow or forearm. ORIF was performed when it was felt the fracture could be reconstructed, with replacement otherwise performed. Radial head resection was performed without replacement if the radial head was removed and there was no concern over associated elbow or forearm instability.

Patients were placed in the supine position with the arm supported on a hand table, unless there was an associated olecranon fracture when the patient was routinely placed in the lateral decubitus position with the arm over a bolster. For approaching the radial head, a standard lateral operative exposure of the radial head using the Kocher interval between the extensor carpi ulnaris and anconeus was routinely employed. We often found that the exposure was simplified by mobilizing the lateral collateral ligament (LCL) and extensor digitorum communis, as they had been avulsed from their origins on the lateral epicondyle. Otherwise, care was taken not to damage the lateral ligamentous complex (if not already injured) and to avoid elevation of anconeus. When dissection was required distally down the neck, care was taken to protect the posterior interosseous nerve by pronating the forearm[79]. Inspection of the coronoid was routinely performed.

Radial head fracture fragments were removed and used to determine the size of the radial head prosthesis. The radial neck was prepared and a trial reduction performed to ensure the radiocapitellar joint was not overstuffed. The radial head prosthesis was then inserted. All radial head implants were loose monoblock prostheses, with 90 (86%) smooth metal and 15 (14%) silastic. Two implants were inserted with cement as the prosthesis was not adequately captured by the radial neck and at risk of dislocation.

The LCL generally was either repaired using sutures placed through drill holes in the lateral epicondyle or using suture anchors. The medial collateral ligament (MCL) was not explored unless the elbow was persistently unstable after replacement and repair of the coronoid ± LCL. The coronoid was repaired when it was more than a small avulsion fragment, displaced and/or necessary for elbow stability, with 27 repaired using sutures placed through drill holes in the proximal ulna and 2 fixed with screws. Injuries associated with a proximal ulna fracture underwent ORIF through a posterior midline incision. The ulnar nerve was identified and released when indicated, but was not routinely transposed. For managing terrible triad injuries, as routine we would use the protocol laid out by

Pugh et al[356]. The coronoid was inspected in all cases to ensure there was no occult injury. A thorough examination of the elbow was performed to test for instability in flexion-extension and varus-valgus.

Postoperatively patients were immobilized for a period of 2 to 3 weeks and then active motion exercises were commenced. Postoperative physiotherapy was employed for any residual functional deficit and/or elbow stiffness. It is not routine at the EOTU to remove a radial head prosthesis unless clinically indicated.

7.4.4 Outcome assessment

Short-term outcome

The primary outcome measure in the short-term was functional outcome, with the minimum follow-up time from surgery three months. All patients underwent short-term follow-up assessment at the EOTU, which is the solitary provider of orthopaedic trauma care in the region. Patients were evaluated in the short-term according to the system of Broberg and Morrey (Section 2.5)[124,170], with a minimum of three months follow-up included (n = 74).

Long-term outcome

The primary outcome measure in the long-term for patients undergoing radial head replacement was revision or removal of the radial head prosthesis for any cause. All patients needed to be registered at our institution for ongoing medical care with other specialties at the time of the study, or have been reviewed within the past year at our institution. The minimum time from surgery was one year. To determine whether the patient had undergone revision of removal of the prosthesis, the last medical record entry was used. Details of subsequent complications and the requirement for secondary intervention were recorded when encountered. If no further intervention was documented the follow-up point was taken as the time of medical note review.

7.4.5 Statistical analysis

A Student's unpaired t-test was employed to analyse parametric continuous data. The Mann-Whitney U test used to compare nonparametric continuous data. A one-way ANOVA was used to compare parametric continuous data among several categories, with the Kruskal-Wallis test being used for nonparametric data. Categorical binary data were analysed using either the chi-square test (all observed frequencies in each cell > 5) or the Fisher's exact test (one cell had an observed frequency of ≤ 5).

Cox regression analysis was used to determine independent factors associated with revision or removal of the prosthesis when controlling for baseline patient (age, gender, comorbidities) and fracture (fracture location, fracture classification, associated injury) characteristics. Two-tailed p values were reported and statistical significance was set at p values of less than 0.05, with 95% CIs presented.

7.5 Results

Of the 105 patients who fit the inclusion criteria, there were 57 females (54%) and 48 males (46%), with a mean age of 50 years (range, 16–93 years; SD, 19 years). The mean age at the time of injury was higher ($p < 0.001$) in females (57 years; range, 16–93 years; SD, 18 years) than in males (40 years; range, 18–81 years; SD, 16 years). One or more comorbidities were documented in 52 patients (50%).

The most frequent mechanism of injury was a fall from standing height (n = 57, 54%), followed by a fall from height (n = 26, 25%), motor vehicle collision (n = 11, 10.5%), assault (n = 4, 3.8%), sports (n = 4, 3.8%), and other (n = 3, 2.9%). Females most commonly sustained their fractures after a fall from standing height, while most commonly males sustained high-energy injuries, eg, fall from height or motor vehicle collision ($p < 0.001$).

There were 95 (91%) radial head fractures and 10 (9%) radial neck fractures. Four patients (3.8%) had fractures classified as Mason Type 2 (radial head: n = 4; radial neck: n = 0), 88 (84%) Mason Type 3 (radial head: n = 78; radial neck: n = 10), and 13 (12.4%) Mason Type 4 (radial head: n = 13; radial neck: n = 0). There were 98 associated injuries (Figure 7.2) documented in 70 patients (66%). There were 26 patients with an associated elbow dislocation, with 18 of these a terrible triad type injury and 2 having an associated fracture of the proximal ulna. There were 24 patients with an associated fracture of the proximal ulna (excluding coronoid). There were nine patients with an isolated fracture of the coronoid, with two associated with a fracture of the proximal ulna. Three patients had an Essex-

Lopresti type injury. The median time to surgery after injury was 3 days (range, 0–20 days).

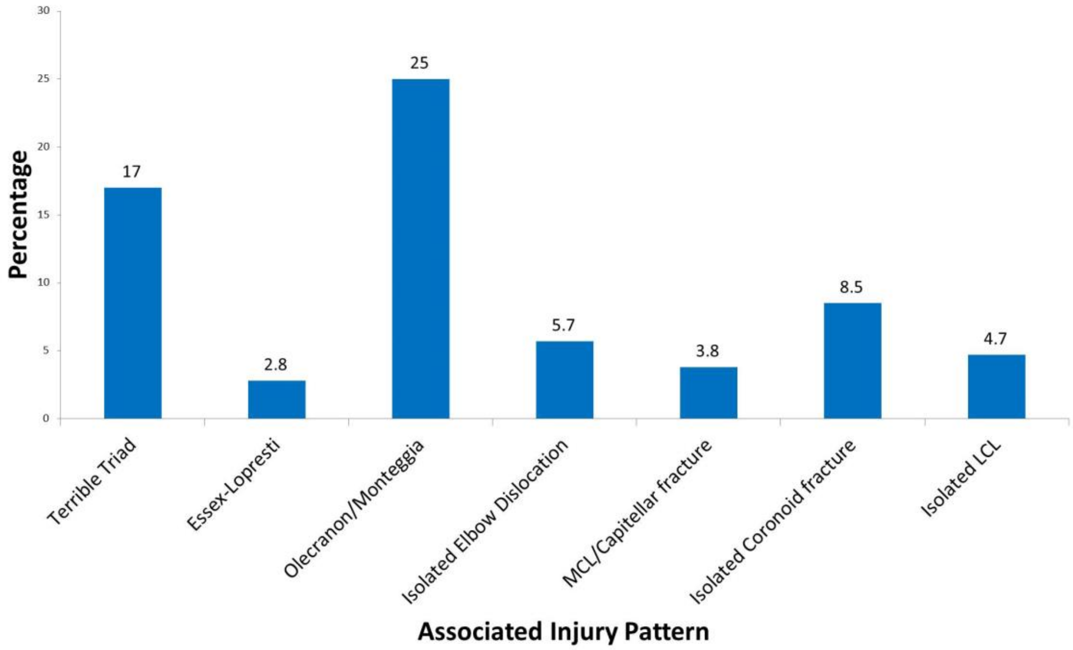

Figure 7.2: A graph that details the associated injury patterns.

7.5.1 Short-term outcome

At a mean short-term follow-up of 1.1 years (range, 0.3–5.5; SD, 1) after surgery, the mean Broberg and Morrey score was 80 (range, 40–99; SD, 12), with 43 of 74 patients (58%) achieving an excellent (n = 4) or good (n = 39) outcome. However, 26 patients had a fair outcome and five a poor outcome. The mean elbow flexion was 133 degrees (range, 90–159; SD, 13), the mean extension was 21 degrees (range, 0–80; SD, 17), and the mean flexion arc was 112 degrees (range, 10–140; SD, 25).

The mean pronation was 84 degrees (range, 0–90; SD, 18), the mean supination was 73 degrees (range, 0–90; SD, 28), and the mean forearm rotation arc was 156 degrees (range, 0–180; SD, 38).

7.5.2 Long-term outcome

By a mean of 6.7 years after injury (range, 1.8–18 years; SD, 3.9 years), 29 patients (27%) had undergone revision (n = 3) or removal (n = 26) of the prosthesis. The median time to secondary surgery was 7 months (range, 0–65 months). Within the first year post surgery, 21 patients (20%) had undergone revision (n = 3) or removal (n = 18) of the prosthesis. The three revisions were for persistent subluxation of the radial head, which was corrected through exchange of the prosthesis. The most common reason for removal was persistent stiffness with or without pain (n = 12, 41%), followed by prosthetic loosening (n = 5, 17%) (Table 7.1). Five patients underwent arthrolysis for persistent stiffness. Two patients underwent ulnar nerve decompression and transposition for persistent ulnar neuritis.

Reason for revision or removal of the prosthesis	**N of 105 (%)**
Stiffness +/- pain	12 (11.4)
Painful loosening	5 (4.8)
Pain alone	4 (3.8)
Radial head subluxation	3 (2.9)
Synovitis	2 (1.9)
Ulnar neuritis	2 (1.9)
Deep infection	1 (1.0)

Table 7.1: Reason for revision or removal of the radial head prosthesis in 29 patients.

7.5.3 Predictors of long-term outcome

On Cox regression analysis independent predictors of revision or removal of the implant were silastic implant type (p = 0.004) and lower age (p = 0.002) after adjusting for confounding variables. Silastic implants had a higher removal rate (60% versus 22%) than metallic implants (odds ratio, 5.25; 95% CI, 1.67–16.52; p = 0.002). The mean age of patients undergoing further surgery (45 years; range, 16–81 years; SD, 19.1 years) was lower than that of patients who did not undergo further surgery (52 years; range, 17–93 years; SD, 18.9 years; p = 0.10).

On sub-analysis of the metallic implants alone (n = 90), when controlling for other factors using Cox regression analysis, lower age (p = 0.001) and the absence of pre-existing comorbidities (p = 0.014) were independent predictors of removal or revision. The mean age of patients undergoing further surgery (45 years; range, 18–69 years; SD, 17) was lower than that of patients who did not undergo further surgery (52 years; range, 17–93 years; SD, 19 years; p = 0.11).

7.6 Chapter Discussion

This is the largest series in the literature reporting the outcome following radial head replacement for complex fractures of the radial head. For the majority of complex radial head fractures, restoration of radiocapitellar contact is essential and the choice is between radial head fixation[77,158,161,166,201,267,268] and replacement[182,183,197,198,202], with recent data from prospective randomized trials suggesting replacement is superior[200,205]. There is good short- and mid-term data supporting metal and pyrocarbon prostheses[182,183,198,201,202,206,207]; however, the reoperation rates after radial head replacement are largely unknown. This chapter demonstrated a high rate of removal or revision for both metallic and silastic implants, with silastic implants and younger patients being at the greatest risk of requiring further surgery for revision or removal. This data provides useful prognostic information for both the patient and the surgeon managing these complex injuries.

The data presented here supports the findings of Chapter 3 and other literature that complex fractures of the radial head (Mason type 3) are routinely associated with a bony and/or ligamentous injury of the elbow or forearm[69,105,116], with accurate diagnosis and management essential in providing an optimal outcome. Authors have proposed injury patterns that may aid in the diagnosis[94,136], all of which were found in this chapter. These include: 1) radial head fracture + posterior dislocation of the elbow; 2) the terrible triad injury; 3) radial head fracture + MCL rupture +/- capitellar fracture; 4) Essex-Lopresti lesion and variants; and 5) proximal ulna fracture + radial head fracture. For the rare scenario when a complex radial head fracture is not associated with potential instability of the elbow or forearm, radial head excision can produce satisfactory results[169-172,175-177]. However, the potential complications associated with radial head excision in the presence of instability are valgus or posterolateral instability, ulnohumeral arthrosis and radial shortening associated with symptomatic distal radial ulna joint dysfunction[47,49,50,53,71].

This work has found a high rate of revision or removal for radial head prostheses used in the management of acute complex fractures of the radial head, although the rate in the literature is both wide-ranging (0-32%) and unclear[180,182,198,210]. The overall rate of 28%, with a rate of 22% for metal prostheses, is in keeping with Doornberg et al who reported a rate of 32% at a mean of 40 months post-surgery using a modular metal spacer[198]. Harrington et al reported a removal rate of 20% at a mean of 12 years following metal radial head replacement for unstable elbow fractures, with removal having no correlation to outcome[180]. The exact cause for the variable rates in the literature is unclear, but would suggest this is likely multi-factorial with important factors including surgeon preference, patient and injury characteristics, the type of prostheses used, and most importantly the length of follow-up. The most common cause for revision or removal of the prosthesis was persistent stiffness, followed by unexplained pain and prosthetic loosening, which is consistent with other studies[217,218,357]. Persistent pain can be associated with radiographic loosening[217,224], although as with others this study found this to affect a small number of patients when the prostheses are intentionally loose[198,225]. Other noted complications associated with removal of the prosthesis include neuritis, deep infection, or persistent instability (subluxation/dislocation), which were all observed in this series[180,182,185,198,209].

The reported short-term outcome scores and range of motion from this data are similar to previous studies[180,182,198,210], with an overall satisfactory outcome reported following the use of a loose metallic radial head spacer. Grewal et al reported mean elbow flexion at 138 degrees and elbow extension at 25 degrees at two years post injury, with a large majority of this recovery occurring within the first 6 months following injury[182]. This study found that almost half of the patients in our series had a poor or fair short-term outcome, which is probably related to the short follow-up and the overall severity of these injuries[217]. Harrington et al found that 80% of patients had attained an excellent or good outcome at a mean of 12 years following injury. This would suggest that patients can expect ongoing improvement even several years following their injury.

7.6.1 Predictors of outcome

This is the first data to identify independent factors associated with prosthesis revision or removal. One study has reported that a delay in surgery after injury (> 1 week) was associated with a reduced ROM and associated complications[217]. Interestingly, this data found that younger patients were more likely to require further surgery for removal or revision. This would suggest that the threshold for progressing to implant removal and further surgery for stiffness is likely reduced in younger patients with higher functional demands. Younger patients should be counselled regarding the increased risk of further surgery being required. Silicone was the first radial head prosthetic replacement to be marketed but has since been found to be associated with fragmentation and destructive synovitis[189-192,194-196]. These studies are consistent with the findings from this chapter that demonstrated silicone implants were associated with an increased rate of complications leading to an increased rate of removal or revision.

7.6.2 Strengths and limitations

The primary strength of this chapter is that it includes a large cohort of patients undergoing acute replacement for a complex fracture of the radial head, in contrast to other studies that include a heterogeneous cohort of acute and chronic radial head replacements and a range of differing implant types[217]. It has reported the mid- to long-term follow-up from a defined population, with only one centre providing an acute musculoskeletal trauma service for the region.

Undoubtedly, the primary limitation of this chapter is the retrospective design, along with the variable follow-up times of patients over both the short and longer terms that can lead to over and under-estimating the benefits of replacement. Specific problems with the retrospective design include multiple surgeons for both the management and post-operative assessment of the patient that can lead to selection and assessor bias, varying technical standards of the surgery that may affect outcome, along with an evolving management protocol over time. The subjective nature of prosthesis removal is noted and it could be argued that these findings are most applicable to the EOTU, although this data does provide valuable prognostic information for all surgeons managing these injuries. The association with silicone implants could be affected by bias as some may have been removed due to a fear of developing synovitis, although this did not appear to be obviously the case on retrospective review of the notes. This certainly was not found for metallic implants and a high rate of removal or revision was reported for both types of implant.

It is acknowledged that some would argue that using no further intervention as the primary outcome measure is limited, as patients may have attended another hospital for treatment. However, the EOTU is the only orthopaedic trauma service for the local population, patients were still registered and/or undergone recent review for other medical complaints at the time of retrospective note review, with all patients from out with the catchment area excluded. Although a minimum of three months is short for functional follow-up, it is acknowledged this is short-term data and literature has suggested that most patients regain the majority of their function within three to six months following injury[358]. The type and number of associated injuries is difficult to determine accurately using retrospective review, as this is dependent on the treating surgeon clearly documenting the presence and management, especially in the absence of the original imaging. The number of radiographs available was satisfactory, given the regional policy of culling hard-copy radiographs older than 5 years when the patient is not under regular clinical assessment. The frequency of associated injuries was probably underestimated from this series, given the strict definition for classifying associated injuries and the lack of further imaging in all patients.

8 A RETROSPECTIVE ANALYSIS OF OLECRANON FRACTURES: LONG-TERM OUTCOME OF OPERATIVE MANAGEMENT

8.1 Hypothesis and Aims

The aims for this chapter were to document both the short and long-term outcome following primary operative management of isolated displaced fractures of the olecranon, along with defining the predictors of long-term outcome.

The hypothesis for this chapter was that the operative fixation of isolated stable olecranon fracture has a notable complication rate and potentially inferior outcome in older patients.

8.2 Chapter Summary

A retrospective search of a prospective trauma database identified all patients who were managed operatively for an isolated displaced fracture of the olecranon over a 1-year period. Inclusion criteria included all isolated fractures of the olecranon with >2 mm displacement of the articular surface. Comminuted fractures were included. Demographic data, fracture classification, management, complications and subsequent surgeries were collected and analysed. The primary short-term outcome measure was the Broberg and Morrey elbow score. The primary long-term outcome measure was the DASH.

There were 36 patients in the study cohort with a mean age of 56yrs (range, 16-97yrs). Thirty-four patients were managed with TBW fixation. At a mean of five months (range, 1-15) following injury the mean Broberg and Morrey score was 81 (range, 46-100; n=32). The rate for removal of symptomatic metalwork was 47%. Long-term follow-up was available in 18 of 25 patients (72%). At a mean of seven years (range, 6.9-7.8) post injury, the mean DASH score was 2.5 (range, 0-13.3), the mean Oxford Elbow Score was 47 (range, 44-48) and overall patient satisfaction was 100%.

This chapter has found satisfactory short-term and long-term outcomes following the operative management of isolated displaced olecranon fractures. However, given the high rate of metalwork removal with TBW fixation, further work is needed to define the role of plate fixation in younger patients, as this may be associated with a reduced metalwork removal rate and a superior outcome.

8.3 Chapter Introduction

The surgical management of isolated displaced olecranon fractures involves anatomical restoration of the articular surface, with the aim to restore function and encounter minimal associated complications[9,230]. Tension-band wiring (TBW) is the most recognized and frequently used fixation method for stable displaced fractures of the olecranon[14], although plate fixation[246], intramedullary screw or nail fixation[251] and suture fixation[359] are advocated by some.

There is limited data in the literature documenting both the short and long-term outcome following the operative management of isolated displaced fractures of the olecranon[7,14,18,360,361], as well as limited data regarding the risks factors for a poorer outcome following operative management of these injuries. These are noted to include fracture morphology and associated elbow instability or fractures around the elbow[7,231].

The vast majority of series include a heterogeneous group of patients and report high re-operation and metalwork removal rates from centres where metalwork removal is routine. The highest re-operation rate quoted in the literature is 85% from the five year retrospective analysis by Macko and Szabo[18].

8.4 Patients and Methods

8.4.1 Patients and database construction

A prospective database of all inpatient and outpatient fractures presenting over a one-year period (Section 2.1.1 and Chapter 3) was used to identify all patients aged 16 years or older who sustained an isolated displaced fracture of the olecranon, the Mayo type 2 fracture[49], that was managed with primary operative intervention using either TBW of plate fixation. The generally accepted criterion of >2mm of articular displacement on standard radiographs was used as the criteria for operative intervention within the study centre[9,226]. Patients who refused primary surgical intervention within the first two weeks following injury were excluded. Patients were also excluded if they had sustained an undisplaced fracture, a concomitant fracture around the ipsilateral elbow, a fracture dislocation of the elbow, an open fracture, or had undergone primary non-operative intervention. Based on these criteria 41 patients were identified over a one year period from July 2007 to June 2008. There were 24 (58.5%) females and 17 males (41.5%) with a mean age of 56yrs (range, 16-97yrs, SD 23).

Of the original 41 patients identified, five patients were excluded, leaving 36 (88%) patients that made up the study cohort for analysis (Figure 8.1). Of the 5 patients excluded, four were due to inadequate follow-up and one was a patient who died during their original admission. There was no difference between the included and excluded groups in terms of age (p=0.784), gender (p=0.633), mechanism of injury (p=0.704) or co-morbidities (p=0.663).

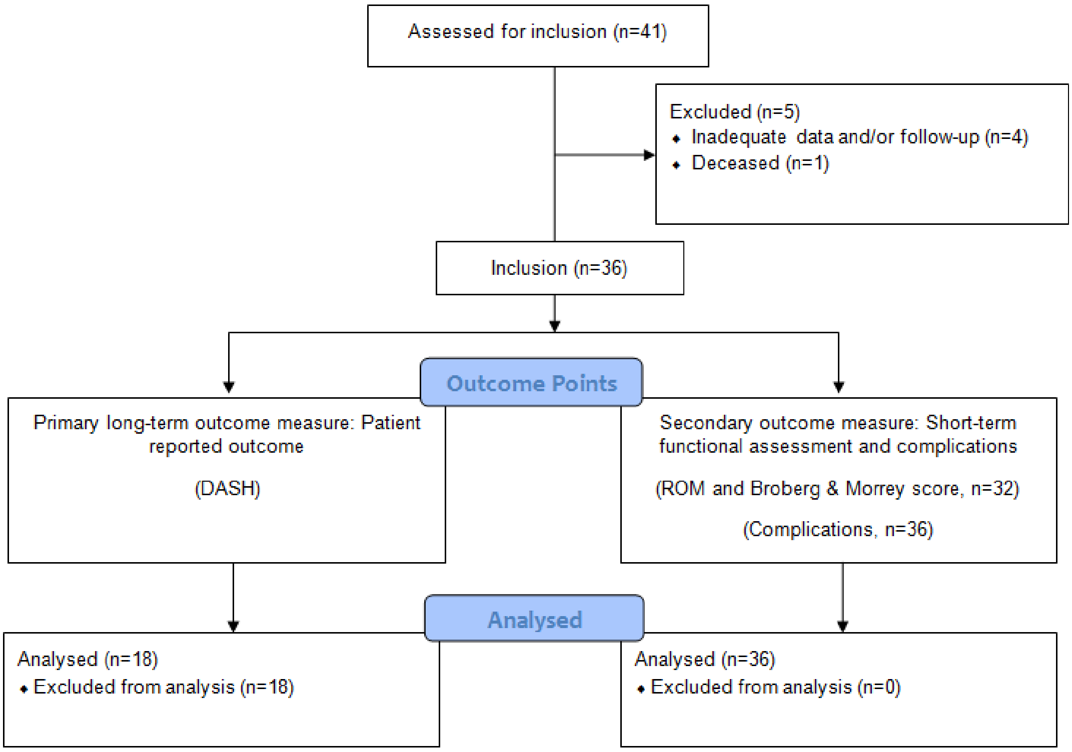

Figure 8.1: A flowchart that demonstrates the patient selection process.

Clinical records and the prospective trauma database were retrospectively reviewed to record demographic data including age, gender, side affected, mechanism of injury and all chronic medical co-morbidities. Management, duration of treatment, the use of physiotherapy, complications and subsequent surgical procedures were recorded.

8.4.2 Radiographic classification

Initial AP and lateral elbow radiographs were all reviewed as part of Chapter 3. These were used to confirm fracture displacement, comminution, classification, and the absence of an associated fracture and/or subluxation/dislocation of the elbow (Section 2.4).

8.4.3 Management protocol

Initial management, the surgical technique employed and postoperative rehabilitation were all determined by the supervising surgeon, all of whom were experienced consultant orthopaedic trauma surgeons. Details of the standard surgical technique and post-operative protocol are found in Section 9.4.3. It is not routine at the EOTU to remove metalwork following olecranon fracture fixation unless symptomatic.

8.4.4 Outcome assessment

Short-term outcome

Patients underwent short-term follow-up at the EOTU. The routine policy is to keep patients under review until the patient had regained satisfactory function and are symptom free. Details of complications and subsequent surgeries were recorded at each visit. Complications were defined as loss of fracture reduction (>2mm articular surface re-displacement), prominent and symptomatic metalwork, further surgery including removal of metalwork, superficial or deep wound infections and new onset of neurological symptoms or signs following treatment.

All follow-up radiographs (AP and lateral of elbow) were reviewed to confirm fracture union and metalwork complications including prominence and loss of reduction. Immediate post-operative radiographs were only available in 30 (83%) patients. The quality of the initial reduction (initial post-operative radiographs), metalwork failure and loss of reduction (>2mm articular surface re-displacement) were assessed. The quality of reduction was determined as satisfactory if the articular surface was reduced to within 2mm, which was adapted from the trial by Hume and Wiss[20].

Patients were evaluated in the short-term according to the system of Broberg and Morrey[124,170], which was the primary short-term outcome measure (Section 2.5). There were six patients who did not have sufficient information to complete a Broberg and Morrey score but were included in the analysis for the purpose of assessing complications.

Long-term outcome

Long-term follow-up was carried out through telephone and questionnaire review. There were 50% (n=18/36) of patients who provided long-term follow-up. Seven patients either did not respond or declined (n=7), with the remainder either deceased (n=7), demented (n=1), or had moved out with the local catchment with no details available (n=3), Two PROMs validated to assess patients following an elbow injury or surgery were used – the Oxford Elbow Score (OES)[292] and the Disabilities of Arm, Shoulder and Hand (DASH)[275] (Section 2.5).

Patients were asked to confirm if they had undergone further surgery for a persistent problem associated with their initial injury and/or surgery. This included subsequent removal of metalwork, which is not performed as routine at the study centre. Beside the patient reported OES, other secondary outcome measures included subjective pain, stiffness, instability and satisfaction (Section 2.5.4). All patients were asked at what stage post injury they returned to work and sports.

8.4.5 Statistical analysis

Age was normally distributed. Flexion arc, forearm rotation, the Broberg and Morrey score, the OES and the DASH score had a skewed distribution. A Student's unpaired t-test was employed to analyse parametric continuous data, with the Mann-Whitney U-test for non-parametric continuous data. Categorical binary data were analysed using either the chi-square test were the all the observed frequencies in each cell were greater than 5, with the Fisher's exact test used when one cell had an observed frequency of ≤ 5. The Spearman correlation was used to analyse the correlation between two continuous variables (e.g. age versus DASH).

8.5 Results

There were 36 patients in the cohort with a mean age of 56yrs (range, 16-97yrs; SD 23.8). There were 22 females (61.1%) and 14 males (38.9%; Table 8.1).

	Male N (%)	**Female** N (%)	**p value**
Total	14 (38.9)	22 (61.1)	0.182*
Mean age (range, SD, 95% CI)	41 (16-75, 21, 30-53)	65 (23-97, 21, 56-75)	**0.002[a]**
MOI			
Fall from standing height	7 (50)	16 (72.7)	
Fall from height	3 (21.4)	2 (9.1)	0.601*
RTA	2 (14.3)	1 (4.5)	
Sport	1 (7.1)	2 (9.1)	
Direct blow	1 (7.1)	1 (4.5)	
ASA Grade			
1	11 (78.6)	6 (27.3)	
2	2 (14.3)	10 (45.5)	**0.011***
3	1 (7.1)	6 (27.3)	
Short-term outcome	(range, SD, 95% CI) (n=12)	(range, SD, 95% CI) (n=20)	
Mean Flexion arc	114 (70-140, 22, 100-128)	113 (40-140, 28, 100-125)	0.893[b]
Mean Rotation arc	178 (160-180, 5.8, 175-182)	179 (160-180, 4.5, 177-181)	0.893[b]
Mean Broberg & Morrey	77 (52-93, 15, 67-86)	84 (46-100, 12, 78-89)	0.289[b]
Long-term outcome	(range, SD, 95% CI) (n=9)	(range, SD, 95% CI) (n=9)	
Mean OES	47 (44-48, 1.5, 48-48)	48 (47-48, 0.44, 47-48)	0.161[b]
Mean DASH	1.8 (0-13.3, 4.3, -1.5-5.2)	3.1 (0-10.8, 3.8, 0.20-6.0)	0.258[b]

Table 8.1: Patient demographics and outcome. ([a]Student's t-test, [b]Mann-Whitney test, * Chi-squared)

The mean age of females was 65yrs (23-97yrs, SD 21), which was significantly older (p=0.002) from the mean age of males (41yrs, 16-75yrs, SD 21) at the time of injury. The left side was affected in 25 (69.4%) cases. One or more co-morbidities were documented in 52.8% (n=19) of patients and a majority of patients were an ASA grade 1 (n=17, 47.2%) or grade 2 (n=12, 33.3%). The most frequent mechanism of injury was a fall from standing height (n=23, 63.9%), followed by a fall from height (n=5, 13.9%), motor vehicle collision (n=3, 8.3%), sports (n=3, 8.3%) and a direct blow (n=2, 5.6%).

There were 34 (94.4%) Mayo type 2A fractures that were all managed with TBW, and two (5.6%) were a Mayo type 2B that were both managed with plate fixation. Three patients (8.3%) had concomitant injuries including one ipsilateral proximal humeral fracture, one ipsilateral patella fracture, and one patient with bilateral distal radius fractures.

8.5.1 Short-term outcome

At a mean of 5 months (range, 1-15) following injury the mean Broberg and Morrey score was 81 (range, 46-100; SD 13.3), with 72% achieving an excellent (n=2) or good (n=21) outcome. Five patients had a fair outcome, with 4 poor. The mean elbow flexion was 127 degrees (range, 100-150; SD 13.7), the mean extension was 14 degrees (range, 0-80; SD 17.8) and the mean flexion arc was 113 degrees (range, 40-140; SD 25.4). The mean pronation was 89 degrees (range, 80-90; SD 2.5), the mean supination was 89 degrees (range, 80-90; SD 2.5) and the mean forearm rotation was 179 degrees (range, 160-180; SD 4.9).

Complications were assessed in 36 patients. Initial fracture reduction was deemed satisfactory in 27/30 (90%) patients. There were 26 complications reported in 19 (52.8%) patients and included removal of symptomatic metalwork (n=17, 47.2%), loss of fracture reduction (n=6, 16.7%; Figure 8.2), infection (n=2, 5.6%) and the need for revision surgery (n=1, 2.7%). Sixteen (44.4%) patients underwent further surgery within the first year following injury, with removal of metalwork the most common reason. Three (8.3%) of the patients who lost reduction developed a functional fibrous non-union with no further intervention required.

Figure 8.2: Loss of fracture reduction in an elderly patient that went onto a fibrous non-union.

The two (5.6%) patients who developed an infection were managed successfully with short-term antibiotics and removal of metalwork, with one of these patients also requiring a debridement at the time of surgery. One young patient required revision from TBW to plate fixation following an early loss of reduction, with subsequent removal of metalwork once the fracture had united.

8.5.2 Long-term outcome

There were 50% (n=18/36) of patients who provided long-term follow-up. The mean age was 55yrs (range, 16-80yrs; SD 21) with nine females and nine males. At a mean of seven years (range, 7-8) following injury, the mean DASH score was 2.5 (range, 0-13.3; SD 4.0) and the mean Oxford Elbow Score was 47 (range, 44-48; SD 1.2). All (100%) of patients were satisfied and the median satisfaction score was 10 (range, 8-10). The median time to return to work was 6 weeks (range, 1-26; n=11), with two patients not returning to employment following their injury. The median time to return to sports was 8 weeks (range 4-78; n=12), with one patient not returning to any level of sport.

Three (17%) patients noted some subjective stiffness, but none a feeling of subjective instability. There were 4 (22%) patients complaining of some degree of pain with all these patients rating this as mild. The overall median pain score was 0 (range, 0-2). One patient underwent two further surgeries (EUA and subsequent arthrolysis) over a year following their original surgery due to ongoing stiffness.

8.5.3 Predictors of long-term outcome

Gender (p=0.258), mechanism of injury (p=0.338), past medical history (p=0.222), ASA grade (p=0.073), associated injuries (p=0.732) and fracture union (p=0.556) were not predictive of long-term outcome according to the DASH score. Age (p=0.05, correlation coefficient 0.467) was approaching significance, with increasing age associated with a poorer outcome according to the DASH.

8.6 Chapter Discussion

This chapter has documented both the short and long-term outcome of a series patients managed with primary operative intervention for an isolated displaced fracture of the olecranon. These findings demonstrate that operative management of displaced olecranon fractures with TBW fixation yields good or excellent long-term outcomes in the vast majority of patients, with patient satisfaction high. However, the rate of symptomatic metalwork removal is high and given the lower documented rate with plate fixation in the literature, further work is warranted to directly compare TBW and plate fixation for isolated displaced fractures of the olecranon.

There is short and long-term data reporting good functional outcomes following TBW fixation[7,14,18,360,361], which is consistent with the findings of this chapter. Flinterman et al reported the long-term patient reported outcome in 41 patients (TBW in 37, plate in three, screws alone in one) with a mean age of 35 years who sustained a simple transverse displaced fracture of the olecranon[362]. At a mean of 20 years following surgery the mean DASH score was 10, the mean MES was 98 and the mean elbow flexion arc was 142 degrees.

A symptomatic metalwork removal rate of 47% and a loss of fracture reduction rate of 14% are consistent with the existing literature. Karlsson et al reviewed 61 patients who were managed with either a figure-of-eight-wire or TBW at a mean of 19 years and reported a removal of metalwork rate of 48% and joint incongruity of 33%[13]. The higher rate of loss of reduction in this series is probably related to the differing techniques used. Villanueva et al reviewed 37 patients all managed with TBW fixation at a mean follow-up of 4 years and reported a mean DASH of 18.1 and an overall implant removal rate of 46%[231].

Other complications associated with TBW fixation in the literature are wound breakdown, infection, malunion and non-union[7,9,14,18-20,236]. The non-union and infection rate from this series is consistent with data from Chalidis et al who reviewed the long-term outcome in 62 patients who underwent TBW fixation at a mean follow-up of 8 and reported a wound infection rate of 6.5% and a non-union rate of 3.2%[14]. However, these patients required re-intervention, whereas all the non-unions in the data presented here were fibrous and did not require further surgery.

Some authors advocate plate fixation as an alternative to TBW fixation for simple isolated fractures of the olecranon, despite the limited available data. Although a perceived complication of plate fixation is prominent metalwork given the position of the plate on the dorsal ulna, the literature would suggest the rates of removal are lower than TBW fixation ranging from 5-20%, and the functional outcome is reported to be comparable to TBW[9,20,21]. Bailey et al reviewed 25 patients at an average of 34 months who underwent plate fixation for displaced fractures of the olecranon and reported patient satisfaction of 9.7/10 and the mean DASH score was 10[21]. The symptomatic prominent metalwork removal rate was 20% in this series, although two of these patients had concomitant TBW.

8.6.1 Predictors of outcome

In the previous study discussed by Flinterman et al, the only long-term predictor of the DASH was increasing age at the time of surgery[362], which is consistent with the findings of this study. This study reported a lower mean age than in this chapter – 35 years vs 56 years. However, the association between age and outcome has already been found with radial head fractures in both the short (Chapter 4) and long-term (Chapter 5) and is to be expected given the inevitable decline in function detected in the available patient reported outcome scores used for the upper limb[320,322]. Given the association between increasing age and a poorer long-term outcome, as well as the high rate of further surgery required to remove metalwork, work is needed to determine whether operative fixation is needed in older lower demand patients to provide a satisfactory outcome.

8.6.2 Strengths and limitations

The main strength of this study is that it documents both the short and long-term from a defined population with only one centre providing an acute musculoskeletal trauma service. Validated upper limb patient reported outcome measures have been used and the reported rates of metalwork removal are from a centre where this is not performed as routine.

Undoubtedly, a major limitation of this series is the retrospective nature of the follow-up and the inevitable losses associated with this. However, a majority of patients that could not be reviewed in the long-term were deceased or demented, which is a consequence of the number of elderly patients who sustain olecranon fractures. Defining the short-term outcome retrospectively is prone to bias and there are potential inaccuracies with defining complications such as infection, although we have used clearly defined criteria to document these complications. Although multiple surgeons were involved in the care of these patients, the investigation and management protocol has long been defined at the EOTU.

Although important data on the predictors of long-term outcome was presented, given the small sample size and under powering of this case series, no firm conclusions can be made from this data and further work is obviously required.

9 PROSPECTIVE RANDOMISED CONTROLLED TRIAL OF PLATE FIXATION VERSUS TENSION BAND WIRE FOR OLECRANON FRACTURES

9.1 Hypothesis and Aims

The aims for this chapter were to determine if any difference exists in the primary outcome measure (DASH) after one year between tension band wire (TBW) and plate fixation for an isolated displaced fracture of the olecranon. The secondary aims were to determine if there was any difference between the two groups with regards to the secondary outcome measures including range of motion, rate of complications, pain, cost and surgeon reported outcome measures.

The null hypothesis was that there is no difference in functional outcome, as measured by the Disability Arm Shoulder and Hand (DASH) score at one-year post injury, between TBW and plate fixation for an isolated displaced fracture of the olecranon in patients under 75yrs of age (<75yrs).

9.2 Chapter Summary

A registered prospective randomized, single blind, single centre trial in 67 patients aged between sixteen and seventy-four years with an acute isolated displaced fracture of the olecranon was undertaken. Patients were randomised to either TBW (n=34) or plate fixation (n=33). The primary outcome measure was the Disability Arm Shoulder and Hand (DASH) score at one year post injury. Secondary outcome measures included surgeon reported outcome measures, return to work and sports, complications and cost.

The baseline demographic and fracture characteristics of the two groups were comparable. There was a significant improvement in elbow function over the 12 months following injury in both groups (p<0.001). At one year following surgery the DASH score for the TBW group was not statistically different to the plate fixation group (13.5 vs 8.5; p=0.252). Complication rates were significantly higher in the TBW group (63.3% vs 37.5%; p=0.042), predominantly due to a significantly higher rate of symptomatic metalwork removal (50.0% vs 21.9%; p=0.021). Loss of reduction following surgery was more common in the TBW arm (26.7% vs 12.5%, p=0.206). All four infections occurred in the plate group (0% vs 12.5%; p=0.114), as did all three of the revision surgeries (0% vs 9.4%; p=0.238). Although plates are more expensive than TBW, overall costs were comparable due to the higher rate of metalwork removal (p=0.131).

In active patients with an isolated stable displaced fracture of the olecranon, TBW and plate fixation provide comparable patient reported outcomes in the short-term. The complication rate is higher following TBW fixation due to a higher rate of symptomatic metalwork removal.

9.3 Chapter Introduction

TBW is the most commonly employed technique for isolated displaced stable fractures of the olecranon. For the comminuted, unstable, distal and/or oblique fractures, plate fixation is promoted as providing superior fracture reduction and fixation results[9,12,20,21,228,230,232-234]. Despite advocates for alternative surgical techniques including plate, intramedullary nail[251] and suture fixation[359], TBW remains the standard management of Mayo type 2A olecranon fractures[14].

There have been recent retrospective comparative reports of TBW and plate fixation for both simple and comminuted displaced fractures of the olecranon[363-365], which are consistent with the findings reported in Chapter 8. These studies have consistently reported comparable functional outcomes, a higher rate of metalwork removal for TBW fixation, and increased costs with plate fixation. It remains unclear, however, whether the increased metalwork removal rate with TBW could off-set the cost of plate fixation.

A recent Cochrane meta-analysis was performed regarding the surgical management of 244 olecranon fractures from six randomised controlled trials[366]. Of the six trials included, four were PRCTs and two were quasi-RCTs. Only one directly compared plate and TBW fixation and this study was performed in 1992 and reported comparable functional results at six months following injury, but with a higher rate of symptomatic metalwork and complications following TBW[20]. The authors of this Cochrane review concluded that further work is essential to determine the optimal surgical management of simple isolated fractures of the olecranon.

9.4 Patients and Methods

9.4.1 Patients and database construction

This was a registered single centre prospective, randomized controlled trial of adult patients with an isolated displaced fracture of the olecranon (ClincalTrials.gov ID NCT01391936). The study centre is a large academic urban trauma centre. The primary outcome measure was the Disability Arm Shoulder and Hand (DASH) score at one year post injury[367,368]. The appropriate ethical and clinical trial committees authorised the study.

Between October 2010 and October 2014, 67 patients between 16-74 years of age with an acute (within two weeks of injury) isolated displaced fracture of the olecranon were recruited into the study (Figure 9.1). The inclusion and exclusion criteria are described in Table 9.1. Displacement of >2mm of the articular surface on standard radiographs was used as the definition of displacement[9,226]. Mayo type 2A fractures were included.

Inclusion criteria	**Exclusion criteria**
1. Age ≥16 years to <75yrs 2. Displaced fracture of the olecranon 3. Minimal or moderate fragmentation of the olecranon 4. Within two weeks of olecranon fracture	1. Pregnant women with pre-determined treatment 2. Patients unable to give informed consent 3. Associated fractures to the coronoid, radial head and/or distal humerus 4. Associated ligamentous injury, dislocation or subluxation 5. Open fractures 6. Patients unable to comply with follow-up

Table 9.1: Inclusion and exclusion criteria for the trial.

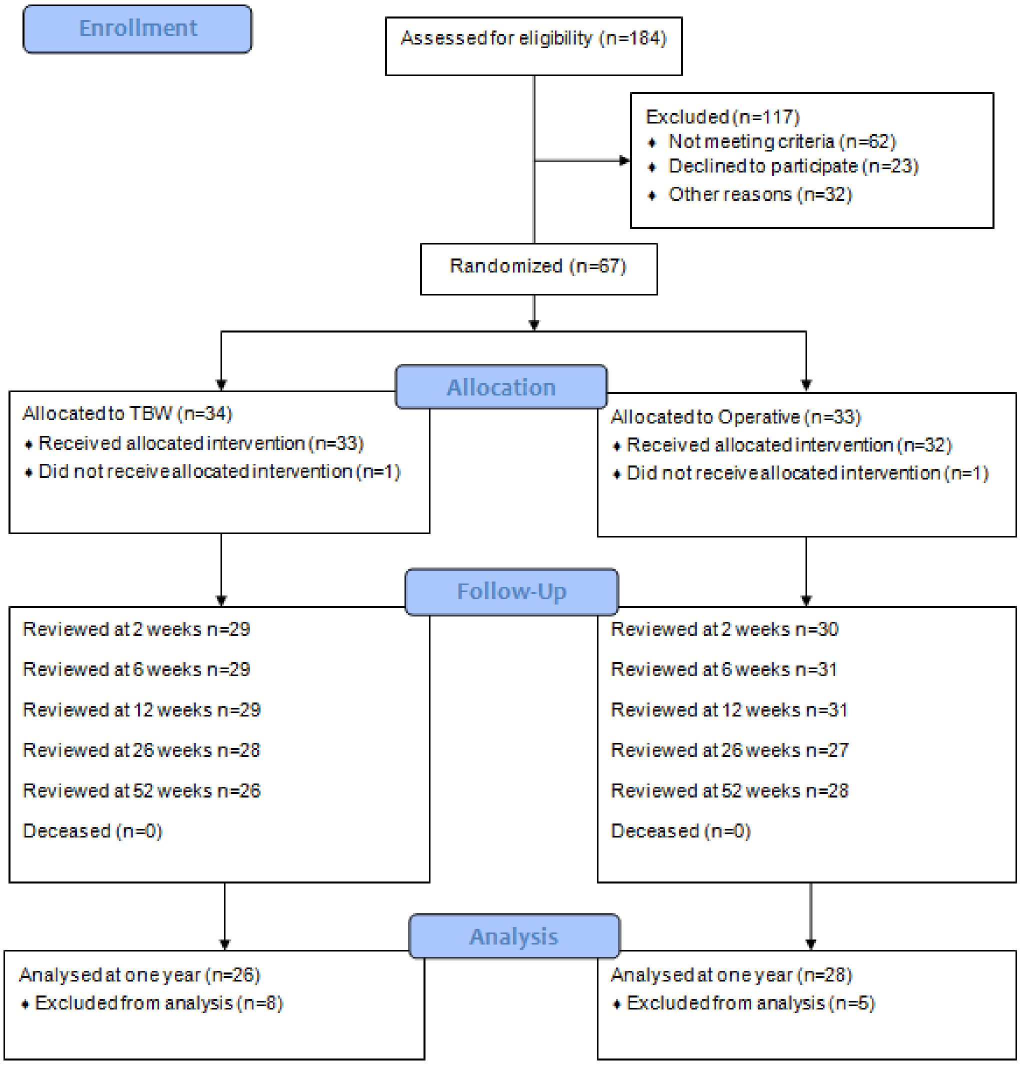

Figure 9.1: CONSORT diagram for recruitment and flow of participants through the trial. Three patients (2 TBW and 1 plate) are awaiting one year follow-up.

Demographic data was documented at initial presentation including age, gender, co-morbidities, smoking, alcohol, BMI, mechanism of injury and injury dominance. The Index of Multiple Deprivation (IMD 2009) was used to assess socioeconomic deprivation[281], which is described in Section 2.2. Patients were asked to complete a retrospective DASH score as a baseline at presentation.

Randomisation

Following informed consent, patients were randomized to receive either operative or non-operative management[i]. This was performed by opening sequential closed opaque envelopes that contained a card detailing to which of the two groups (non-operative or operative) the patient had been randomised. Randomisation was on a 1:1 basis.

9.4.2 Radiographic classification

All fractures were assessed at the time of presentation using standard anteroposterior (AP) and lateral radiographs of the injured elbow. The AO-OTA fracture classification system[134,135] and the Mayo classification for olecranon fractures[34] were used to classify all fractures (Section 2.4). Initial radiographs were reviewed to confirm fracture displacement, comminution, classification, and the absence of an associated fracture and/or subluxation/dislocation of the elbow (Section 2.4). Fracture displacement was defined as the distance or gap between the articular surface of the fracture, using the lateral radiograph of the elbow at presentation[20]. Measurements were carried out in a standardised fashion with a calibrated radiograph.

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[i] Thank you to Dr Rob Elton for his assistance with the randomisation.

9.4.3 Management protocol

The median time to definitive surgery was two days (range, 0-14), which was comparable between both groups (p=0.796). All fractures were operated on under the supervision of the treating consultant trauma surgeon. In 19 (28.4%) cases the consultant was the primary surgeon, with a trauma fellow or senior trainee the primary surgeon in the remaining 48 (71.6%) cases. This was not significantly different between groups (p=0.152). Due to the proximal nature of the fracture one patient in the plate group underwent TBW fixation, and one patient in the TBW group underwent plate fixation due to the unexpected comminution of the fracture (Figure 9.1).

Patients were routinely placed in the lateral decubitus position with the affected arm over a bolster with a tourniquet on the arm, which was inflated just prior to prepping of the arm. The median tourniquet time was 42 minutes (range, 25-62; n=61). Although plate fixation routinely takes longer, the tourniquet time was not significantly different between groups (p=0.116). Intravenous antibiotics (routinely 1.5g cefuroxime unless contraindicated) were given prior to inflation. A posterior longitudinal direct midline skin incision was routinely used, with an incision curving just lateral to the olecranon depending on surgeon preference. Lateral and medial fasciocutaneous flaps were raised to allow adequate exposure of the fracture site, with the length dependant on the type of fixation being used and the fracture complexity. The ulnar nerve was not routinely dissected out or transposed. The triceps tendon was identified proximally inserting into the proximal fracture segment. Sub-periosteal dissection was performed between the FCU and ECU interval as necessary to identify the fracture site and the proximal ulna, with FCU and anconeus elevated as required off the medial and lateral aspects of the ulna to allow visualisation of the joint and fracture fragments. The fracture was cleaned in the standard fashion and then held reduced with a fracture reduction clamp.

Both TBW and plate fixation techniques were performed under image intensifier guidance. A standard TBW technique was used in all cases, employing two K-wires in a longitudinal direction going from the proximal fragment of the olecranon into the ulna distally. Care was also taken to ensure these were extra-articular and it was up to the discretion of the surgeon whether these were placed in the anterior cortex or straight down the shaft of the ulna. If they were placed in the anterior cortex, care was taken to prevent them penetrating too far anteriorly, with length allowed for the final burying of the trimmed wires in the proximal ulna. A transverse tunnel was then placed distally in the ulna using a drill at approximately the same distance from the fracture site as the fracture was from the olecranon trip. The cerclage wire was then passed posterior to the two K-wires and through the triceps tendon proximally, the two ends were then crossed and one end placed through the distal tunnel. The wire is then tensioned in the standard fashion and all wire ends trimmed and buried.

For plate fixation, K-wires were sometimes used initially to supplement the fracture reduction and then removed once stability was achieved. Once the fracture was reduced a pre-contoured dorsal proximal ulnar plate (©Zimmer) was applied in the standard fashion and initially a lag screw was placed longitudinally down the ulna to hold the fracture reduced. Once the construct was stable, distal screws were then placed to stabilise the construct. The median number of screws used per case was 5 (range, 3-7).

Following surgery, patients were routinely immobilised in either an above elbow back slab or thick wool and crepe dressing for 10-14 days while the wound healed. Supervised physiotherapy was employed at the discretion of the supervising surgeon, with the indication either a residual functional deficit and/or elbow stiffness. It is not routine at the EOTU to remove metalwork following olecranon fracture fixation unless symptomatic.

9.4.4 Outcome assessment

Clinical, functional and radiological evaluations were carried out prospectively at two weeks, six weeks, twelve weeks, six months and one-year post injury. Radiographs were not performed at one year unless clinically indicated. Patients were reviewed out with these times as clinically indicated, with clinical and radiographic assessment performed as required, and this was recorded as part of the cost-analysis assessment (Section 2.5.5). The development of complications and the need for subsequent surgeries were recorded. Request for compensation related to the patient's injury was also recorded.

A full outcome assessment was completed by a dedicated research physiotherapist not involved in the patient's management[j]. Range of motion in the unaffected and affected elbow (flexion, extension, supination, pronation) was measured using a standard full-circle goniometer. The primary outcome measure was the DASH at one year post injury[275] (Section 2.5). Three patients (all plates) had their final one year outcome performed over the phone due to logistical issues. Their final range of movement measurements were carried forward as they all had regained full elbow movement by six months. Secondary outcome measures also included surgeon reported outcome measures, pain, complications, radiographic assessment and cost of treatment. The two surgeon reported outcome measures used were the Mayo Elbow Score (MES)[272] and the Broberg and Morrey Score[124,170], which are detailed in Section 2.5. Pain was assessed on an analogue scale of 0-10 (0 being no pain and 10 being the worst pain).

Complications were defined as loss of fracture reduction, prominent and symptomatic metalwork, and further surgery including removal of metalwork, superficial or deep wound infections and new onset of neurological symptoms or signs following treatment. Superficial infections were defined as a wound infection that settled with antibiotics and required no surgical intervention. Deep infections fulfilled the criteria as set out by Horan et al[369].

Radiographic assessment using AP and lateral radiographs of the elbow were performed to determine the quality of initial reduction (initial post-operative radiographs), metalwork failure and loss of reduction (>2mm articular surface re-

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[j] Thank you to Elizabeth Will for her assessment of the patients.

displacement), as well as progression to union. Quality of reduction was determined as satisfactory if the articular surface was reduced to within 2mm, which was adapted from the trial by Hume and Wiss[20]. Time to fracture healing was assessed periodically at the planned follow-up visits. It was defined as endosteal healing, bridging of three of four cortices and 75 % percentage organised trabecular bridging of defect on both radiographic views of the elbow[370,371]. Although healing time is likely to be an over-estimate of the actual time, this should not be biased between management arms.

9.4.5 Statistical analysis

Details of the power analysis are found in Section 2.1.5. Data was analysed using the intention to treat principle. Outcomes between the two groups were compared by chi-squared (all numbers in cell ≥5) or Fisher's exact (one cell <5) tests for binary variables, with the Student's t-test used for parametric quantitative variables. A paired samples t-test was used to analyse the improvement in DASH scores at six weeks to one year post injury. The Pearson correlation was used to analyse the correlation between two continuous variables (e.g. age and displacement versus DASH), with the ANOVA used for parametric continuous data where a variable had more than two categories.

Multivariate linear regression analysis was used to control for confounding variables including age, gender, deprivation, co-morbidities and ASA grade. A p value of <0.05 was considered statistically significant. Two tailed p-values were reported and statistical significance was set at $p<0.05$, with 95% confidence intervals (95% CI) presented.

9.5 Results

Of the 184 patients assessed for eligibility during the study period, 67 patients were randomised to receive TBW (n=34) or plate (n=33) fixation (Figure 9.1). The overall mean age was 47yrs (range, 18-74yrs; SD 17), 38 (56.7%) were male and 29 (43.3%) were female (p=0.272). The mean age of females was 53yrs (range, 21-74; SD 17), which was significantly older (p=0.008) than the mean age of males (43yrs; range, 18-73yrs; SD, 15) at the time of injury.

The left side was affected in 38 (56.7%) cases. One or more co-morbidities were documented in 59.7% (n=40) of patients and a majority of patients were an ASA grade 1 (n=30, 44.8%) or 2 (n=29, 43.3%). The most frequent mechanism of injury was a fall from standing height (n=40, 59.7%), followed by a motor vehicle collision (n=13, 19.4%), sports (n=5, 7.5%), a fall from height (n=4, 6.0%), fight/assault (n=3, 4.5%) and other (n=2, 3.0%).

All fractures were originally classified as a Mayo type 2A, although three fractures had some notable articular comminution at the time of surgery – two were randomised to a plate and one was converted to a plate after being randomised to a TBW. The mean fracture displacement was 13mm (range, 4-32). Sixteen patients (23.9%) had concomitant injuries including one ipsilateral proximal humeral fracture, one ipsilateral non-displaced acetabular fracture, one contralateral distal radius fracture, one contralateral 5th metacarpal fracture, contralateral third and fourth metatarsal fractures, a back soft tissue injury and seven minor head injuries, all of which were managed non-operatively. There was one ipsilateral neck of femur fracture managed with a dynamic hip screw, one ipsilateral ACJ dislocation managed surgically and one ipsilateral open tibial fracture treated with intramedullary nailing.

The baseline demographic and fracture characteristics of the two arms are found in Table 9.2. The mean age of patients was younger in the TBW arm (43 vs 52 years), with all other characteristics comparable including co-morbidities, ASA grade and the baseline pre-injury DASH score.

9.5.1 Primary outcome

At one year following injury the mean DASH score was 10.9 (range, 0-79.3; SD 16; n=54). For all patients there was a significant improvement in the DASH score from 6 weeks (mean 36.3) to one year (mean 10.0) following injury (Table 9.3, Figure 9.2, $p<0.001$).

The current follow-up rate in those available was 87% (n=58), with three patients (2 TBW, 1 plate) awaiting their final one year review at the time of writing. The six month results for these patients have not been brought forward to one year for the purpose of the analysis. There was no difference between groups in terms of the DASH score at all the assessment points over the one-year following injury (Table 9.3, Figure 9.2, all $p\geq0.05$), with the mean DASH score at one year 13.5 (range, 0-79.3) in the TBW group and 8.5 (range, 0-40.5) in the plate group ($p=0.252$).

(n/% unless otherwise stated)		**TBW (n=34)**	**Plate (n=33)**
Mean age (range, SD, 95% CI)		43 (19-73, 16, 37-49)	52 (18-74, 17, 46-58)
Gender	*Male*	21 (61.8)	17 (51.5)
	Female	13 (38.2)	16 (48.5)
Dominant Hand	*Left*	1 (2.9)	2 (6.1)
	Right	33 (97.1)	31 (93.9)
Side of Injury	*Left*	19 (55.9)	19 (57.6)
	Right	15 (44.1)	14 (42.4)
Associated Injury		9 (26.5)	7 (21.2)
Smoker		13 (38.2)	12 (36.4)
Alcohol consumption (units/week)	*≤21*	30 (90.9)	28 (84.8)
	>21	3 (9.1)	5 (15.2)
Co-morbidities ≥1		17 (50)	23 (69.7)
SIMD	*1*	8 (23.5)	4 (12.1)
	2	7 (20.6)	2 (6.1)
	3	7 (20.6)	5 (15.2)
	4	4 (11.8)	10 (30.3)
	5	8 (23.5)	12 (36.4)
ASA Grade	*1*	19 (55.9)	11 (33.3)
	2	11 (32.4)	18 (54.5)
	3	4 (11.8)	4 (12.1)
Mechanism of injury			
	Fall from standing height	20 (58.8)	20 (60.6)
	Fall from height	3 (8.8)	1 (3.0)
	Other	0 (0)	2 (6.1)
	MVC	7 (20.6)	6 (18.2)
	Sports	2 (5.9)	3 (9.1)
	Fight/Assault	2 (5.9)	1 (3.0)
Pre-injury DASH (range, SD, 95% CI)		1.1 (0-31.7, 5.5, 0-3) (n=33)	2.3 (0-30, 6.2, 0-4.5)

Table 9.2: Baseline characteristics of 67 study participants by randomisation treatment group.

Time Point	**Mean Outcome**	**TBW**	**Plate**	**p-value***
	(Range, SD, 95% CI)	(n=29)	(n=30)	
6 weeks	Elbow Flexion Arc	94 (45-150, 30, 83-106)	97 (10-151, 31, 85-108)	0.759
	Forearm Rotation Arc	174 (80-180, 19, 167-181)	171 (85-180, 20, 164-178)	0.511
	B&M Score	68 (34-86, 13, 63-73)	67 (32-91, 14, 62-72)	0.932
	MES	74 (25-95, 15, 68-79)	77 (30-100, 16, 71-83)	0.430
	DASH	35 (0-90, 23, 27-44)	36 (0.8-89, 19, 29-44)	0.728
	(Range, 95% CI)	(n=29)	(n=31)	
12 weeks	Elbow Flexion Arc	120 (58-150, 24, 111-129)	117 (50-149, 21, 109-125)	0.566
	Forearm Rotation Arc	174 (100-180, 19, 100-180)	178 (150-180, 6.5, 175-180)	0.332
	B&M Score	79 (52-100, 13, 74-84)	78 (34-100, 15, 73-84)	0.902
	MES	83 (65-100, 11, 79-87)	84 (30-100, 17, 78-90)	0.801
	DASH	21 (0-80, 22, 13-30)	20 (0-66, 16, 14-26)	0.831
	(Range, 95% CI)	(n=28)	(n=28)	
26 weeks	Elbow Flexion Arc	131 (90-160, 17, 125-138)	130 (80-158, 19, 123-138)	0.809
	Forearm Rotation Arc	178 (135-180, 8.6, 175-181)	178 (135-180, 8.6, 175-181)	0.951
	B&M Score	84 (54-100, 13, 79-89)	86 (52-100, 12, 82-91)	0.572
	MES	86 (65-100, 11, 82-91)	86 (65-100, 11, 82-91)	0.906
	DASH (n=28 vs 27)	19.7 (0-82, 20, 11-28)	15.9 (0-54, 15, 9.8-22)	0.464
	(Range, 95% CI)	(n=26)	(n=29)	
52 weeks	Elbow Flexion Arc	136 (84-155, 15, 130-142)	131 (95-158, 15, 126-137)	0.228
	Forearm Rotation Arc	178 (130-180, 10, 174-182)	180 (170-180, 2.0, 179-180)	0.316
	B&M Score	89 (35-100, 15, 83-95)	95 (78-100, 6.7, 92-97)	0.056
	MES	89 (40-100, 14, 83-95)	96 (85-100, 6.8, 93-98)	**0.030**
	DASH (n=26 vs 28)	13.5 (0-79, 20, 5.3-22)	8.5 (0-41, 10, 4.4-12.5)	0.252

Table 9.3: Functional, patient reported and surgeon reported outcomes one year after injury by treatment group. (*All Student's t-test)

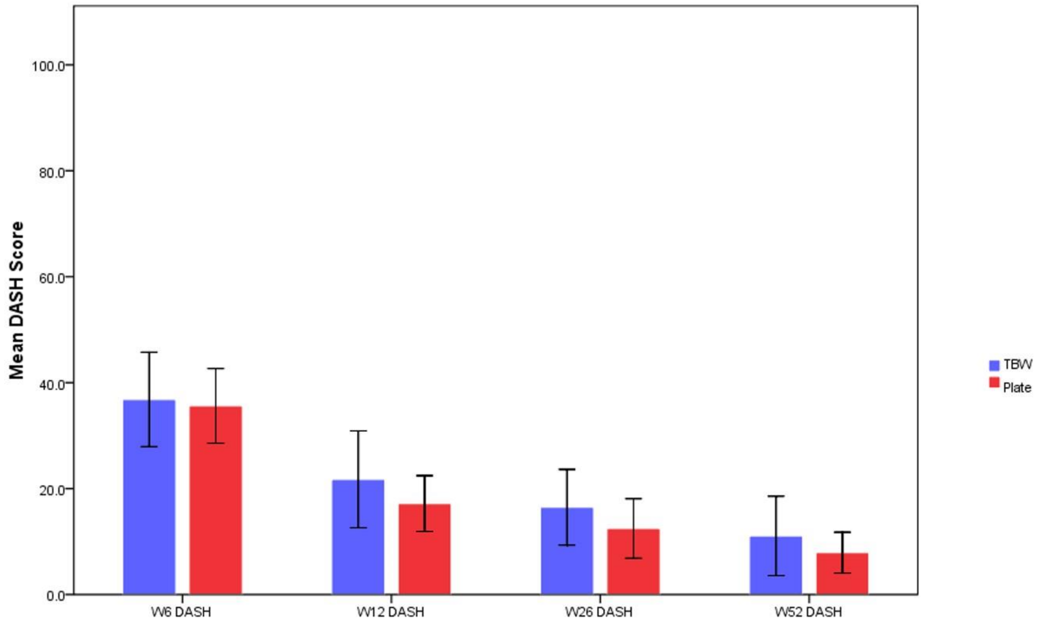

Figure 9.2: Change in DASH score over time with 95% confidence intervals.

9.5.2 Secondary outcomes

Functional and surgeon reported outcomes

At one year following injury the mean Broberg and Morrey score was 92 (range, 35-100; SD 11.8; n=55), with 89% achieving an excellent (n=29) or good (n=20) outcome. Five patients had a fair outcome and one patient a poor outcome. At one year the mean MES was 93 (range, 40-100; SD 11), with 93% achieving an excellent (n=34) or good (n=17) outcome. Three patients had a fair outcome and one was poor. The mean elbow flexion was 144 degrees (range, 112-160; SD 8.3), the mean extension deficit was 10 degrees (range, -3-35; SD 9.3) and the mean flexion arc was

134 degrees (range, 84-158; SD 15). The mean pronation was 89 degrees (range, 60-90; SD 4.1), the mean supination was 89 degrees (range, 70-90; SD 3.3) and the mean forearm rotation was 179 degrees (range, 130-180; SD 7.0). At one year following injury, the MES was significantly better in the plate group (89 vs 96; p=0.030). There was no other significant differences found between groups in terms of elbow flexion arc, forearm rotation arc, Broberg and Morrey Score, or the MES at any other point over the one-year following injury (Table 9.3, all p≥0.05).

Complications

Complications were assessed in 62 patients who had undergone a minimum of 3 months follow-up (Table 9.4). There were 41 complications reported in 31 (50%) patients and included removal of symptomatic metalwork (n=22, 35.4%), loss of fracture reduction (n=12, 19.4%), infection (n=4, 6.5%) and the need for revision surgery (n=3, 4.8%).

(n/% unless otherwise stated)	**TBW** (n=30)	**Plate** (n=32)	**p value**
Total complications	19 (63.3)	12 (37.5)	**0.042***
Infection	0 (0)	4 (12.5)	0.114¶
Loss of reduction	8 (26.7)	4 (12.5)	0.206¶
Subsequent surgeries			
Removal of metalwork	15 (50)	7 (21.9)	**0.021***
Revision	0 (0)	3 (9.4)	0.238¶

Table 9.4: Complications within one year following injury by treatment group. (* Chi-squared, ¶ Fisher's exact test)

Complication rates were significantly higher in the TBW group (63.3% vs 37.5%; p=0.042), predominantly due to a significantly higher rate of symptomatic metalwork removal (50.0% vs 21.9%; p=0.021). One patient in the TBW group required an early MUA for stiffness before undergoing metalwork removal once the fracture had united. Loss of reduction following surgery was more common in the TBW arm (26.7% vs 12.5%, p=0.206). Four infections occurred in the plate group (0% vs 12.5%; p=0.114), as did the three revision surgeries (0% vs 9.4%; p=0.238).

Of the four infections in the plate group, two were superficial and two were deep. Both superficial infections settled within one week of commencing antibiotic therapy and no surgery was required. One of these patients also lost reduction and went onto a functional fibrous non-union (Figure 9.3). One patient with a deep infection was managed with antibiotics and plate removal once the fracture had healed, with complete resolution of symptoms.

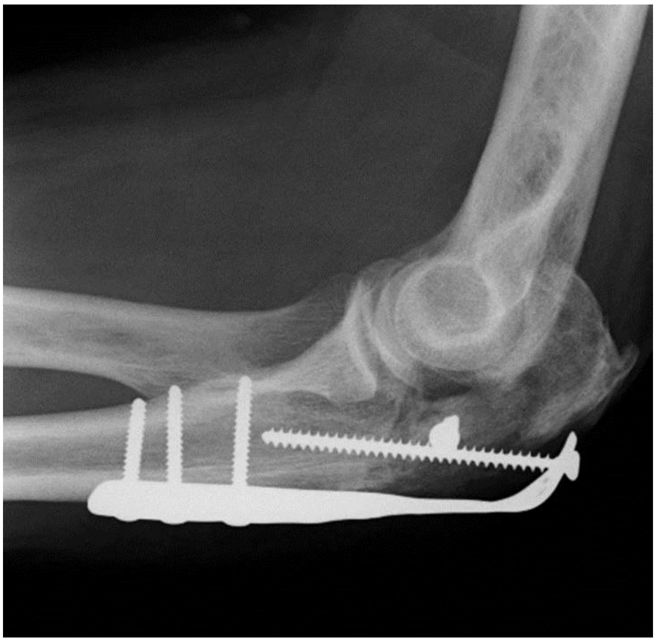

Figure 9.3: Fibrous non-union following an infected plate fixation.

The other patient with a deep infection underwent revision to a TBW construct. The infection settled following a prolonged course of antibiotics and further surgery to remove the TBW but a fibrous non-union developed. The two other revision surgeries were in the plate group – one was for failed fixation that was converted successfully to a TBW construct, and the other was for an exchange of a long screw that was blocking forearm rotation.

Radiographic outcome

Initial fracture reduction was deemed satisfactory in 29 (85%) patients treated with TBW and in 31 (94%) patients managed with plate fixation. In the 57 of 62 patients who progressed to radiographic union, the median time to radiograph union was 12 weeks (range, 6-52). Three patients in the plate group and two patients in the TBW group progressed to a functional fibrous non-union (Figure 9.3). All of these patients had a loss of reduction, with two associated with infection. Only the patient in the plate group (described above) underwent further surgery to revision TBW.

Cost analysis

Costs were assessed in 62 patients who had undergone a minimum of 3 months follow-up. The median number of days in hospital was two (range, 1-38). The mean cost per patient was £5529 (range, 2961-27936), with the cost per patient not significantly different between the two groups (Table 9.5; p=0.131), despite a significantly higher cost for the primary intervention in the plate group (Table 9.5, p<0.001).

	TBW (n=30)	**Plate** (n=32)
Median total days in hospital (n/range)	2 (1-38)	2 (1-30)
Mean cost of primary intervention (£/range)*	32	536 (32-563)
Median no. of clinic reviews (n/range)	6 (5-8)	5 (5-12)
Mean cost of antibiotics (£/range)	0	8 (0-141)
Number of extra trips to theatre (n)	16	10
Median cost of further implants (£/range)	0	0 (0-32)
Overall mean cost/patient (£)	5505 (2961-27936)	6201 (3476-23056)

Table 9.5: Cost analysis by treatment group. *Does not include a standard theatre cost of £1824, which was included in the overall costings.

9.5.3 Predictors of outcome

Co-morbidities (p=0.035) and increasing ASA grade (p=0.001) were predictive of the DASH at one year. There was also a correlation between fracture non-union and the DASH at one year (34 vs 9.0, p=0.002). There was a strong correlation between the pre-injury DASH and outcome at one year (p=0.001; coefficient 0.45). Age (p=0.423), gender (p=0.973), deprivation (p=0.800), mechanism of injury (p=0.157), degree of fracture displacement (p=0.196) and associated injuries (p=0.737) were not predictive of the primary outcome (DASH) at one year.

On multivariate linear regression analysis, controlling for age, gender, deprivation, co-morbidities and ASA grade there was no correlation between treatment arm and the DASH score at one year, with the only predictor of a poorer outcome being increasing ASA grade (Table 9.6).

Variable	**Regression Coefficient**	**95% Confidence Limits**	**p-value**
Age	-0.103	-0.4 to 0.21	0.505
Gender	2.160	-6.9 to 11	0.634
Deprivation	-0.664	-3.9 to 2.6	0.682
Co-morbidities	-2.146	-16 to 11	0.751
ASA Grade	13.710	3.3 to 24	**0.011**
Management	-6.438	-15 to 2.1	0.134

Table 9.6: Multivariate linear regression analysis controlling for baseline demographic characteristics. (R squared value 0.268)

9.6 Chapter Discussion

This is the largest prospective randomised controlled trial in the literature comparing TBW with plate fixation for an isolated displaced fracture of the olecranon. The data presented here demonstrate that TBW and plate fixation provide comparable patient reported outcomes in the short-term. The complication rate is higher following TBW fixation due to a high rate of symptomatic metalwork removal, although the more serious complications in this series occurred in the plate group.

In 1992 Hume and Wiss performed the only other prospective randomized trial in the literature comparing TBW (n=19) and plate fixation (n=22) for displaced olecranon fractures[20]. Follow-up was over a one year period, but comminuted and open fractures were included and no validated PROMs were used. Despite this, the results of this study on the whole compare well with the data presented here. The authors reported that elbow motion at six months was comparable, but with loss of fracture reduction and prominent symptomatic metalwork significantly more common following TBW, as this trial has reported. Hume and Wiss found that the overall clinical outcome was far superior in the plate fixation group, with 86% obtaining a good result compared to 47% in the TBW group. Although this chapter has found no difference in outcome at one year in the DASH score, the score was superior (lower) in the plate group and there was a significant difference in the MES at one year in favour of plate fixation. Given these isolated findings, the relevance of this is questionable.

In the Hume and Wiss trial, symptomatic metalwork was seen in 42% of patients who underwent TBW fixation, compared to 5% in the plate group. The current trial found a comparable rate to Hume and Wiss's trial for TBW, but with a higher rate for plate fixation. There is almost no literature exclusively examining the use of plates for the treatment of isolated displaced olecranon fractures. Much of the literature in this area examines the use of plate fixation for comminuted, distal or unstable fractures of the olecranon[9,12,20,21,228,230,232-234]. As discussed in Chapter 8, the main perceived complication associated with plate fixation is prominent metalwork given the position of the plate on the dorsal ulna, which has been shown to provide superior strength to the dual medial-lateral plating technique[248]. However, the literature would suggest the rates of removal are lower than those for TBW (5-20%)[9,20,21], which is consistent with this trial (21.9%). Interestingly, all other complications occurred in the TBW group in the original trial by Hume and Wiss, which is not consistent with this trial where infection and revision surgery occurred exclusively in the plate group. The reason for this is not entirely clear and the actual numbers are small.

There have been recent retrospective comparative reports of TBW and plate fixation for both simple and comminuted displaced fractures of the olecranon[363-365]. These have consistently reported comparable functional outcomes, a higher rate of metalwork removal for TBW fixation, and increased costs with plate fixation. A recent study by Tarallo et al compared the outcome of TBW and plate fixation in 78 patients with a Mayo type 2A or 2B fracture[364]. At a mean of 33 months post-surgery no significant differences were found between groups in terms of functional or clinical outcomes, but with a higher rate of complications and hardware removal following TBW – 38% vs 17% for type 2A fractures and 20% vs 6% for type 2B fractures.

Although the trial presented in this chapter did find an increased rate of metalwork removal following TBW, overall costs were comparable with plate fixation due to the much higher rate of metalwork removal in the TBW group. Amini et al compared 20 patients matched for age and length of follow-up who underwent TBW (n=10) or plate (n=10) fixation for an isolated simple transverse fracture of the olecranon. The authors found that operative time was significantly longer with plate fixation (55 vs 85 minutes) and that the overall costings were significantly higher for plate fixation ($6598.36 vs $14,333.46; p=0.001) despite a higher rate of metalwork removal for TBW (40% vs 10%). The reason for the differences found between the Amini study and this trial are likely due to their smaller patient numbers, no evidence of consideration of other costs such as the length of stay, and most importantly the notably higher cost for the implant in their study ($6688.52 vs $836.72).

The high loss of reduction rate in the TBW group is consistent with biomechanical evidence that questions the validity of the TBW construct to maintain fracture stability and reduction. In a recent study, Wilson et al performed a biomechanical comparison of TBW and plate fixation in twenty ulna models with identical transverse fractures of the olecranon[372]. They found that the modern pre-contoured location specific plates were significantly better at providing fracture compression, particularly at the articular surface, than the TBW construct. However, the data presented here has found that the loss of reduction does not seem to influence patient reported outcome at one year following surgery, providing the patient progresses to union. In this trial non-union was associated with an inferior outcome at one year.

9.6.1 Strengths and limitations

The primary strengths of this trial are the large number of patients recruited, a good level of compliance with over 90% of patients receiving their allocated treatment, and the high follow-up rate at one year (88%). The numbers recruited in each arm were greater than that required according to our initial power calculation. Although multiple surgeons of different grade were involved in the surgery of these patients, this scenario is most representative of day-to-day clinical practice i.e. pragmatic.

A primary limitation of the study is the lack of blinding of both the surgeon and the patient to the allocated treatment arm. It is argued that this is pragmatic in that in routine practice a patient would always be aware of their proposed treatment[373,374]. Another primary limitation is the difference found in age between the two groups despite randomisation, with the TBW group nine years younger on average than the plate group. A superior (lower) DASH score was found in the plate group at one year and it is possible a significant difference would be apparent if the age of the groups were more comparable. However, when controlling for age and other confounding factors on multivariate linear regression analysis, no difference was found in the primary outcome measure between the two groups.

10 A RETROSPECTIVE ANALYSIS OF OLECRANON FRACTURES: LONG-TERM OUTCOME OF NON-OPERATIVE MANAGEMENT

10.1 Hypothesis and aims

The aims for this chapter were to document both the short and long-term outcome following primary non-operative management of isolated displaced fractures of the olecranon, along with defining the predictors of long-term outcome.

The hypothesis was that in a defined group of patients with an isolated displaced fracture of the olecranon, non-operative management results in a satisfactory long-term patient reported outcome that is comparable to operative management.

10.2 Chapter Summary

A retrospective search of a prospective trauma database identified all patients who were managed non-operatively for a displaced olecranon fracture over a 13-year period. Inclusion criteria included all isolated fractures of the olecranon with >2 mm displacement of the articular surface. Comminuted fractures were also included. Demographic data, fracture classification, management, complications and subsequent surgeries were recorded. The primary short-term outcome measure was the Broberg and Morrey elbow score. The primary long-term outcome measure was the DASH.

There were 43 patients in the study cohort with a mean age of 76yrs (range, 40-98yrs). A low energy fall from standing height accounted for 84% of all injuries, with ≥1 co-morbidities documented in 38 (88%) patients. At a mean of 4 months (range, 1.5-10) following injury the mean Broberg and Morrey score was 83 (range, 48-100), with 72% achieving an excellent or good short-term outcome. No patients underwent further surgery for a symptomatic non-union. Long-term follow-up was available in 53% (n=23) patients, with the remainder deceased. At a mean of six years (range, 2-15) post injury, the mean DASH score was 2.9 (0-33.9), the mean Oxford Elbow Score was 47 (42-48) and overall patient satisfaction was 91% (n=21).

This chapter has documented satisfactory short-term and long-term outcomes following the non-operative management of isolated displaced olecranon fractures in older lower demand patients. Further work is needed to directly compare operative and non-operative management in this patient group.

10.3 Chapter Introduction

Fractures of the olecranon account for just under 20% of all proximal forearm fractures. Undisplaced fractures of the olecranon (Mayo type 1) are routinely managed non-operatively[9,34], whereas tension band wiring (TBW) or plate fixation is frequently employed for stable displaced fractures (Mayo type 2)[7,13,14,20,21,231,246]. However, there is conflicting evidence regarding the outcomes and complications when operative fixation is employed in elderly patients; in particular, there have been reports of poor fixation in osteoporotic bone (Figure 10.1) and problems with wound breakdown[18,22-24,29]. Fracture excision with advancement of the triceps has been put forward as an alternative option for osteoporotic patients[17,25], although concerns regarding complications and triceps weakness have been reported[26,27]. Chapter 8 reported an inferior long-term outcome for older patients following operative fixation, with a high rate of further surgery to remove symptomatic metalwork.

Recent literature has documented the increasing incidence of olecranon fractures in the elderly. However, there is minimal data regarding the outcome of non-operative management for displaced fractures of the olecranon, particularly in elderly patients with multiple co-morbidities, lower functional demand and poor bone quality. It is now acknowledged that further work is needed to determine whether surgical treatment in these patients provides any significant benefit over non-operative management. There are currently three small case series reporting favourable short-term results, within the first two years post injury, following the non-operative management of displaced olecranon fractures in both young and elderly patients[28-30]. However, there have currently been no studies documenting the longer-term outcome for these patients using validated patient reported outcome measures.

Figure 10.1: Six-week post injury lateral radiograph of the left elbow in an 88-year-old woman demonstrating loss of reduction.

10.4 Patients and Methods

10.4.1 Patients and database construction

From the EOTU trauma database, all patients aged 16 years or older who sustained an isolated displaced fracture of the olecranon, the Mayo type 2 fracture[49], were identified over a 13 year period. The generally accepted criterion of >2mm of displacement of the articular surface on standard radiographs was used as the definition of displacement[9,226]. Comminuted fractures were included. Patients who refused primary surgical intervention, either due to personal preference or due to a late presentation, were also included. Patients were excluded if they had sustained an undisplaced fracture, an open fracture, a concomitant fracture around the ipsilateral elbow or a fracture dislocation of the elbow. Based on these criteria 61 patients were identified over a thirteen year period from December 1996 to January 2010. There were 41 (67%) females and 20 males (33%) with a mean age of 78yrs (range, 40-98yrs, SD 12.4).

Of the original 61 patients identified, 18 patients were excluded, leaving 43 (70%) patients that made up the study cohort for analysis (Figure 10.2). Of the 18 patients excluded, three were from out with the local catchment area, four died whilst in hospital and 11 had insufficient data and/or inadequate follow-up. Of these 11 patients, seven subsequently returned to the EOTU for another unrelated injury; none had undergone further treatment for their olecranon fracture. There was no difference between the included and excluded groups in terms of gender (p=0.59), mechanism of injury (p=0.72) or co-morbidities (p=0.31). Patients were older in the excluded cohort (p=0.04).

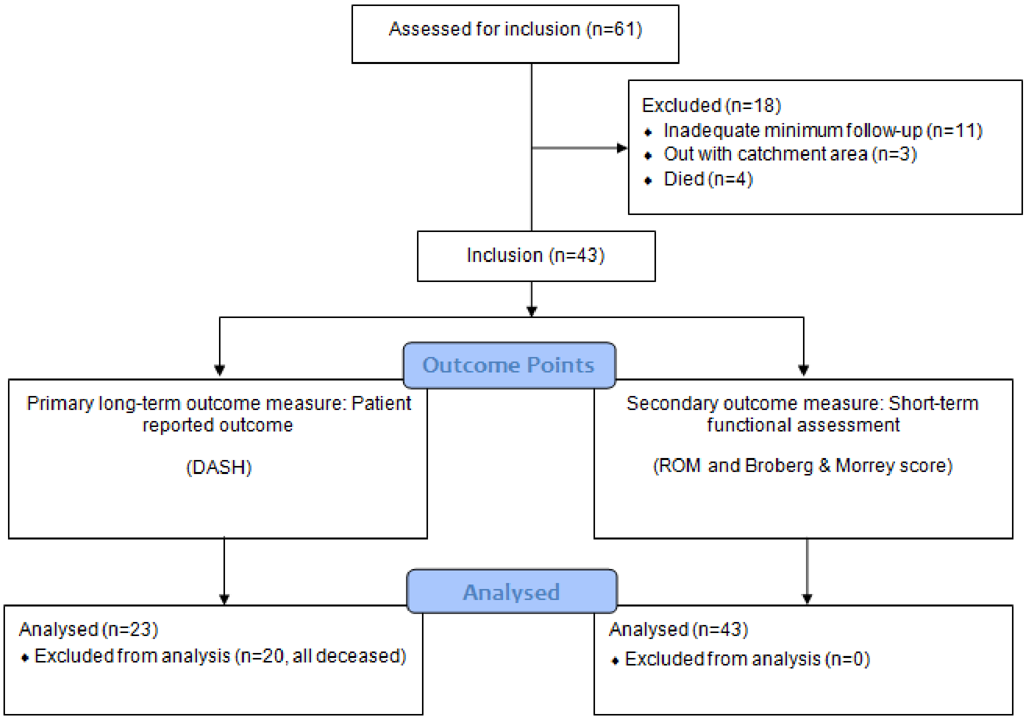

Figure 10.2: A flowchart that demonstrates the patient selection process.

Clinical records and the trauma database were retrospectively reviewed to record demographic data including age, gender, side affected, mechanism of injury and all chronic medical co-morbidities. Management, duration of treatment, the use of physiotherapy, complications and subsequent surgical procedures were recorded.

10.4.2 Radiographic classification

Diagnosis and confirmation of satisfying the inclusion criteria was done through medical record and radiographic review. Initial radiographs were reviewed where available (n=28, 65%) to confirm fracture displacement, comminution, classification, and the absence of an associated fracture and/or subluxation/dislocation of the elbow (Section 2.4). Fractures were classified according to the Mayo classification for olecranon fractures[34]. Fracture displacement was defined as the distance or gap between the articular surface of the fracture, using the lateral radiograph of the elbow at presentation[20].

10.4.3 Management protocol

The mode and duration of management was determined by the supervising consultant, all of whom were experienced consultant orthopaedic trauma surgeons. All patients were treated non-operatively using either a collar and cuff with active mobilisation, or an above-the-elbow plaster cast with the elbow in 60-90 degrees of flexion. Supervised physiotherapy was employed at the discretion of the supervising surgeon, with the indication either a residual functional deficit and/or elbow stiffness.

10.4.4 Outcome assessment

Short-term outcome

Patients underwent short-term follow-up assessment at the local institution, which is the solitary provider of orthopaedic trauma care in the region. Routine policy was to aim to keep patients under review until the patient had regained satisfactory function and was symptom free. Details of complications and subsequent surgeries were recorded at each visit, as was the progression to union on radiographs. Where available (n=32, 74%), follow-up radiographs were reviewed to confirm fracture union. Patients were evaluated in the short-term according to the system of Broberg and Morrey[124,170], which was the primary short-term outcome measure (Section 2.5).

Long-term outcome

Long-term follow-up was carried out by means of a telephone and questionnaire review[k]. There were 53% (n=23) patients available, with the remainder deceased (Figure 10.2). Two PROMs that are validated to assess patients following elbow injury or surgery were used – the Oxford Elbow Score (OES)[292] and the Disabilities of Arm, Shoulder and Hand (DASH)[275] (Section 2.5).

Patients were asked to confirm if they had undergone any further treatment for complications associated with their initial injury. Patients were questioned regarding persistent pain, stiffness and instability, as well as if they were satisfied with their outcome (Section 2.5.4). Finally, all patients were asked whether they were able to push themselves up from a sitting position to a standing position as a marker for extension (triceps) weakness.

10.4.5 Statistical analysis

Age was normally distributed. Flexion arc, forearm rotation, the Broberg and Morrey score, the OES and the DASH score had a skewed distribution. A Student's unpaired t-test was employed to analyse parametric continuous data. The Mann-Whitney U-test was employed for non-parametric continuous data. Categorical binary data were analysed using either the chi-square test were the all the observed frequencies in each cell were greater than 5, with the Fisher's exact test used when one cell had an observed frequency of ≤5. The Spearman correlation was used to analyse the correlation between two continuous variables (age and displacement versus DASH).

Receiver operating characteristic (ROC) curve analysis was used to identify the threshold for fracture displacement that identified patient satisfaction following the non-operative management of a displaced olecranon fracture[l]. A ROC curve plots sensitivity (y-axis) against 1-specificity (x-axis) for the variable being examined. Patient satisfaction was chosen, as this methodology requires a binary outcome measure. The cuff-off point or threshold was defined as equivalent to the point

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[k] Thank you to Kate Bugler for her assistance with the telephone follow-up.
[l] Thank you to Nick Clement for his statistical advice.

(fracture displacement) at which the sensitivity and specificity were maximal in predicting patient satisfaction[375,376]. The area under the ROC curve (AUC) determines how predictive the variable is in determining patient satisfaction. The AUC ranges from 0.5 (indicating a test with no accuracy in distinguishing whether a patient is satisfied) to 1.0 (the test is perfectly accurate identifying all satisfied patients and those with fulfilled expectations). Two tailed p-values were reported and statistical significance was set at p=0.05, with 95% confidence intervals (95% CI) presented.

10.5 Results

There were 43 patients in the cohort with a mean age of 76yrs (range, 40-98yrs; SD 12.9) and a significant female predominance (n=28, 65%, p=0.047, Table 10.1).

	Male (%, 95% CI)	**Female (%, 95% CI)**	**p value**
Total	15 (35, 22-50)	28 (65, 50-78)	**0.047***
Mean age (range, SD, 95% CI)	72 (40-98, 16.0, 63-81)	77 (51-91, 10.8, 73-81)	0.224[a]
MOI			
Fall from standing height	12 (80, 54-94)	24 (86, 68-95)	
Fall from height	1 (6.6, 0-3)	2 (7, 1-2)	0.931*
RTA	1 (6.6, 0-3)	1 (3.5, 0-2)	
Other	1 (6.6, 0-3)	1 (3.5, 0-2)	
ASA Grade			
1	4 (26.5, 10-52)	1 (3.5, 0-2)	
2	5 (33.5, 15-59)	12 (42.5, 26-61)	0.079*
3	6 (40, 20-64)	15 (54, 36-70)	
Treatment mode			
Collar and cuff	4 (27, 10-52)	11 (39, 24-58)	0.512
Above elbow plaster cast	11 (73, 48-90)	17 (61, 42-77)	
Short-term outcome	(range, SD, 95% CI)	(range, SD, 95% CI)	
Mean Flexion arc	108 (70-130, 22.2, 96-120)	109 (50-135, 25.6, 99-119)	0.769[b]
Mean Rotation arc	157 (125-160, 10.1, 151-163)	160 (160-160, 0, 160-160)	0.149[b]
Mean Broberg & Morrey	81.3 (51-92, 11.7, 75-88)	84.1 (48-100, 13.6, 79-89)	0.474[b]
Long-term outcome	(range, SD, 95% CI) (n=8)	(range, SD, 95% CI) (n=15)	
Mean OES	48 (48-48, 0, 48-48)	46.5 (42-48, 2.4, 45-48)	**0.044[b]**
Mean DASH	0 (0-0, 0, 0)	4.5 (0-33.9, 10.1, 0-10)	**0.045[b]**

Table 10.1: Patient demographics and outcome. ([a]Student’s t-test, [b]Mann-Whitney test, * Chi-squared, ¶ Fisher’s exact test)

The mean age of females was 77yrs (51-91yrs, SD 10.8), which was not significantly different (p=0.224) from the mean age of males (72yrs, 40-98yrs, SD 16.0) at the time of injury. The left side was affected in 26 (61%) cases. One or more co-morbidities were documented in 88% (n=38) of patients and a majority of patients were an ASA grade 3 (n=21, 48.8%, p=0.08). The most frequent mechanism of injury was a fall from standing height (n=36, 84%), followed by a fall from height (n=3, 7%), motor vehicle collision (n=2, 4%), assault (n=1, 2.5%) and a direct blow (n=1, 2.5%).

Comminution was noted in 50% of available radiographs (14/28), with the mean displacement 10mm (range, 3-29; Figure 10.3). Six patients (14%) had concomitant injuries including two ipsilateral proximal humeral fractures, one ipsilateral clavicle fracture, one pubic rami fracture, one T11 vertebral fracture and one patient had an associated head injury.

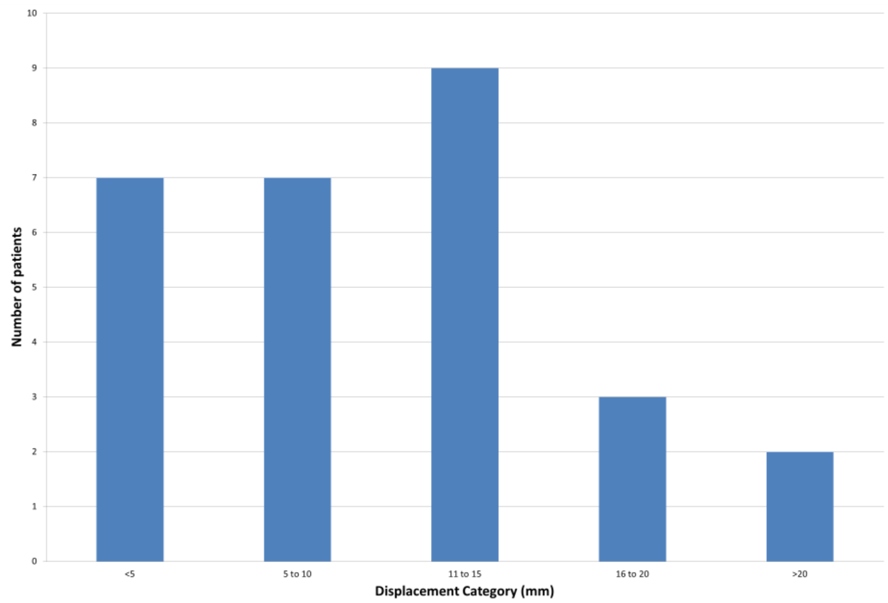

Figure 10.3: Categories of olecranon fracture displacement.

A collar and cuff followed by active mobilisation was used in 15 patients (35%), with an above-the-elbow plaster cast with the elbow in 60-90 degrees of flexion used in 28 cases (65%). The mean duration of the immobilisation in a plaster cast was 4 weeks (range, 1-6).

10.5.1 Short-term outcome

At a mean of 4 months (range, 1.5-10) following injury the mean Broberg and Morrey score was 83 (range, 48-100; SD 12.0), with 72% achieving an excellent (n=7) or good (n=24) outcome. Nine patients had a fair outcome, with 3 poor. The mean elbow flexion was 126 degrees (range, 90-140; SD 12.8), the mean extension was 18 degrees (range, 0-60; SD 13.3) and the mean flexion arc was 109 degrees (range, 50-135; SD 24.2). The mean pronation was 79 degrees (range, 45-80; SD 5.3), the mean supination was 80 degrees (range, 80-80; SD 0) and the mean forearm rotation was 159 degrees (range, 125-160; SD 5.3).

From the available radiographs (n=32), 25 (78%) patients developed a functional non-union (i.e. the patient was asymptomatic and satisfied with their outcome), with the remaining patients progressing to union (n=7, 22%). No patients underwent further surgery within the first year following injury for a symptomatic non-union or for any other cause.

10.5.2 Long-term outcome

Long-term follow-up was available in 53% (n=23) of patients, with the remainder deceased. The mean age was 71yrs (range, 40-87yrs; SD 12.3) with a greater number of females (n=15, 65%, p=0.14). At a mean of six years (range, 2-15) following injury, the mean DASH score was 2.9 (range, 0-33.9; SD 8.4) and the mean Oxford Elbow Score was 47 (range, 42-48; SD 2.1). Of these 23 patients, 17 (74%) were defined has having a non-union, 5 (22%) a union and in one patient the radiographs were not available. No patients reported further intervention since their original injury (Figure 10.4).

A B

Figure 10.4: A) A lateral radiograph of the left elbow demonstrating an isolated displaced fracture of the olecranon in an 86-year-old man who was managed non-operatively with a collar and cuff. B) Radiographs taken at six months following injury. At 3-year follow-up the patient was asymptomatic with an excellent outcome according to the DASH and Oxford Elbow Score.

Overall patient satisfaction was 91% (n=21), with the two patients unsatisfied due to on-going elbow stiffness (n=1) and elbow pain (n=1). Subjective stiffness was found in only one patient (2%). No subjective pain was reported in 87% of patients (n=20), with two patients reporting only mild intermittent pain and one patient reporting moderate to severe pain. Four patients (n=17%) reported a weakness or inability at pushing themselves up from a chair, with the remaining 19 (83%) reporting no limitation.

10.5.3 Predictors of long-term outcome

Gender (Table 10.1), degree of fracture displacement (p=0.025) and mode of treatment (p=0.045) were the only predictors of the long-term DASH score. A higher (worse) DASH score was found in females, for patients with greater fracture displacement, and for those treated only with a collar and cuff. The AUC was 0.94 (95% CI 0.82 to 1.0) for the ROC curve, with the cut off value found to be at 15.25 mm. Patients above this degree of displacement were not as satisfied. Age, mechanism of injury, past medical history, ASA grade and associated injuries were not predictive of long-term outcome according to the DASH score. No correlation was found between fracture union and the DASH (p=0.249).

10.6 Chapter Discussion

This chapter represents the largest series in the literature documenting both the short and long-term outcome of patients managed with primary non-operative intervention for an isolated displaced fracture of the olecranon. These findings demonstrate that non-operative management of displaced olecranon fractures is a feasible treatment option in lower demand patients with multiple co-morbidities, as it yielded a good or excellent long-term outcome in the vast majority of cases. Patient satisfaction is high, subjective pain is minimal and the need for further intervention is negligible. Further work is now warranted to directly compare operative and non-operative management in this patient group.

The use of operative fixation for a displaced olecranon fracture in elderly patients can be associated with an increased anaesthetic risk, poor fixation in osteoporotic bone, problems with wound breakdown, a further operation due to prominent metalwork causing soft tissue irritation, and an inferior outcome[18,22-24,29]. However, it is necessary for non-operative treatment to adequately manage pain, allow early movement, provide active extension power at the elbow and meet the long-term demands of the patient[26,27,29].

The results from this chapter in both the short and long-term are comparable to the limited short-term literature on the non-operative management of displaced fractures of the olecranon[28-30]. Parker et al documented the short-term outcome of 23 patients with a mean age of 48 years (range, 13-91) who were managed conservatively using early active motion within the first two weeks following injury for a displaced fracture of the olecranon[28]. In their study they included young patients, comminuted fractures, concomitant fractures to the ipsilateral elbow and open fractures. At a mean follow-up of two years the outcome was reported as good or fair in 21 (91%) patients, with comparable findings in patients over the age of 50 years. Only three patients were found to have minimal loss of power (MRC +4) at the elbow.

Veras del Monte et al reported on 12 elderly low demand patients with a mean age of 82 years managed in a 90 degree above elbow cast for a mean of 4 weeks for a displaced fracture of the olecranon[29]. They reported patient satisfaction at a mean of 15 months post injury was excellent in 92% of cases, which is comparable to the long-term results in this chapter. In their series, eight (67%) patients were pain free.

10.6.1 Predictors of outcome

This is the first data that to document the predictors of outcome following the non-operative management of displaced olecranon fractures. However, given the small sample size and under powering of this case series, no firm conclusions can be made from this data and further evidence is required. Furthermore, radiographs were not available for all patients and the measurement of articular displacement is inevitably subject to a degree of intra- and inter-observer variability. Female gender was predictive of a poorer outcome, although this is not surprising given the older age at which they sustain their injury. Interestingly, the use of short-term immobilization appeared to have a beneficial effect on long-term outcome for these patients. Studies have suggested that prolonged periods of immobilisation for elbow fractures may lead to increased rates of pain and stiffness[145]. However, a recent Cochrane review determined there was no robust evidence regarding the risks and benefits of early mobilisation following the non-operative management of elbow fractures[377]. Fracture displacement was also predictive of long-term outcome and it is possible that above a certain degree of displacement, operative intervention should be considered. However, the degree of displacement is difficult to define and it is unknown whether intervention would provide a superior outcome over non-operative treatment for these cases.

10.6.2 Strengths and limitations

The main strength of this data is that it represents a large series of patients documenting both the short and long-term follow-up in a group of patients from a defined population with only one centre providing an acute musculoskeletal trauma service. This is the first study to report on the long-term outcome and satisfaction of these patients, as well as the first to use validated upper limb patient reported outcome measures.

Undoubtedly, a limitation of this series is the retrospective nature, which leads to issues such as loss of radiographs and loss of patients to follow-up. However, as the EOTU is the only centre providing an acute musculoskeletal trauma service for the local population, it can be surmised that the majority of these patients did not present again for treatment because they were asymptomatic. The number of available radiographs was satisfactory, particularly given the local policy of culling radiographs greater than five years old in patients not under regular clinical review. However, strict inclusion and exclusion criteria were employed, and when radiographs were not available the diagnosis was confirmed through clear documentation in the medical records from the treating surgeon. The loss to long-term follow-up rate of almost 50% is high. However, all these patients were deceased, which is a consequence of investigating outcome in a set of elderly patients with multiple co-morbidities. Furthermore, there was 100% follow-up rate in those patients who were available. It would be preferable to obtain even longer-term data (mean greater than 10 years) on these patients, although in practice this is likely to prove difficult given the demographics of this patient group.

11 PROSPECTIVE RANDOMISED CONTROLLED TRIAL OF NON-OPERATIVE VERSUS OPERATIVE MANAGEMENT OF OLECRANON FRACTURES IN THE ELDERLY

11.1 Hypothesis and Aims

The aims for this chapter were to determine if any difference exists in the primary outcome measure (DASH) after one year between non-operative management and operative treatment for isolated stable displaced olecranon fractures in elderly patients with lower functional demands. The secondary aims were to determine if there was any difference between the two groups with regards to the secondary outcome measures including range of motion, rate of complications, pain, cost and surgeon reported outcome measures.

The null hypothesis was that there is no difference in functional outcome, as measured by the Disability Arm Shoulder and Hand (DASH) score at one-year post injury, between non-operative management and operative treatment for displaced fractures of the olecranon in patients 75yrs or older (≥75yrs).

11.2 Chapter Summary

A registered prospective randomized two centre trial in elderly patients (≥75yrs of age) with an acute displaced fracture of the olecranon was performed. Patients were randomised to either operative (tension band wire or plate fixation) or non-operative (two weeks immobilisation followed by early active motion) management. The primary outcome measure was the Disability Arm Shoulder and Hand (DASH) score at one year post injury. Secondary outcome measures included surgeon reported outcome measures, complications, pain and cost.

There were 19 patients randomised to receive non-operative (n=8) or operative (n=11) management. The baseline demographic and fracture characteristics of the two arms were overall comparable. Two patients died of unrelated issues in the year following surgery, with the current follow-up rate in those available being 100%. There was a significant improvement in elbow function in both groups over the one year period following injury (p=0.001). There was no difference between groups in terms of functional or patient reported outcomes at all points assessed over the one-year following injury (all p≥0.05). There was a significantly higher rate of complications (81.8% vs 14.3%; p=0.013) and cost (p=0.01) following surgical intervention.

In older lower demand patients, this data provides evidence to support the primary non-operative management of isolated displaced olecranon fractures. This trial was stopped early due to the high rate of complications found in the operative treatment arm on interim analysis and safety monitoring.

11.3 Chapter Introduction

The aims of treatment in displaced olecranon fractures are the restoration of function and stability to the elbow joint, with surgical intervention ordinarily recommended irrespective of age or functional demand[7]. The technique employed should allow preservation and reconstruction of the articular surface with minimal associated complications. Tension-band wiring (TBW) is the most recognised and commonly used fixation method, although plate fixation and intramedullary screw fixation are noted alternatives[7,9,12-17]. While these techniques can be employed in elderly patients with lower functional demands, Chapter 8 and other literature has reported a poorer outcome in elderly patients with wound breakdown and infection, further surgery to remove prominent metalwork, and loss of reduction[18,22-24,29].

Chapter 3 documented the increasing incidence of olecranon fractures in the elderly and Chapter 10 reported good long-term patient reported outcomes following non-operative management for displaced fractures of the olecranon, particularly in lower demand elderly patients with multiple co-morbidities and poor bone quality. This is supported by small case series in the literature reporting favourable short-term results, within the first two years post injury, following the non-operative management of displaced olecranon fractures in both young and elderly patients[28-30]. From this data it is clear that further work is needed to determine whether surgical treatment within this patient group provides any significant benefit over non-operative management.

11.4 Patients and Methods

11.4.1 Patients and database construction

This was a registered two centre prospective, randomized controlled trial of elderly patients (≥75yrs of age) with a stable displaced fracture of the olecranon (ClincalTrials.gov ID NCT01397643). The study centres were a large academic urban trauma centre and a large district general hospital. The primary outcome measure was the Disability Arm Shoulder and Hand (DASH) score at one year post injury[367,368]. The appropriate ethical and clinical trial committees authorised the study.

Between October 2010 and August 2014, 19 elderly patients greater than or equal to 75 years of age with an acute (within two weeks of injury) displaced fracture of the olecranon were recruited into the study (Figure 11.1). The inclusion and exclusion criteria are described in Table 11.1. Displacement of >2mm of displacement of the articular surface on standard radiographs was used as the definition of displacement[9,226]. Mayo type 2A and 2B fractures were included.

Inclusion criteria	**Exclusion criteria**
1. Age ≥75 years 2. Displaced fracture of the olecranon 3. Minimal, moderate or severe fragmentation of the olecranon 4. Within two weeks of olecranon fracture	1. Patients unable to give informed consent 2. Associated fractures to the coronoid, radial head and/or distal humerus 3. Associated ligamentous injury, dislocation or subluxation 4. Open fractures 5. Patients unable to comply with follow-up

Table 11.1: Inclusion and exclusion criteria for the trial.

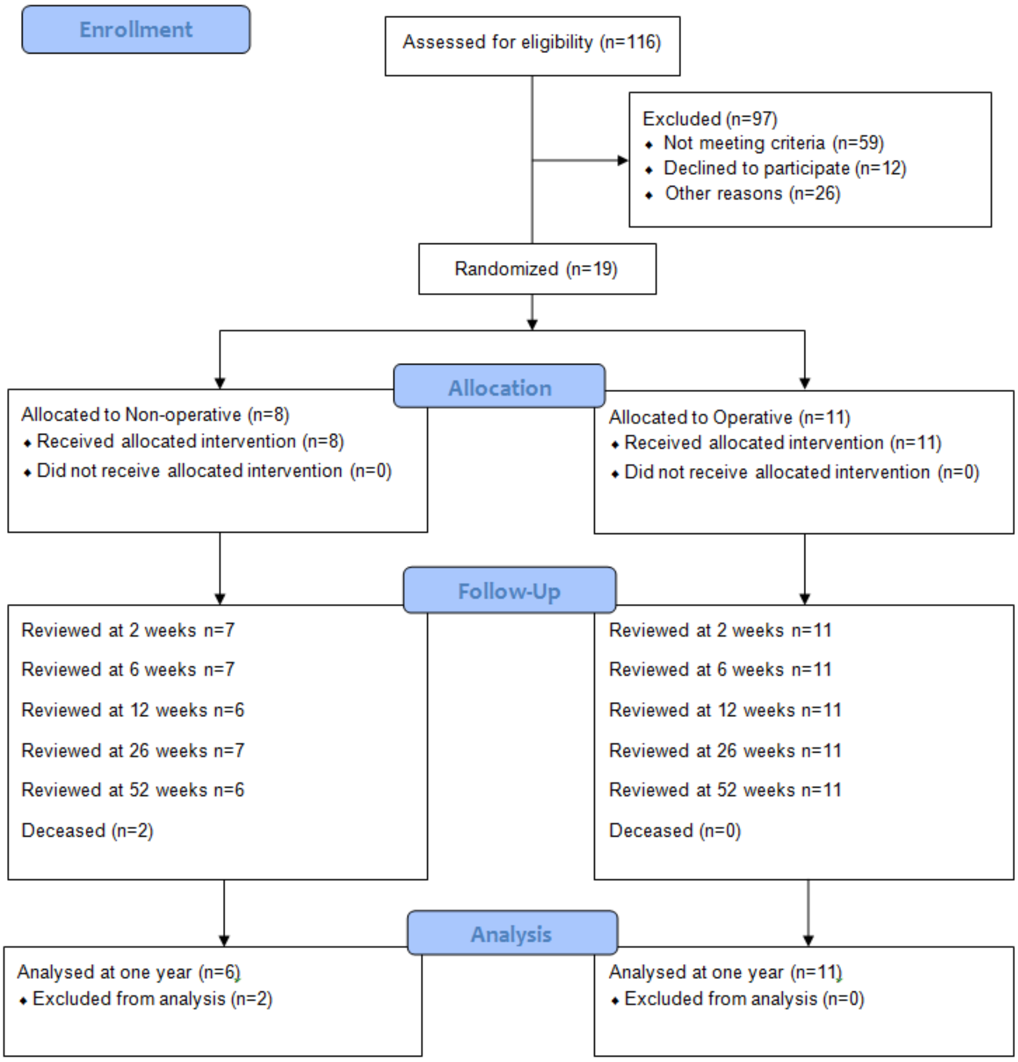

Figure 11.1: CONSORT diagram for recruitment and flow of participants through the trial. One patient (non-operative) is awaiting one year follow-up.

Demographic data was documented at initial presentation including age, gender, co-morbidities, smoking, alcohol, BMI, mechanism of injury and injury dominance. The Index of Multiple Deprivation (IMD 2009) was used to assess socioeconomic deprivation[281], which is described in Section 2.2. Patients were asked to complete a retrospective DASH score as a baseline at presentation.

Randomisation

Following informed consent, patients were randomized to receive either operative or non-operative management[m]. This was performed by opening sequential closed opaque envelopes that contained a card detailing to which of the two groups (non-operative or operative) the patient had been randomised. Randomisation was on a 1:1 basis.

11.4.2 Radiographic classification

The radiographic classification of these patients is described in Section 9.4.2.

11.4.3 Management protocol

Patients in the non-operative group were placed in a collar and cuff (n=4) for two weeks and allowed to mobilise under supervised physiotherapy as per normal protocol. Patients in this group could be placed alternatively into a cast (~60 degrees of flexion) if pain was not controlled with a collar and cuff alone (n=4).

[m] Thank you to Dr Rob Elton for his assistance with the randomisation.

For those patients in the operative group, tension band wire (n=9) or plate (n=2) fixation was employed depending on the fracture configuration, with plate fixation used for severely comminuted fractures. The median time to definitive surgery was two days (range, 1-11) and the median tourniquet time was 42 minutes (range, 30-62). All fractures were operated on under the supervision of a treating consultant trauma surgeon. In four (36.3%) cases the consultant was the primary surgeon, with a trauma fellow or senior trainee the primary surgeon in the remaining 7 (63.7%) cases. Details of the surgical technique and post-operative protocol are found in Section 9.4.3.

11.4.4 Outcome assessment

The outcome assessment of these patients is described in Section 9.4.4.

11.4.5 Statistical analysis

Details of the power analysis are found in Section 2.1.5. Data was analysed using the intention to treat principle. Outcomes between the two groups were compared using a Fisher's exact test for binary variables as one cell in each analysis was always <5. The Mann-Whitney used to compare quantitative variables with the naturally skewed distribution of data given the relatively small numbers analysed. A paired Wilcoxon rank test was used to analyse the improvement in DASH scores at six weeks to one year post injury. The Spearman correlation was used to analyse the correlation between two continuous variables (e.g. age and displacement versus DASH), with the Kruskal-Wallis test used for non-parametric continuous data where a variable had more than two categories. A p value of <0.05 was considered statistically significant.

Multivariate linear regression analysis was used to control for confounding variables including age, gender, deprivation, co-morbidities and ASA grade. Two tailed p-values were reported and statistical significance was set at $p<0.05$, with 95% confidence intervals (95% CI) presented.

11.5 Results

Of the 116 patients assessed for eligibility during the study period, 19 patients were randomised to receive non-operative (n=8) or operative (n=11) management (Figure 11.1). The overall mean age was 83yrs (range, 75-92yrs; SD 5.3) and a significant female predominance was found (n=17, 89.5%, p<0.001). The mean age of females was 83yrs (range, 75-92; SD 7.8), which was not significantly different (p=0.790) from the mean age of males (85yrs; range, 79-90yrs; SD, 7.8) at the time of injury. The right side was affected in 12 (63.2%) cases. One or more co-morbidities were documented in 94.7% (n=38) of patients and a majority of patients were an ASA grade 2 (n=10, 52.6%) or 3 (n=8, 42.1%). The Abbreviated Mental Test (AMT) score for all patients was 10. The most frequent mechanism of injury was a fall from standing height (n=17, 89.5%), followed by a fall from height (n=1, 5.3%) and a motor vehicle collision (n=1, 5.3%). Comminution (Mayo type 2B) was found in 10 (52.65) fractures, with the remaining 9 a Mayo type 2A. The mean fracture displacement was 15mm (range, 7-29). Two patients (10.5%) had concomitant injuries including one ipsilateral proximal humeral fracture managed non-operatively and one ipsilateral neck of femur fractures managed with a dynamic hip screw.

The baseline demographic and fracture characteristics of the two arms are found in Table 11.2. The mean age of patients was marginally younger in the non-operative arm (80 vs 85 years), with all other characteristics comparable including co-morbidities, ASA grade, fracture characteristics and the baseline pre-injury DASH score.

		Non-operative (n=8)	Operative (n=11)
Mean age (range, SD, 95% CI)		80 (75-91, 5.0, 76-84)	85 (79-92, 4.5, 82-88)
Gender (n)	*Male*	1	1
	Female	7	10
Dominant Hand (n)	*Left*	0	1
	Right	8	10
Side of Injury (n)	*Left*	3	4
	Right	5	7
Smoker		2	0
Alcohol consumption (units/week)	*≤21*	7	11
	>21	1	0
Co-morbidities ≥1 (n)		7	11
SIMD			
	1	3	1
	2	2	1
	3	0	4
	4	1	1
	5	2	4
ASA Grade (n)			
	1	1	0
	2	3	7
	3	4	4
Median Abbreviated Mental Test (AMT) Score			
Mechanism of injury (n)			
	Fall from standing height	0	1
	Fall from height	7	10
	MVC	1	0
Mayo Fracture Classification			
	Type 2A	4	5
	Type 2B	4	6
Median fracture displacement mm (range, SD, 95% CI)		14.2 (9-21, 4.5, 10-18)	15.4 (7-29, 6.6, 11-20)
Pre-injury DASH (range, SD, 95% CI)		(n=7) 12.6 (0-49, 17.6, -3.7-29)	(n=10) 5.9 (0-20, 8.7, 0-12)

Table 11.2: Baseline characteristics of 19 study participants by randomisation treatment group.

11.5.1 Primary outcome

At one year following injury the mean DASH score was 22.5 (range, 0-59.6; SD 18). For all patients there was a significant improvement in the DASH score from 6 weeks (mean 39.1) to one year (mean 22.5) following injury (Table 11.3, Figure 11.2, p=0.001).

Time Point	Mean Outcome	Non-operative	Operative	p-value*
	(Range, SD, 95% CI)	(n=7)	(n=11)	
6 weeks	Elbow Flexion Arc	98 (40-136, 32, 69-128)	105 (55-132, 23, 89-121)	0.716
	Forearm Rotation Arc	154 (70-180, 43, 114-193)	167 (130-180, 16, 156-178)	0.961
	B&M Score	66 (45-92, 17, 51-82)	72 (44-85, 16, 62-82)	0.389
	MES	74 (50-100, 16, 60-89)	77 (55-85, 11, 70-84)	0.512
	DASH	37 (8.3-58,18, 21-54)	39 (12-80, 22, 25-54)	0.892
	(Range, SD, 95% CI)	(n=6)	(n=11)	
12 weeks	Elbow Flexion Arc	111 (75-135, 22, 88-134)	116 (55-141, 24, 100-132)	0.580
	Forearm Rotation Arc	155 (75-180, 41, 112-198)	173 (160-180,10, 166-179)	0.363
	B&M Score	77 (60-97, 13, 63-91)	78 (44-93, 16, 68-89)	0.580
	MES	85 (70-100, 9.5, 75-95)	79 (50-85, 13, 70-87)	0.318
	DASH	24 (3.4-44, 18, 5.4-42)	32 (6-88, 25, 16-49)	0.365
	(Range, SD, 95% CI)	(n=7)	(n=11)	
26 weeks	Elbow Flexion Arc	116 (70-145, 28, 90-141)	118 (70-140, 20, 105-132)	0.785
	Forearm Rotation Arc	160 (70-180, 40, 123-197)	172 (160-180, 10, 165-178)	1.000
	B&M Score	84 (66-100, 12, 73-95)	88 (71-100, 10, 81-94)	0.650
	MES	87 (80-100, 9.1, 79-96)	90 (70-100, 12, 83-98)	0.502
	DASH	31 (0-73, 24, 8.7-54)	21 (0-72, 21, 6.6-35)	0.365
	(Range, SD, 95% CI)	(n=6)	(n=11)	
52 weeks	Elbow Flexion Arc	109 (75-140, 27, 81-137)	129 (105-145, 12, 120-137)	0.156
	Forearm Rotation Arc	160 (80-180, 40, 118-202)	175 (160-180, 9.3, 168-181)	0.659
	B&M Score	89 (66-100, 13, 75-103)	94 (80-100, 7.1, 89-99)	0.504
	MES	95 (80-100, 8.4, 86-104)	95 (85-100, 7.6, 89-99)	0.906
	DASH	23 (0-59.6, 20, 2.9-44)	22 (2.5-57.8, 18, 9.8-34)	0.763

Table 11.3: Functional, patient reported and surgeon reported outcomes one year after injury by treatment group. *All p-values are using a Mann-Whitney test.

Two patients died of unrelated issues in the year following surgery. The current follow-up rate in those available is 100%, with one patient in the non-operative arm awaiting their final one year review at the time of writing. This patient had already attained excellent scores at six months so the outcome was brought forward to one year for the purpose of this analysis. There was no difference between groups in terms of the DASH score at all the assessment points over the one-year following injury (Table 11.3, Figure 11.2, all p≥0.05), with the mean DASH score at one year 22 (range, 2.5-57.8) in the operative group and 23 (range, 0-59.6) in the non-operative group (p=0.763).

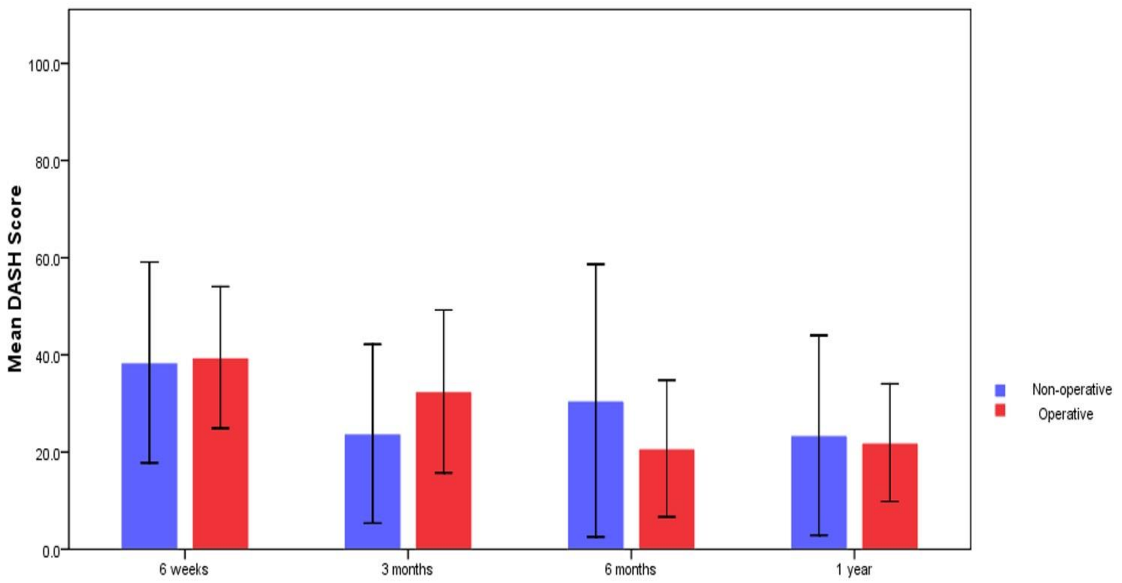

Figure 11.2: Change in DASH score over time with 95% confidence intervals.

11.5.2 Secondary outcomes

Functional and surgeon reported outcomes

At one year following injury the mean Broberg and Morrey score was 92 (range, 66-100; SD 9.6), with 94% achieving an excellent (n=9) or good (n=7) outcome. One patient had a fair outcome. At one year the mean MES was 95 (range, 80-100; SD 8.0), with 100% achieving an excellent (n=12) or good (n=5) outcome. The mean elbow flexion was 140 degrees (range, 105-155; SD 13.5), the mean extension deficit was 19 degrees (range, 5-40; SD 11) and the mean flexion arc was 122 degrees (range, 75-145; SD 20). The mean pronation was 83 degrees (range, 0-90; SD 22), the mean supination was 86 degrees (range, 70-90; SD 6) and the mean forearm rotation was 169 degrees (range, 80-180; SD 25). There was no difference between groups in terms of elbow flexion arc, forearm rotation arc, Broberg and Morrey Score, or the MES at all the assessment points over the one-year following injury (Table 11.3, all $p \geq 0.05$).

Complications

There were 17 complications found in 10 patients, with a significantly higher rate of complications in the operative arm (Table 11.4, 81.8% vs 14.3%, p=0.013). Only one patient in the non-operative arm had a complication. This patient had an associated subtle subluxation of the radial head that was more apparent at the two week review and required operative fixation, which unfortunately failed and lost reduction secondary to infection. The infection settled following a second operation to excise the sinus and remove the metalwork, followed by a prolonged course of oral flucloxacillin and co-trimoxazole. The most common complications in the operative arm were a loss of fracture reduction (n=6, Figure 11.3) and further surgery for removal of metalwork (n=3). All three involved prominent symptomatic metalwork, with one of these cases also undergoing a chronic sinus excision associated with a previous superficial wound infection.

	Non-operative (n=7)	**Operative** (n=11)	**p value***
Total complications	1	9	**0.013**
Infection	1	1	1.000
Loss of reduction	1	6	0.151
Subsequent surgery	1	3	0.245
Removal of metalwork	0	3	
Revision	1	0	

Table 11.4: Complications within one year following injury by treatment group. *All p-values are a Fisher's exact test.

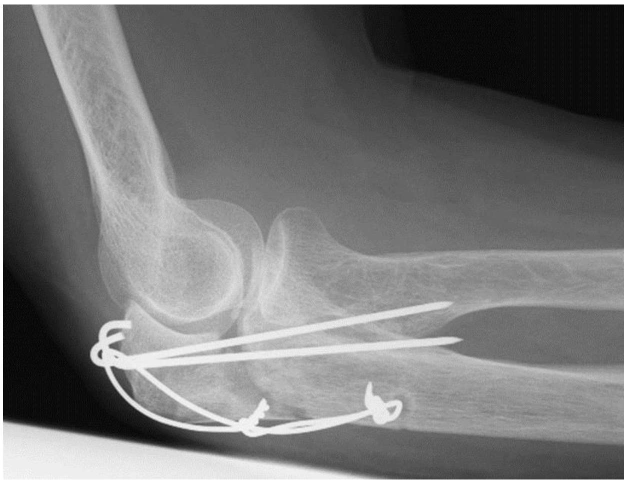

Figure 11.3: Loss of fracture reduction.

Radiographic outcome

Initial fracture reduction in the operative group was deemed satisfactory in 8 of 9 patients treated with TBW and in 2 of 2 patients managed with plate fixation. There were nine patients who progressed to a radiological union (9/11 in the operative group), with the remaining nine developing a functional fibrous non-union (7/7 in the non-operative group and 2/9 in the operative group). A functional non-union was when the patient had a functional range of motion, any symptoms were well controlled and no further intervention was planned. The two non-unions in the operative group were secondary to early loss of fracture reduction and fixation. One patient in the non-operative group who developed a fibrous non-union had a persistent radial head subluxation (Figure 11.4) following infection and fixation failure (see above). This patient was pain free at one year with a functional range of movement and did not want any further intervention.

Figure 11.4: Persistent radial head subluxation and a non-union of the olecranon in a patient that had failed fixation secondary to infection.

Cost analysis

The median number of days in hospital was four (range, 0-28), which was higher for those patients in the surgical treatment arm (Table 11.5). The median cost per patient was £5080 (range, 433-21186), with the cost per patient following surgery significantly higher than those who underwent non-operative intervention (Table 11.5, p=0.01). On average non-operative intervention was £6795 cheaper than operative intervention.

	Non-operative (n=7)	**Operative** (n=11)
Median total days in hospital (n/range)	2 (0-9)	6 (1-28)
Median cost of primary intervention (£/range)	20 (3-20)	32 (32-563)*
Median no. of clinic reviews (n/range)	5 (5-10)	5 (5-8)
Median cost of antibiotics (£/range)	0 (0-14)	0 (0-3.90)
Number of extra trips to theatre (n/%)	2	3
Median cost of further implants (£/range)	0 (0-32)	0
Overall mean cost/patient (£)	3249 (433-10649)	10044 (2961-21186)

Table 11.5: Cost analysis by treatment group. *Does not include a standard theatre cost of £1824, which was included in the overall costings.

11.5.3 Predictors of outcome

Age (p=0.458), gender (p=0.618), past medical history (p=0.118), deprivation (p=0.909), ASA grade (p=0.199), mechanism of injury (p=0.409), degree of fracture displacement (p=0.633) and associated injuries (p=0.721) were not predictive of the primary outcome (DASH) at one year. No correlation was found between fracture union and the DASH at one year (p=0.815). On multivariate linear regression analysis, controlling for age, gender, deprivation, co-morbidities and ASA grade there was no correlation between treatment arm and the DASH score at one year (Table 11.6).

Variable	Regression Coefficient	95% Confidence Limits	p-value
Age	1.144	-1.4 to 3.7	0.337
Gender	-2.489	-36 to 31	0.872
Deprivation	1.674	-6.3 to 9.7	0.652
Co-morbidities	3.236	-65 to 71	0.917
ASA Grade	15.947	-8.3 to 40	0.174
Management	-9.744	-37 to 17	0.438

Table 11.6: Multivariate linear regression analysis controlling for baseline demographic characteristics. (R squared value 0.310)

11.6 Chapter Discussion

This is the first randomised controlled trial directly comparing non-operative and operative management for stable displaced fractures of the olecranon. Despite the trial stopping early, comparable patient and surgical reported outcomes were reported at every assessment stage in the year following injury, with a significantly higher rate of complications and cost found in the operative group. This data, in combination with the findings reported in Chapter 10, provide evidence to support the primary non-operative management of isolated displaced olecranon fractures in older lower demand patients. The primary caveat in employing non-operative management for displaced olecranon fractures is the rare subtle unstable injury that may not be obviously apparent on initial radiographs, which was seen in this series. Prompt and definitive fixation is recommended in all these cases.

The reported issues in the literature associated with operative fixation for a displaced olecranon fracture in elderly patients were all reported in this small series and included poor fixation in osteoporotic bone leading to loss of reduction (two thirds of the operatively managed group in this trial), problems associated with wound breakdown and infection, and the requirement for a further procedure to remove prominent symptomatic metalwork[18,22-24,29]. However, as already discussed, it is essential that conservative management does adequately manage pain, allow early movement, provide active extension power at the elbow and meet the longer-term requirements of the patient[26,27,29].

The findings of this trial would suggest that in the early period post injury there does not seem to be a delayed recovery or increased complication rate when compared to operative intervention for patients managed non-operatively for a displaced fracture of the olecranon. The outcome was comparable at all the time points in the year following injury with regards to range of motion, surgeon reported outcome scores and PROMs in this study. Despite the predominant adverse outcomes following the non-operative management of displaced olecranon fractures appearing to be a weakness of elbow extension strength and the development of a fibrous non-union[11,378], this does not appear to significantly affect the PROM in the short or longer term for this patient group. No association was found between the development of a fibrous non-union and the DASH score in this study or in Chapter 10.

Gallucci et al recently reported on a retrospective short-term case series of 28 elderly patients all over 70 years of age (mean age 82 years) who were treated with five days in an above elbow cast for a displaced olecranon fracture, which was defined as any articular displacement or displacement of the posterior cortex of >5mm[378]. Ten (36%) fractures were comminuted (Mayo type 2B) but no fractures were open or associated with an elbow dislocation. At a mean of 16 months post injury the mean satisfaction score was 9 and the Parker outcome score was good in 25 patients and fair in three. The median DASH score was 15 and the mean MES was 95, with all patients rated excellent (n=22) and or good (n=6). Nine (35%) patients reported loss of extension strength (MRC grade 4) and 22 (85%) developed a radiographic non-union. This study is consistent and comparable to the results presented in Chapter 10 and adds further support to the findings of this chapter.

There are advocates for alternative surgical techniques in the elderly patient to avoid the potential complications associated with prominent metalwork. A well-established alternative is fracture excision with advancement of the triceps[17,25,259,260], with important pre-requisites being a stable elbow and forearm and that the excision involves <50% of the trochlear notch[9,230,261]. An alternative fixation method uses a suture technique to reduce and fix displaced fractures of the olecranon in the elderly patient. Bateman et al reported a 100% union rate with no re-operations using a suture anchor fixation technique for both Mayo type 2A and type 2B fractures in eight female patients with a mean age of 74 years[359]. In the six patients available at a mean of 5 years post injury, the mean OES was 47 and the mean DASH was 6.4. However, there is currently no evidence to suggest these techniques give a superior outcome to non-operative management in this patient group.

11.6.1 Strengths and limitations

The primary strengths of this trial are the high level of compliance with over 90% of patients receiving their allocated treatment, and the high follow-up rate at one year in those patients available (100%). As with the young trial presented in Chapter 9, although there was a lack of blinding and multiple surgeons were involved in the care of these patients, this scenario is most representative of day-to-day clinical practice i.e. pragmatic[373,374].

The primary limitation of this data is that the trial was stopped early due to the high rate of complications found in the operative treatment arm on interim analysis and safety monitoring. This was associated with a lack of equipoise that developed during the trial from both those involved with running it and the surgeons within the study centres. Give the small numbers analysed and the fact the trial has been potentially stopped prematurely, the data is not powered to determine a difference in the primary outcome measure as was originally planned. This issue is also apparent given the difference found in age between the two groups, with the operative group five years older on average than the non-operative group. However, when controlling for age using multivariate analysis, no difference was found in the primary outcome measure between the two groups. Despite these issues, positive findings in terms of complication rates and cost have been found and it would still seem that this data does add to a growing body of evidence to support the role of non-operative treatment for displaced olecranon fractures in lower demand elderly patients.

An inherent issue with any study in elderly patients is using age as a marker for true biological age. The age of 75 years was chosen based on epidemiological (Chapter 3) and retrospective (Chapter 10) data presented within this thesis. It is acknowledged that this is a crude marker of functional activity and some authors have advocated the use of physical activity scoring systems to stratify these patients[379,380]. However, there is not currently a reliable alternative used regularly within the orthopaedic literature.

12 CONCLUSIONS

The study on the epidemiology of proximal forearm fractures demonstrated an association with fragility and highlighted the importance of investigating the role of non-operative management for these injuries. Given the number of elderly patients sustaining these injuries, consideration of osteoporosis is also important and future work is needed to determine the role of assessing bone quality following these fractures, particularly in post-menopausal women.

From both prospective and retrospective data on the non-operative management of isolated stable radial head and neck fractures, excellent long-term patient reported outcomes were found in the majority of patients and very few patients required secondary intervention for persisting complaints. These studies found that increasing age, co-morbidities, socioeconomic deprivation and compensation were the patient related factors predictive of outcome. The only injury characteristic potentially associated with an inferior outcome was displacement, with fractures displaced 5mm or more associated with an inferior outcome. However, given the small number of fractures displaced 5mm or more, it is difficult to draw firm conclusions from this and also to determine whether surgery would necessarily provide a superior outcome over non-operative treatment for these cases.

For complex unstable radial head fractures where replacement is indicated, a satisfactory short-term functional outcome is possible despite the severity of these injuries. There is a high rate of implant removal or revision, especially in younger patients, and they should be counselled regarding the increased risk of requiring further surgery following replacement. Combing the data presented here with the existing literature, a management algorithm can be suggested (Figure 12.1).

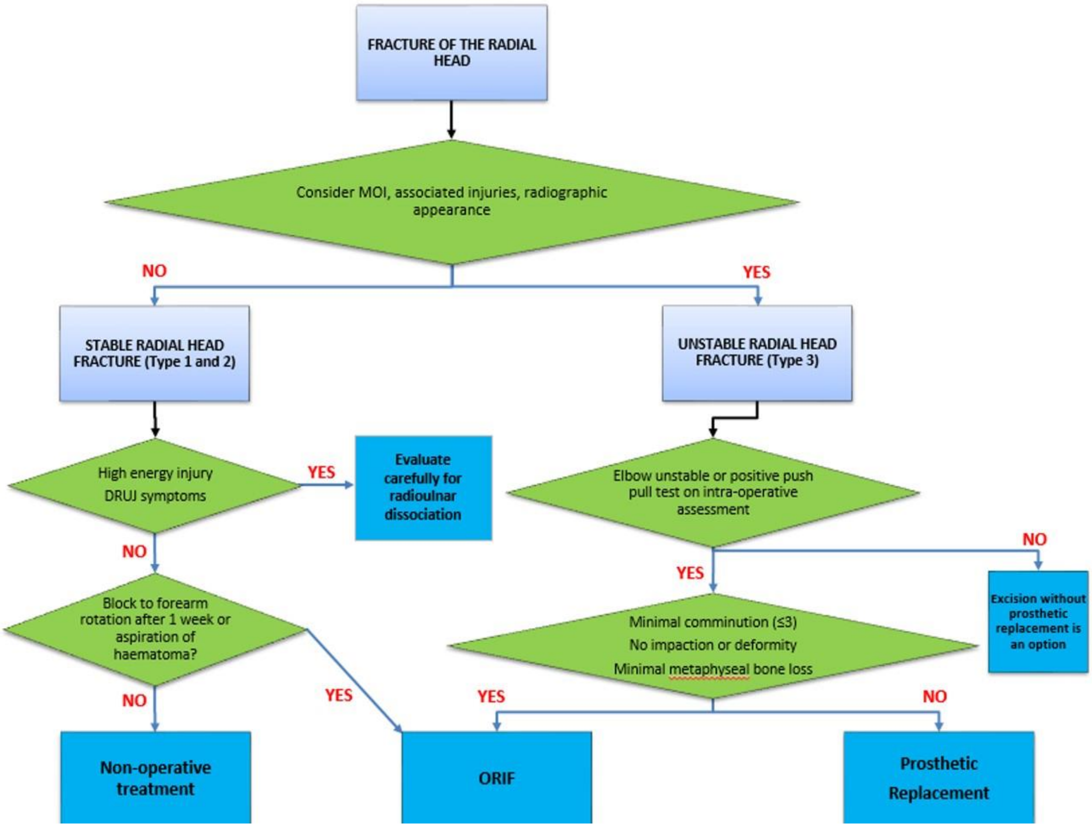

Figure 12.1: A management algorithm for fractures of the radial head.

From long-term retrospective work and a subsequent large prospective randomised controlled trial, TBW and plate fixation were found to have comparable functional and patient reported outcomes for younger active patients who sustain an isolated displaced fracture of the olecranon. Both techniques appear to be as cost effective, as one in two patients who undergo TBW fixation requires subsequent metalwork removal. Future work could focus on alternative fixation methods associated with a lower rate of symptomatic metalwork e.g. suture fixation, to determine if they are as effective as TBW or plate fixation in the short and long term.

Data from a large long-term retrospective study and a small prospective randomised controlled trial supported the role of non-operative management for isolated displaced olecranon fractures in older lower demand patients. Although initial work suggested that increased fracture displacement was predictive of an inferior long-term outcome, the number of patients in this analysis was too small to make definitive conclusions and the subsequent randomised controlled trial found no association between displacement and the short-term patient reported outcome.

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APPENDICIES

APPENDIX 1 – SMFA Questionnaire

StudyID_______________

Short Musculoskeletal Function Assessment

Injury and Arthritis Survey

Please complete this survey today.

For further information contact:
MFA Project / 325 - 9th Avenue / Harborview Medical Center
University of Washington, Box 359798 / Seattle, Washington 98104 / (206) 731-4113

Short Version, Form MFA46A

PART I: INSTRUCTIONS

We are interested in finding out how you are managing with your injury or arthritis this week. We would like to know about any problems you may be having with your daily activities because of your injury or arthritis.

Please answer each question by putting a check in the box ☑ next to the choice that best describes you.

If you wish to comment on any of the questions, please use the space in the margins. Please answer all questions, even though some of the questions may not apply to your injury or arthritis.

These questions are about how much difficulty you may be having this week with your daily activities because of your injury or arthritis.

1. HOW DIFFICULT IS IT FOR YOU TO GET IN OR OUT OF A LOW CHAIR?

☐ Not at All Difficult ☐ A Little Difficult ☐ Moderately Difficult ☐ Very Difficult ☐ Unable to Do

2. HOW DIFFICULT IS IT FOR YOU TO OPEN MEDICINE BOTTLES OR JARS?

☐ Not at All Difficult ☐ A Little Difficult ☐ Moderately Difficult ☐ Very Difficult ☐ Unable to Do

3. HOW DIFFICULT IS IT FOR YOU TO SHOP FOR GROCERIES OR OTHER THINGS?

☐ Not at All Difficult ☐ A Little Difficult ☐ Moderately Difficult ☐ Very Difficult ☐ Unable to Do

4. HOW DIFFICULT IS IT FOR YOU TO CLIMB STAIRS?

☐ Not at All Difficult ☐ A Little Difficult ☐ Moderately Difficult ☐ Very Difficult ☐ Unable to Do

5. HOW DIFFICULT IS IT FOR YOU TO MAKE A TIGHT FIST?

☐ Not at All Difficult ☐ A Little Difficult ☐ Moderately Difficult ☐ Very Difficult ☐ Unable to Do

6. HOW DIFFICULT IS IT FOR YOU TO GET IN OR OUT OF THE BATHTUB OR SHOWER?

☐ Not at All Difficult ☐ A Little Difficult ☐ Moderately Difficult ☐ Very Difficult ☐ Unable to Do

7. HOW DIFFICULT IS IT FOR YOU TO GET COMFORTABLE TO SLEEP?

☐ Not at All Difficult ☐ A Little Difficult ☐ Moderately Difficult ☐ Very Difficult ☐ Unable to Do

8. HOW DIFFICULT IS IT FOR YOU TO BEND OR KNEEL DOWN?

☐ Not at All Difficult ☐ A Little Difficult ☐ Moderately Difficult ☐ Very Difficult ☐ Unable to Do

9. HOW DIFFICULT IS IT FOR YOU TO USE BUTTONS, SNAPS, HOOKS, OR ZIPPERS?

☐ Not at All Difficult ☐ A Little Difficult ☐ Moderately Difficult ☐ Very Difficult ☐ Unable to Do

10. HOW DIFFICULT IS IT FOR YOU TO CUT YOUR OWN FINGERNAILS?

☐ Not at All Difficult ☐ A Little Difficult ☐ Moderately Difficult ☐ Very Difficult ☐ Unable to Do

11. HOW DIFFICULT IS IT FOR YOU TO DRESS YOURSELF?

☐ Not at All Difficult ☐ A Little Difficult ☐ Moderately Difficult ☐ Very Difficult ☐ Unable to Do

12. HOW DIFFICULT IS IT FOR YOU TO WALK?

☐ Not at All Difficult ☐ A Little Difficult ☐ Moderately Difficult ☐ Very Difficult ☐ Unable to Do

13. HOW DIFFICULT IS IT FOR YOU TO GET MOVING AFTER YOU HAVE BEEN SITTING OR LYING DOWN?

☐ Not at All Difficult ☐ A Little Difficult ☐ Moderately Difficult ☐ Very Difficult ☐ Unable to Do

14. HOW DIFFICULT IS IT FOR YOU TO GO OUT BY YOURSELF?

☐	☐	☐	☐	☐
Not at All Difficult	A Little Difficult	Moderately Difficult	Very Difficult	Unable to Do

15. HOW DIFFICULT IS IT FOR YOU TO DRIVE?

☐	☐	☐	☐	☐
Not at All Difficult	A Little Difficult	Moderately Difficult	Very Difficult	Unable to Do

16. HOW DIFFICULT IS IT FOR YOU TO CLEAN YOURSELF AFTER GOING TO THE BATHROOM?

☐	☐	☐	☐	☐
Not at All Difficult	A Little Difficult	Moderately Difficult	Very Difficult	Unable to Do

17. HOW DIFFICULT IS IT FOR YOU TURN KNOBS OR LEVERS, FOR EXAMPLE, OPEN DOORS, ROLL DOWN CAR WINDOWS?

☐	☐	☐	☐	☐
Not at All Difficult	A Little Difficult	Moderately Difficult	Very Difficult	Unable to Do

18. HOW DIFFICULT IS IT FOR YOU TO WRITE OR TYPE?

☐	☐	☐	☐	☐
Not at All Difficult	A Little Difficult	Moderately Difficult	Very Difficult	Unable to Do

19. HOW DIFFICULT IS IT FOR YOU TO PIVOT?

☐	☐	☐	☐	☐
Not at All Difficult	A Little Difficult	Moderately Difficult	Very Difficult	Unable to Do

20. HOW DIFFICULT IS IT FOR YOU TO DO YOUR USUAL PHYSICAL RECREATIONAL ACTIVITIES, SUCH AS BICYCLING, JOGGING, OR WALKING?

☐ Not at All Difficult ☐ A Little Difficult ☐ Moderately Difficult ☐ Very Difficult ☐ Unable to Do

21. HOW DIFFICULT IS IT FOR YOU TO DO YOUR USUAL LEISURE ACTIVITIES, SUCH AS HOBBIES, CRAFTS, GARDENING, CARD PLAYING, GOING OUT WITH FRIENDS?

☐ Not at All Difficult ☐ A Little Difficult ☐ Moderately Difficult ☐ Very Difficult ☐ Unable to Do

22. HOW MUCH DIFFICULTY ARE YOU HAVING WITH SEXUAL ACTIVITY?

☐ Not at All Difficult ☐ A Little Difficult ☐ Moderately Difficult ☐ Very Difficult ☐ Unable to Do

23. HOW DIFFICULT IS IT FOR YOU TO DO <u>LIGHT</u> HOUSEWORK <u>OR</u> YARDWORK, SUCH AS DUSTING, WASHING DISHES, OR WATERING PLANTS?

☐ Not at All Difficult ☐ A Little Difficult ☐ Moderately Difficult ☐ Very Difficult ☐ Unable to Do

24. HOW DIFFICULT IS IT FOR YOU TO DO <u>HEAVY</u> HOUSEWORK <u>OR</u> YARDWORK, SUCH AS WASHING FLOORS, VACUUMING, OR MOWING LAWNS?

☐ Not at All Difficult ☐ A Little Difficult ☐ Moderately Difficult ☐ Very Difficult ☐ Unable to Do

25. HOW DIFFICULT IS IT FOR YOU TO DO YOUR USUAL WORK, SUCH AS A PAID JOB, HOUSEWORK, VOLUNTEER ACTIVITIES?

☐ Not at All Difficult ☐ A Little Difficult ☐ Moderately Difficult ☐ Very Difficult ☐ Unable to Do

These next questions ask how often you are experiencing problems <u>this</u> <u>week</u>, because of your injury or arthritis.

26. HOW OFTEN DO YOU WALK WITH A LIMP?

☐	☐	☐	☐	☐
None of the Time	A Little of the Time	Some of the Time	Most of the Time	All of the Time

27. HOW OFTEN DO YOU AVOID USING YOUR PAINFUL LIMB(S) OR BACK?

☐	☐	☐	☐	☐
None of the Time	A Little of the Time	Some of the Time	Most of the Time	All of the Time

28. HOW OFTEN DOES YOUR LEG LOCK OR GIVE-WAY?

☐	☐	☐	☐	☐
None of the Time	A Little of the Time	Some of the Time	Most of the Time	All of the Time

29. HOW OFTEN DO YOU HAVE PROBLEMS WITH CONCENTRATION?

☐	☐	☐	☐	☐
None of the Time	A Little of the Time	Some of the Time	Most of the Time	All of the Time

30. HOW OFTEN DOES DOING TOO MUCH IN ONE DAY AFFECT WHAT YOU DO THE NEXT DAY?

☐	☐	☐	☐	☐
None of the Time	A Little of the Time	Some of the Time	Most of the Time	All of the Time

31. HOW OFTEN DO YOU ACT IRRITABLE TOWARD THOSE AROUND YOU, FOR EXAMPLE, SNAP AT PEOPLE, GIVE SHARP ANSWERS, CRITICIZE EASILY?

☐	☐	☐	☐	☐
None of the Time	A Little of the Time	Some of the Time	Most of the Time	All of the Time

32. HOW OFTEN ARE YOU TIRED?

☐	☐	☐	☐	☐
None of the Time	A Little of the Time	Some of the Time	Most of the Time	All of the Time

33. HOW OFTEN DO YOU FEEL DISABLED?

☐	☐	☐	☐	☐
None of the Time	A Little of the Time	Some of the Time	Most of the Time	All of the Time

34. HOW OFTEN DO YOU FEEL ANGRY OR FRUSTRATED THAT YOU HAVE THIS INJURY OR ARTHRITIS?

☐	☐	☐	☐	☐
None of the Time	A Little of the Time	Some of the Time	Most of the Time	All of the Time

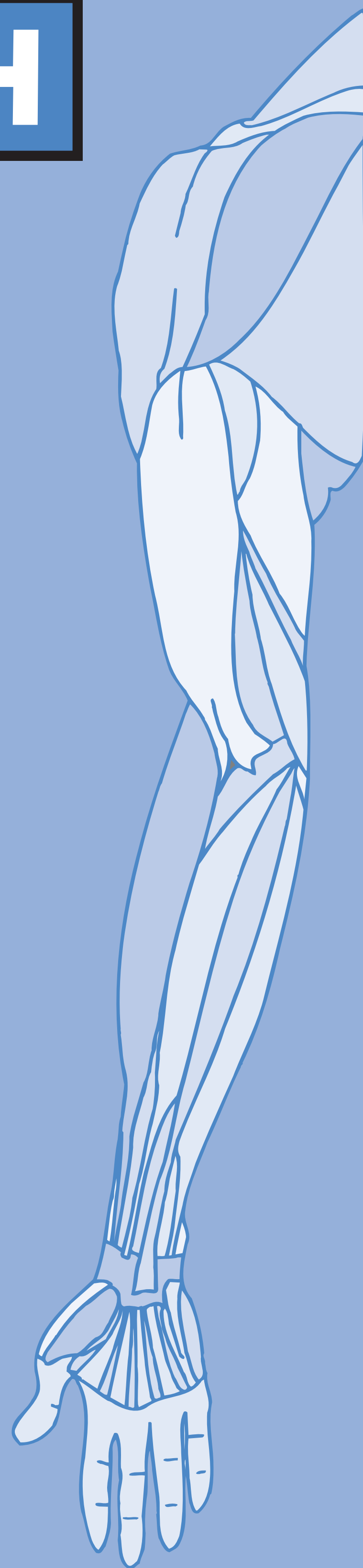
These questions are about how much you are bothered by problems you are having this week, due to your injury or arthritis.

How much are you bothered by...

		Not at All Bothered	A Little Bothered	Moderately Bothered	Very Bothered	Extremely Bothered
35.	PROBLEMS USING YOUR HANDS, ARMS OR LEGS	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐
36.	PROBLEMS USING YOUR BACK	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐
37.	PROBLEMS DOING WORK AROUND YOUR HOME	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐
38.	PROBLEMS WITH BATHING, DRESSING, TOILETING, OR OTHER PERSONAL CARE	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐
39.	PROBLEMS WITH SLEEP AND REST	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐
40.	PROBLEMS WITH LEISURE OR RECREATIONAL ACTIVITIES	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐
41.	PROBLEMS WITH YOUR FRIENDS, FAMILY OR OTHER IMPORTANT PEOPLE IN YOUR LIFE	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐
42.	PROBLEMS WITH THINKING, CONCENTRATING OR REMEMBERING	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐
43.	PROBLEMS ADJUSTING OR COPING WITH YOUR INJURY OR ARTHRITIS	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐
44.	PROBLEMS DOING YOUR USUAL WORK	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐
45.	PROBLEMS WITH FEELING DEPENDENT ON OTHERS	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐
46.	PROBLEMS WITH STIFFNESS AND PAIN	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐

APPENDIX 2 – DASH Questionnaire

THE DASH



INSTRUCTIONS

This questionnaire asks about your symptoms as well as your ability to perform certain activities.

Please answer *every question*, based on your condition in the last week, by circling the appropriate number.

If you did not have the opportunity to perform an activity in the past week, please make your *best estimate* on which response would be the most accurate.

It doesn't matter which hand or arm you use to perform the activity; please answer based on your ability regardless of how you perform the task.

Disabilities of the Arm, Shoulder and Hand

Please rate your ability to do the following activities in the last week by circling the number below the appropriate response.

	NO DIFFICULTY	MILD DIFFICULTY	MODERATE DIFFICULTY	SEVERE DIFFICULTY	UNABLE
1. Open a tight or new jar.	**1**	**2**	**3**	**4**	**5**
2. Write.	**1**	**2**	**3**	**4**	**5**
3. Turn a key.	**1**	**2**	**3**	**4**	**5**
4. Prepare a meal.	**1**	**2**	**3**	**4**	**5**
5. Push open a heavy door.	**1**	**2**	**3**	**4**	**5**
6. Place an object on a shelf above your head.	**1**	**2**	**3**	**4**	**5**
7. Do heavy household chores (e.g., wash walls, wash floors).	**1**	**2**	**3**	**4**	**5**
8. Garden or do yard work.	**1**	**2**	**3**	**4**	**5**
9. Make a bed.	**1**	**2**	**3**	**4**	**5**
10. Carry a shopping bag or briefcase.	**1**	**2**	**3**	**4**	**5**
11. Carry a heavy object (over 10 lbs).	**1**	**2**	**3**	**4**	**5**
12. Change a lightbulb overhead.	**1**	**2**	**3**	**4**	**5**
13. Wash or blow dry your hair.	**1**	**2**	**3**	**4**	**5**
14. Wash your back.	**1**	**2**	**3**	**4**	**5**
15. Put on a pullover sweater.	**1**	**2**	**3**	**4**	**5**
16. Use a knife to cut food.	**1**	**2**	**3**	**4**	**5**
17. Recreational activities which require little effort (e.g., cardplaying, knitting, etc.).	**1**	**2**	**3**	**4**	**5**
18. Recreational activities in which you take some force or impact through your arm, shoulder or hand (e.g., golf, hammering, tennis, etc.).	**1**	**2**	**3**	**4**	**5**
19. Recreational activities in which you move your arm freely (e.g., playing frisbee, badminton, etc.).	**1**	**2**	**3**	**4**	**5**
20. Manage transportation needs (getting from one place to another).	**1**	**2**	**3**	**4**	**5**
21. Sexual activities.	**1**	**2**	**3**	**4**	**5**

Disabilities of the Arm, Shoulder and Hand

	NOT AT ALL	SLIGHTLY	MODERATELY	QUITE A BIT	EXTREMELY
22. During the past week, *to what extent* has your arm, shoulder or hand problem interfered with your normal social activities with family, friends, neighbours or groups? *(circle number)*	1	2	3	4	5

	NOT LIMITED AT ALL	SLIGHTLY LIMITED	MODERATELY LIMITED	VERY LIMITED	UNABLE
23. During the past week, were you limited in your work or other regular daily activities as a result of your arm, shoulder or hand problem? *(circle number)*	1	2	3	4	5

Please rate the severity of the following symptoms in the last week. *(circle number)*

	NONE	MILD	MODERATE	SEVERE	EXTREME
24. Arm, shoulder or hand pain.	1	2	3	4	5
25. Arm, shoulder or hand pain when you performed any specific activity.	1	2	3	4	5
26. Tingling (pins and needles) in your arm, shoulder or hand.	1	2	3	4	5
27. Weakness in your arm, shoulder or hand.	1	2	3	4	5
28. Stiffness in your arm, shoulder or hand.	1	2	3	4	5

	NO DIFFICULTY	MILD DIFFICULTY	MODERATE DIFFICULTY	SEVERE DIFFICULTY	SO MUCH DIFFICULTY THAT I CAN'T SLEEP
29. During the past week, how much difficulty have you had sleeping because of the pain in your arm, shoulder or hand? *(circle number)*	1	2	3	4	5

	STRONGLY DISAGREE	DISAGREE	NEITHER AGREE NOR DISAGREE	AGREE	STRONGLY AGREE
30. I feel less capable, less confident or less useful because of my arm, shoulder or hand problem. *(circle number)*	1	2	3	4	5

DASH DISABILITY/SYMPTOM SCORE = $\left[\left(\frac{\text{sum of n responses}}{n}\right) - 1\right] \times 25$, where n is equal to the number of completed responses.

A DASH score may <u>not</u> be calculated if there are greater than 3 missing items.

DISABILITIES OF THE ARM, SHOULDER AND HAND

WORK MODULE (OPTIONAL)

The following questions ask about the impact of your arm, shoulder or hand problem on your ability to work (including homemaking if that is your main work role).

Please indicate what your job/work is:____________________________

p I do not work. (You may skip this section.)

Please circle the number that best describes your physical ability in the past week. Did you have any difficulty:

	NO DIFFICULTY	MILD DIFFICULTY	MODERATE DIFFICULTY	SEVERE DIFFICULTY	UNABLE
1. using your usual technique for your work?	1	2	3	4	5
2. doing your usual work because of arm, shoulder or hand pain?	1	2	3	4	5
3. doing your work as well as you would like?	1	2	3	4	5
4. spending your usual amount of time doing your work?	1	2	3	4	5

SPORTS/PERFORMING ARTS MODULE (OPTIONAL)

The following questions relate to the impact of your arm, shoulder or hand problem on playing *your musical instrument or sport or both*.
If you play more than one sport or instrument (or play both), please answer with respect to that activity which is most important to you.

Please indicate the sport or instrument which is most important to you:_

o I do not play a sport or an instrument. (You may skip this section.)

Please circle the number that best describes your physical ability in the past week. Did you have any difficulty:

	NO DIFFICULTY	MILD DIFFICULTY	MODERATE DIFFICULTY	SEVERE DIFFICULTY	UNABLE
1. using your usual technique for playing your instrument or sport?	1	2	3	4	5
2. playing your musical instrument or sport because of arm, shoulder or hand pain?	1	2	3	4	5
3. playing your musical instrument or sport as well as you would like?	1	2	3	4	5
4. spending your usual amount of time practising or playing your instrument or sport?	1	2	3	4	5

SCORING THE OPTIONAL MODULES: Add up assigned values for each response; divide by 4 (number of items); subtract 1; multiply by 25.
An optional module score may <u>not</u> be calculated if there are any missing items.

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APPENDIX 3 – Oxford Elbow Score

Oxford Elbow Score (OES)

English version for the United Kingdom

PROBLEMS WITH YOUR ELBOW

Tick (✓) one box for every question.

1. During the past 4 weeks...
Have you had difficulty lifting things in your home, such as putting out the rubbish, because of your elbow problem?

No difficulty	A little bit of difficulty	Moderate difficulty	Extreme difficulty	Impossible to do
☐	☐	☐	☐	☐

2. During the past 4 weeks...
Have you had difficulty carrying bags of shopping, because of your elbow problem?

No difficulty	A little bit of difficulty	Moderate difficulty	Extreme difficulty	Impossible to do
☐	☐	☐	☐	☐

3. During the past 4 weeks...
Have you had any difficulty washing yourself all over, because of your elbow problem?

No difficulty	A little bit of difficulty	Moderate difficulty	Extreme difficulty	Impossible to do
☐	☐	☐	☐	☐

4. During the past 4 weeks...
Have you had any difficulty dressing yourself, because of your elbow problem?

No difficulty	A little bit of difficulty	Moderate difficulty	Extreme difficulty	Impossible to do
☐	☐	☐	☐	☐

5. During the past 4 weeks...
Have you felt that your elbow problem is "controlling your life"?

No, not at all	Occasionally	Some days	Most days	Every day
☐	☐	☐	☐	☐

6. During the past 4 weeks...
How much has your elbow problem been "on your mind"?

Not at all	A little of the time	Some of the time	Most of the time	All of the time
☐	☐	☐	☐	☐

7. During the past 4 weeks...

Have you been troubled by pain from your elbow in bed at night**?**

Not at all	1 or 2 nights	Some nights	Most nights	Every night
☐	☐	☐	☐	☐

8. During the past 4 weeks...

How often has your elbow pain interfered with your sleeping?

Not at all	Occasionally	Some of the time	Most of the time	All of the time
☐	☐	☐	☐	☐

9. During the past 4 weeks...

How much has your elbow problem interfered with your usual work or everyday activities?

Not at all	A little bit	Moderately	Greatly	Totally
☐	☐	☐	☐	☐

10. During the past 4 weeks...

Has your elbow problem limited your ability to take part in leisure activities that you enjoy doing?

No, not at all	Occasionally	Some of the time	Most of the time	All of the time
☐	☐	☐	☐	☐

11. During the past 4 weeks...

How would you describe the worst pain you have from your elbow?

No pain	Mild pain	Moderate pain	Severe pain	Unbearable
☐	☐	☐	☐	☐

12. During the past 4 weeks...

How would you describe the pain you usually have from your elbow?

No pain	Mild pain	Moderate pain	Severe pain	Unbearable
☐	☐	☐	☐	☐

Finally, please check back that you have answered each question.

Thank you very much.

APPENDIX 4 – PUBLICATIONS FROM THESIS

The following are published review papers and original research articles I have written on the data presented in this thesis.

1. **Duckworth AD**, Wickramasinghe NR, Clement ND, Court-Brown CM, McQueen MM. Long-term outcomes of isolated stable radial head fractures. ***J Bone Joint Surg Am. 2014 Oct 15; 96(20):1716-23.***

2. **Duckworth AD**, Wickramasinghe NR, Clement ND, Court-Brown CM, McQueen MM. Radial head replacement for acute complex fractures: what are the rate and risks factors for revision or removal? ***Clin Orthop Relat Res. 2014 Jul; 472(7):2136-43.***

3. **Duckworth AD**, Bugler KE, Clement ND, Court-Brown CM, McQueen MM. Nonoperative management of displaced olecranon fractures in low-demand elderly patients. ***J Bone Joint Surg Am. 2014 Jan 1; 96(1):67-72.***

4. **Duckworth AD**, McQueen MM, Ring D. Fractures of the radial head. ***Bone Joint J. 2013 Feb; 95-B(2):151-9.***

5. **Duckworth AD**, Clement ND, Jenkins PJ, Will EM, Court-Brown CM, McQueen MM. Socioeconomic deprivation predicts outcome following radial head and neck fractures. ***Injury. 2012 Jul; 43(7):1102-6.***

6. **Duckworth AD**, Clement ND, Aitken SA, Court-Brown CM, McQueen MM. The epidemiology of fractures of the proximal ulna. ***Injury. 2012 Mar; 43(3):343-6.***

7. **Duckworth AD**, Court-Brown CM, McQueen MM. Isolated displaced olecranon fracture. ***J Hand Surg Am. 2012 Feb; 37(2):341-5.***

8. **Duckworth AD**, Clement ND, Jenkins PJ, Aitken SA, Court-Brown CM, McQueen MM. The epidemiology of radial head and neck fractures. ***J Hand Surg Am. 2012 Jan; 37(1):112-9.***

9. **Duckworth AD**, Watson BS, Will EM, Petrisor BA, Walmsley PJ, Court-Brown CM, McQueen MM. Radial head and neck fractures: functional results and predictors of outcome. ***J Trauma. 2011 Sep; 71(3):643-8.***

10. **Duckworth AD**, Watson BS, Will EM, Petrisor BA, Walmsley PJ, Court-Brown CM, McQueen MM. Radial shortening following a fracture of the proximal radius. ***Acta Orthop. 2011 May; 82(3):356-9.***

APPENDIX 5 – MANUSCRIPTS IN PREPARATION

From the data presented in this thesis, the following original research articles and invited chapter are in preparation.

1. **Duckworth AD**, Wickramasinghe NR, Clement ND, Court-Brown CM, McQueen MM. The long-term outcome of operatively treated isolated olecranon fractures.

2. **Duckworth AD**, Clement ND, White TO, Court-Brown CM, McQueen MM. A prospective randomized trial of plate fixation versus tension band wire for olecranon fractures.

3. **Duckworth AD**, Clement ND, McEachan JE, White TO, Court-Brown CM, McQueen MM. A prospective randomized trial of non-operative versus operative management of olecranon fractures in the elderly.

4. **Duckworth AD**. Proximal forearm fractures and elbow dislocations. In: Court-Brown CM, McQueen MM, Swiontkowksi M, Ring D, Friedman S, Duckworth AD. Musculoskeletal Trauma in the Elderly. 1st edition. ***CRC Press; 2016.***