CHAPTER 1

General Introduction
Lindenhovius ALC
Anatomy of the Elbow

The elbow consists of three separate joints within a single synovial cavity: the ulnohumeral (or “ulnotrochlear”) joint, the radiohumeral (or “radiocapitellar”) joint, and the radioulnar joint. The elbow joint is a highly congruent and inherently stable joint. It has been suggested that approximately half of elbow stability is due to soft tissue structures (i.e., ligaments, capsule, and muscles) and the other half to the intricate osseous anatomy. The distal humerus has two fossae to accommodate the coronoid process and the olecranon process of the proximal ulna during flexion and extension of the elbow: the coronoid fossa on the anterior side, and the olecranon fossa on the posterior side. A smaller fossa accommodates the radial head during flexion. Together with the slight anterior translation of the distal humerus with respect to the humeral shaft, these fossae enhance the arc of ulnohumeral motion. The joints are enclosed by the anterior and posterior elbow capsules and ligaments, which in fact are thickenings of the capsule. The capsule is attached around the articular surfaces, and blends with the annular ligament. It covers the tip of the olecranon, the coronoid process, and the radial fossa. The fibers are arranged in such a way as to provide stabilization in flexion and in full extension. The medial collateral ligament is a strong and well-demarcated structure that consists of three less-well-identifiable bundles; the oblique anterior, oblique posterior and oblique transverse bundles. The lateral collateral ligament complex (the lateral collateral ligament and the conjoint annular ligament that have a common insertion on the proximal ulna) forms the primary constraint against varus stress. The extensor muscles with their fascial bands and the intermuscular septa (particularly the stout fascial band of the extensor carpi ulnaris) form a secondary constraint. In addition, the anconeus muscle may provide some stability.

Elbow Function

The complex articular anatomy of the elbow, in conjunction with shoulder and hand function, enables the arm to move in a great variety of positions in space that can be envisioned as a sphere. As the volume of a sphere is proportional to the cube of its radius (the arm), one can understand that any loss of elbow motion drastically reduces the reach of the hand. Elbow motion is important for many daily tasks and activities. Elbow flexion brings the hand to the head, mouth, and chest for instance, thereby facilitating activities related to feeding, dressing and body care. Extension brings the hand away from the body, enabling it to grasp objects. Forearm rotation is important in other common activities such as typing or turning a key. The American Academy of Orthopaedic Surgeons describes a normal range of ulnohumeral motion as a flexion and extension arc from 146 to 0 degrees, and a normal arc of forearm rotation from 71 degrees pronation to 84 degrees supination. These measurements were roughly confirmed by a later study that evaluated 109 healthy adult male subjects and...
documented an average flexion and extension arc from 141 to 0 degrees, and an average arc of pronation and supination from 71 to 84 degrees. In 1981, Morrey et al. found that an ulnohumeral arc of 130 to 30 degrees (often referred to as the “functional arc”) and forearm rotation of 50 to 50 degrees are needed to perform twelve common activities of daily living. In a more recent three-dimensional motion analysis, a flexion arc from 146 degrees of flexion to 36 degrees of extension, and an arc of forearm rotation from 55 degrees pronation to 72 supination, was needed to accomplish ten common daily tasks. However, none of these are absolute threshold numbers, given that many activities require more motion whereas some patients easily adapt to less motion.

**Elbow Trauma and Posttraumatic Stiffness**

Fractures about the elbow represent approximately 5.5% of fractures of the entire skeleton. Fractures of the radial head are seen most frequently (2.8%), followed by fractures of the olecranon and radial neck (1% each), the distal humerus (0.5%), and extra-articular fractures of the proximal radius and ulna (0.2%). Complications of elbow trauma include nerve injury, instability, nonunion, malunion, arthrosis, heterotopic ossification, and capsular contracture, all of which may be associated with loss of motion. Elbow stiffness is one of the most common complications of trauma. Although it is often referred to as an ulnohumeral arc of fewer than 100 degrees (30 to 130 degrees), it may be postulated that stiffness is better explained as any loss of motion. Stiffness is most frequently seen after complex intra-articular fractures and elbow fracture-dislocations, but also minor trauma may result in loss of motion.

Morrey classified elbow stiffness based upon the anatomic location of the contracture. Intrinsic factors (intra-articular changes) include intra-articular adhesions, malunions and nonunions, articular malalignment, loss of articular cartilage, or a combination. Extrinsic factors (extra-articular changes) include contracture of the soft tissues (i.e. joint capsules and ligaments), heterotopic ossification and extra-articular malunion and nonunion.

It is unknown why the elbow is so prone to posttraumatic contracture. Prolonged immobilization is a factor that has often been related to development of stiffness: for unclear reasons it seems to be more detrimental for elbows as compared to other joints. Immobilization has been recommended since antiquity: Hippocrates (400 BC) emphasized the importance of immediate reduction after trauma and recommended immobilization in 90 degrees of flexion as “an arm ankylosed in the extended position would be better away for it would be of great hindrance and of little use to the patient.” Centuries later, Ambroise Paré (1510 – 1590) recommended immobilization in 60 to 70 degrees for treatment of complex fractures (eg, both-bone fractures), although he recognized the importance of early mobilization when feasible. Immobilization was further popularized among Anglo-American orthopaedic surgeons in the late nineteenth century by the British surgeon Hugh Owen.
Thomas (1834 – 1891). Conversely, in that same period, the French surgeon Just Lucas-Champonnière (1843 – 1913) opposed the Thomas’ advocacy and introduced the concept of active, early restoration of muscle and joint function after closed or open treatment of fractures. William Arbuthnot Lane (1856 – 1943) and Albin Lambotte (1866 – 1955) subsequently pioneered the principles of open reduction and internal fixation to restore the original anatomy and to achieve stable fixation, thereby allowing early active motion. Immobilization versus early mobilization remained a debatable topic between Anglo-American orthopaedic surgeons and those from the European continent during much of the twentieth century. Yet, in the second half of the twentieth century, the Arbeitsgemeinschaft für Osteosynthesefragen (AO) in Switzerland contributed immensely to advancements in implants and techniques and consequently to the popularization of open reduction and internal fixation of fractures, facilitating early joint motion.

The shortcomings of prolonged immobilization after elbow trauma are still poorly understood. The resting position of the elbow (at which there is minimal electromyographic activity in the major muscles around the joint) as well as the position in which the intra-articular pressure is minimal are in approximately 70 degrees of flexion. In elbow contracture, the capsule is scarred and thickened by fibrosis. It is conceivable that prolonged immobilization (and particularly in the resting position as recommended in the days of Ambroise Paré, with the capsule being lax instead of taut), may contribute to capsular contracture. In addition, if the elbow stiffens up, capsular compliance becomes poor and intra-articular capacity may be reduced by more than 50%, rendering motion beyond the resting point painful due to hemarthrosis or effusion pressing upon the capsule. Unfortunately, prolonged immobilization may sometimes be inevitable as achieving stable reduction and/or fixation can be challenging in elbow injuries.

Another factor that has been suggested to contribute to the propensity of the elbow for development of stiffness is the intricacy of the joints with a highly congruent and complex intra-articular anatomy. Accurate restoration of the original anatomy may not always be feasible after elbow fractures and thereby result in intra-articular changes and malalignment restricting motion. In addition, it has been suggested that the brachialis muscle, which directly covers the anterior elbow capsule, may predispose to the formation of heterotopic bone after elbow fractures. It is thought that trauma, surgery and inflammation stimulate the migration of pluripotential mesenchymal stem cells—ubiquitous in soft tissues. These stem cells would subsequently, in a number of steps, differentiate and proliferate into osteoblasts that cause excessive bone formation.

Posttraumatic elbow stiffness is a common condition that will be encountered by any orthopaedic or trauma surgeon treating injured elbows. Even for experienced surgeons, the treatment of stiffness is challenging and a satisfactory result may not always be obtained. Restoration of joint motion in the posttraumatic stiff elbow may require a rigorous
rehabilitation program and often one or more surgical interventions, rendering it a time consuming and costly challenge.

**Outline of the Thesis**

The general aim of this thesis is to review our current knowledge on posttraumatic elbow stiffness in **part I**, to identify factors that may contribute to better results after management of complex elbow fracture-dislocations in **part II**, to better understand the relationship between stiffness and the patient’s perception of disability in **part III**, and to identify factors that may add to improvement in nonoperative, operative, and postoperative management of posttraumatic elbow stiffness in **part IV**. In **part V**, finally, all previous chapters will be put in perspective in a general discussion and summary of the thesis in the English and Dutch language.

**Part I  Current Issues**

A basic acquaintance of the complex anatomy of the elbow is requisite to understand factors that may contribute to the development of posttraumatic stiffness. In the current chapter, **chapter 1**, elbow anatomy and function are discussed comprehensively and an introduction to the subject of this thesis is given. **Chapter 2** represents an extensive review of the literature that was performed to better define our current knowledge on causes of elbow stiffness, its pathophysiology, and assessment and treatment of posttraumatic elbow stiffness.

**Part II  Elbow Trauma**

The introduction of open reduction and internal fixation has played a major role in fracture management and prevention of stiffness for two reasons: (1) it allowed more accurate restoration of the original osseous anatomy of the joint, and (2) it facilitated stable fixation and consequently permitted early mobilization. Nevertheless, treatment of comminuted and intra-articular fractures as well as elbow fracture-dislocations remains challenging, and patients with these injuries will often end up with some degree of elbow stiffness. Restoration of stability takes priority over motion, even if this requires prolonged immobilization, as motion may be successfully addressed with additional nonoperative or operative treatment, whereas articular damage due to instability may be irreversible.

**Distal Humerus Fractures**

In contrast to extra-articular distal humerus fractures, intra-articular fractures of the distal end of the humerus may often result in stiffness. The extensile operative exposure, complex anatomy, the need for realignment of small and sometimes impacted fragments, and the precise placement of implants countersunk beneath the articular surface add to the technical
difficulties that the surgeon is faced with when operating on these fractures. Approximately half of the intrinsic stability of the elbow is accounted for by the ulnotrochlear articulation. Therefore, accurate reconstruction of the trochlea is of paramount importance during operative treatment of distal humerus fractures with articular involvement. Studies reporting short term and long term results of treatment of intra-articular fractures have demonstrated that stiffness may be a problem in a substantial number of patients and additional surgery may sometimes be needed to restore function. For instance, in a recent article reporting results of treatment of complex articular distal humerus fractures, approximately two thirds of patients had subsequent surgery for contracture release to obtain more motion, and two years postoperatively (and after the additional surgeries), the flexion arc averaged 96 degrees.

Radial Head Fractures
Fractures of the radial head are usually classified according to the Broberg and Morrey modification of the classic system established by Mason in 1954. With respect to stiffness after radial head fractures, attention is not only turned to ulnohumeral motion, but also to the arc of forearm rotation. Nonoperative management is widely accepted as the preferred treatment of isolated Mason I fractures of the radial head (none or minimally displaced (<2mm) fractures involving < 30% of the articular surface) with good results nearly always achieved and stiffness seldom encountered. There remains some debate, however, regarding the best treatment of Mason II (>2mm displaced fractures involving more than 30% of the articular surface) and Mason III (comminuted fractures of the entire radial head) fractures. Open reduction and internal fixation gained popularity for the treatment of Mason II fractures after the introduction of small implants for fracture fixation. Some older articles however, and recent long term data, reported good to excellent recovery of function with nonoperative management. Moreover, recent long term results of open reduction and internal fixation for isolated and stable (i.e. not associated with dislocation or other fractures of the elbow or forearm, and generally stable impacted with an intact periosteum) Mason II radial head fractures did not demonstrate any advantage over late results of nonoperative management of these fractures.

In the light of these results, as well as a recent investigation suggesting that displacement in these fractures may be overdiagnosed, plus the inherent risks and costs of surgery, it can be argued that isolated and stable Mason II fractures are too often treated operatively. Stiffness is uncommon after nonoperative management of these Mason II fractures with an average flexion arc of 134 degrees and an average forearm rotation of 173 degrees reported on the long term. In contrast to the stable Mason II radial head fractures described above, most surgeons agree that unstable and displaced fractures of the radial head (either Mason II or Mason III) do
require operative treatment. These fractures are often part of a more complex injury because of the common associated ligament injuries that are not always apparent during treatment. Open reduction and internal fixation of these fractures is preferred over excision as it results in better initial stability of forearm and elbow, and protects against long term ulnohumeral arthrosis. Although additional surgery may sometimes be needed, loss of motion was found to be limited to an average flexion arc of 129 degrees and an average forearm rotation of 159 degrees on the long term.

Proximal Ulna and Elbow Fracture-Dislocations

The primary goal of treatment of olecranon fractures is anatomic reconstruction of the trochlear notch. Simple non-displaced olecranon fractures can usually be treated nonoperatively and will rarely result in stiffness. Displaced olecranon fractures can be treated with a tension band construct while plate and screw fixation may ensure stronger fixation in the case of comminution or a fracture-dislocation. The importance of the coronoid process of the ulna as a stabilizer of the elbow has been increasingly recognized over the last years. Fractures of the coronoid process may often be larger than they appear to be on radiographs, and operative treatment is nearly always recommended—particularly when part of an elbow fracture-dislocation. Over the past two decades, four complex elbow fracture-dislocation patterns have been identified that all may result in loss of motion fairly commonly:

**Posterior Olecranon Fracture-Dislocations:** these injuries can be considered the most proximal type of a posterior Monteggia fracture and are usually associated with fracture of the radial head.

**Anterior Olecranon Fracture-Dislocations** (also called “Transolecranon” Fracture-Dislocations): anterior radiocapitellar dislocation with the relationship between the proximal radius and ulna intact (i.e. they both dislocate anteriorly).

**Varus Posteromedial Instability Injuries:** posteromedial subluxation with fracture of the anteromedial facet of the coronoid process and avulsion of the lateral collateral ligament from the lateral epicondyle.

**Valgus Posterolateral Rotatory Injuries:** posterolateral dislocation and disruption of the capsuloligamentous stabilizers progressing from lateral to medial. If associated with fractures of the radial head and coronoid, this injury is usually referred to as the “terrible triad” of the elbow.

**Fracture-dislocations of the olecranon** are rare but complex injuries that occur in anterior or posterior direction and are frequently accompanied by fracture of the radial head and coronoid. As for terrible triad injuries, literature on olecranon fracture-dislocations is scarce. Although operative repair of olecranon fracture-dislocations is challenging, reasonable
elbow function can be achieved on the short term provided that the original anatomy is
restored. Many patients develop degenerative changes however, particularly if
the coronoid process is not adequately realigned and secured\textsuperscript{60, 75}. It is unclear if the early
results are durable over time. A trauma database at the Academic Medical Center in
Amsterdam, in which virtually all patients that presented with fractures over the period 1974 –
1994 were classified according to the AO Classification, provides us with a unique
opportunity to study long-term results of fracture treatment. The purpose of chapter 3 is to
document the long-term outcome of operative treatment of anterior and posterior olecranon
fracture dislocations and to compare the early and late results of treatment. Because of the
degenerative changes expected and described after complex intra-articular injuries, we
hypothesize that patients deteriorate over time in terms of ulnohumeral function. Secondly, by
evaluating both early and late follow-up we hope to expand our understanding of factors that
contribute to satisfactory and durable results after these complex fracture-dislocations.
Varus posteromedial injuries are usually associated with fractures of the anteromedial facet of
the coronoid, terrible triad injuries with small transverse fractures of the coronoid tip, and
olecranon fracture-dislocations with large fractures of the coronoid near the base.\textsuperscript{77} It is
important to fix, secure, or reconstruct the fractured coronoid process to prevent recurrent
subluxation or dislocation, and to protect from early onset of posttraumatic arthrosis caused
by incongruency of the ulnohumeral articulation.
Based upon a better understanding of the terrible triad elbow injury pattern and the important
role of elbow stabilizers over the past years, treatment techniques are evolving.\textsuperscript{64, 73, 74, 77-79}
However, a coronoid fracture can easily be missed or confused with a fragment of the
fractured radial head on standard radiographs or two-dimensional computed tomography
scans, while recognition of the fracture pattern is indispensable for adequate treatment.
Sometimes, the complexity of the injury is not even recognized until the patient presents with
persistent subluxation and instability after unsuccessful initial treatment.\textsuperscript{78, 80} Articles
discussing the results of treatment of terrible triad injuries are limited to only very few
papers.\textsuperscript{73, 74, 81} A prior paper by our research unit included seven patients treated for persistent
instability after terrible triad injuries: even after subsequent reconstructive procedures, results
were unpredictable in this subset of patients.\textsuperscript{78} Papandrea et al.\textsuperscript{80} found that, among patients
with persistent disability after a coronoid fracture-dislocation, those who had a delay of more
than seven weeks until definite treatment had a greater risk for an unsatisfactory outcome.
Given the mediocre results reported to date, it is important to learn more about the treatment
of these injuries. In chapter 4, we compare a cohort of patients that had treatment addressing
all three components of the injury (radial head, coronoid process, and lateral collateral
ligament) within two weeks of the injury to a cohort of patients that presented with
subluxation and persistent instability after initial treatment and that had surgery three weeks or
more after the injury. We hypothesize that patients that have treatment within two weeks of
injury do better in terms of flexion arc than patients that have surgery after inadequate initial treatment resulting in persistent instability.

Subsequently, in chapter 5, we investigate the effect of three-dimensional computed tomography (3D-CT) scans on the classification, characterization, and management of coronoid fractures. Three-dimensional images may be easier to interpret for a non-radiologist. On account of the better understanding of coronoid fracture patterns and subsequent treatment, recognition of size, location, and fracture morphology is considered increasingly important. As described above, coronoid fractures are often associated with complex elbow dislocations, and it can be difficult to identify and characterize them on standard radiographs.

Previous investigations documented that 3D-CT reconstructions may facilitate the evaluation of complex distal humerus fractures and fractures at other sites. Shortcomings of these studies included the limited number of observers. In chapter 5, we present an international web-based study to test the hypothesis that 3D-CT images improve interobserver agreement in the evaluation of coronoid fractures as compared to 2D-CT.

Part IV Stiffness and Disability

Impairment is described as objective physical dysfunction and reflects the patient’s capacity to perform a specific function. Disability is a more subjective perception of capacity that reflects impairment as well as personal and environmental factors. Over the last decade, patient-completed questionnaires have gained popularity as addition to physician-completed evaluation instruments, recognizing the clinical importance of the patient’s perception of the treatment result. The Disabilities of Arm Shoulder and Hand (DASH) questionnaire is designed to measure the patient’s ability to perform certain tasks and is commonly used to evaluate upper extremity problems from a patient’s point of view. In the case of posttraumatic stiffness, it would be expected that the degree of stiffness (impairment) would be strongly associated with the degree of reported disability—particularly on the level of a specific task. In a previous study, patients reported only very limited disability on the DASH questionnaire in spite of a considerable loss of motion. In addition, disability may vary substantially among patients with similar levels of impairment. Furthermore, pain and psychosocial factors have a significant influence on perceived disability. It is important not only to identify factors that enhance the objective result, yet also to better understand factors that contribute to a better patient-rated outcome. In chapter 6, the association between objectively measured impairment (loss of motion) and subjectively rated disability after elbow trauma is investigated to test the hypothesis that there is strong correspondence between specific objective impairments with disability on tasks that we expect to be limited by such impairment.
Part V  Treatment

Posttraumatic stiffness may develop in spite of precautionary measures such as accurate restoration of the original osseous anatomy and early active motion. Regaining joint motion in the most time efficient manner is critical for return to function, control of rehabilitation costs, and to prevent the need for additional surgery.

Nonoperative Management

An intensive rehabilitation program initiated early after fracture treatment may help prevent stiffness. At our institution, a splinting program is started in all patients that have difficulty gaining or maintaining a functional flexion arc in spite of standard exercises. Patients with stiffness of longer duration and patients that have difficulty restoring motion after an operative elbow contracture release may benefit from splinting as well. It is believed that in some patients a splinting program may prevent the need for additional surgical release. In the United States, there are two types of splints on the market that have different working mechanism and wearing protocols. Static progressive turnbuckle splints are used in three 30-minute sessions per day and apply a static stress relaxation force to the elbow tissues, which is sequentially increased as motion is achieved. Conversely, dynamic splints, advised to be worn for 6 to 8 continuous hours per day or night, apply a constant prolonged force to the tissues as additional motion is achieved. Although satisfactory results have been reported with both static progressive as well as dynamic splinting devices, the effectiveness of these two devices in clinical practice has never been compared for the treatment of posttraumatic contractures. In chapter 7, we present preliminary results of a prospective randomized trial investigating the effectiveness of static progressive versus dynamic splinting for the restoration of motion after elbow trauma or operative contracture release. In addition, we want to find out whether one of the approaches is more effective in reducing perceived disability as measured by the DASH questionnaire. Our null hypothesis is that there is no difference between static progressive and dynamic splinting in terms of restoration of motion and patient perceived disability six months after initiation of splint use.

Operative Treatment

When active motion exercises and splinting fail to improve motion in the posttraumatic stiff elbow, an operative elbow contracture release may be considered. Although this is a technically challenging procedure, particularly if not limited to capsular contracture alone, it may often result in substantial improvement in motion. Approximately 3% of patients develop heterotopic bone following elbow trauma. However, in the case of associated closed head trauma or injury to the central nervous system heterotopic ossification may be seen in up to 89% of the patients. In addition, thermal burns or multiple surgical interventions within the first week following trauma have been suggested to
Predispose for heterotopic ossification. Presence of heterotopic bone has traditionally been considered a complicating factor for an operative elbow contracture release and the result of the procedure. Although the presence of heterotopic bone may add to the complexity of the operative procedure itself, there are no scientific data about the effect of heterotopic ossification on the result of elbow contracture release. In an attempt to identify factors that influence the results of operative treatment of elbow contractures, we describe, in chapter 8, the results of a retrospective comparison of operative contracture release in patients with heterotopic bone versus patients without heterotopic bone. Our hypothesis is that patients that have no heterotopic bone contributing to elbow stiffness regain more flexion and extension as compared to patients that do have heterotopic bone blocking motion.

Although the objective functional results after elbow contracture release may be satisfactory in a substantial percentage of patients, the impact of improvement in motion on the patient’s general health status has never been documented. Does improvement in motion result in improvement in perceived health status? And does improvement in motion result in less disability? In chapter 9, we will test the hypothesis that improvements in motion correspond with improvements in both general health status and perceived disability.

Postoperative Management

The postoperative management after open elbow contracture release may differ for each individual patient. In general, rehabilitation is aimed at 1) the restoration of a functional arc of motion, 2) recuperation of muscle power, and 3) reincorporation of the limb into functional activities. After an operative contracture release, patients are typically instructed to begin with active-assisted range of motion exercises within two days of surgery with adequate pain medication to facilitate exercises. Although the use of continuous passive motion is used or recommended by many surgeons after elbow contracture release, its effect on restoration of motion remains uncertain. There have been only two studies, both small case series that suggested a beneficial effect of continuous passive motion on restoration of motion for residual flexion contracture (i.e. loss of extension), rendering its support largely anecdotal. Besides the lack of sound scientific evidence supporting the use of continuous passive motion after contracture release, its use entails several risks and disadvantages: pain and discomfort, risks related to regional anesthesia, costs of the device, and prolonged hospital admission—all of which may increase the total expenses of treatment. The uncertainty regarding its benefit is reflected in the ambiguous use of continuous passive motion in our department with one surgeon never using the device and another surgeon using it very inconsistently after contracture release. Because of the lack of compelling evidence supporting the use of continuous passive motion, we test, in chapter 10, the null hypothesis that there is no difference in flexion arc between patients treated with or without CPM at least four months after operative elbow release.
Part VI General Discussion & Summary

In chapter 11, all previous chapters will be put into perspective in a general discussion and summary in the English and Dutch language.

References


