

# **Distal Radius Fracture:**

**Epidemiology, Outcome, and the Prediction of Instability.**

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# Contents

<b>Abstract</b>	iii
<b>Acknowledgements</b>	vi
<b>1. Introduction</b>	1
Anatomy of the distal radius and complications of fracture	
Fracture classification systems and radiological measurements	
Current fracture management	
Aims of the study	
<b>2. Materials and Methods</b>	71
Study section 1: epidemiology, outcome, and prediction of instability	
Study section 2: validation of prediction of instability	
Statistical analysis and study design	
<b>3. Results</b>	105
Study section 1: epidemiology, outcome, and prediction of instability	
Study section 2: validation of prediction of instability	
<b>4. Discussion</b>	179
Study section 1: epidemiology, outcome, and prediction of instability	
Study section 2: validation of prediction of instability	
<b>5. Conclusion</b>	211



## **Abstract**

### **Introduction.**

Distal radius fracture as an injury appeared in the literature 2400 years ago. It was only recognised as a fracture 220 years ago. That it was not a benign fracture was only recognised 60 years ago. Attempts to improve the surgical treatment of the fracture have only been in the last two or three decades. The introduction of this thesis outlines the history of distal radius fracture, describes the relevant anatomy, and describes the methods used to classify and measure the fracture. The aims of the thesis are presented with respect to the main deficiencies in our strategies for the management of the fracture, namely an inability to predict how the fracture will behave.

### **Materials and Methods.**

The studies in the thesis are divided into two broad sections. The first section is descriptive. Data were collected prospectively over a five-and-one-half year period for approximately 4000 fractures. Validation of the data is performed. The data are used to describe the epidemiology of the fracture in the Lothian Region, and the anatomical outcome of the fracture. Multiple logistic regression analysis of the data is performed to identify those factors (recordable at patient presentation) that are prognostic of outcome. The statistical method used provides weighted significance for each of these factors, and thus mathematical formulae predictive of outcome are constructable. A number of formulae are produced, depending on the displacement of

the fracture at presentation (minimally displaced or displaced), and on the outcome measure (early and late instability, the risk of malunion, and carpal malalignment). The second section is validative. The studies in this section are an assessment of the performance of the mathematical formulae in the clinical setting. In the first study, data are collected prospectively for 139 patients, and outcomes recorded. Blinded to outcome, the formulae are applied to each patient's data to calculate the percentage risk of poor outcome. The sensitivity and specificity of mathematical prediction of outcome are calculated. In the second study, a group of clinicians involved in fracture management are asked to predict fracture outcome using first clinical experience and then the predictive formula. This is done using forty radiographs of displaced fractures of known outcome. The two methods of prediction are then compared.

## **Results.**

The distal radius fracture occurred predominately in the older female patient following a simple fall. The fracture in this typical patient was usually unstable. The most consistently important predictors of fracture outcome were patient age, fracture displacement, comminution and ulnar variance. The mathematical formulae were able to correctly predict anatomical outcome in approximately 7/10 patients in the validative study. This was a significant improvement upon the predictive accuracy of the clinicians using experience alone. Use of the predictive formula also significantly reduced inter-observer variation in the assessment of fracture stability.

**Conclusion.**

Use of the predictive formula in the Accident & Emergency setting could improve decision-making in fracture management. By promoting an assessment of fracture stability rather than fracture displacement, appropriate management choices are facilitated. The unstable fracture can be referred for operative management, and ineffective closed reduction avoided. The thesis also demonstrates the potential value of the method employed. Multiple logistic regression analysis may provide a guide to treatment where the management of the condition is dependent upon the natural history.

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# **1. INTRODUCTION**





<b>1.1</b>	<b><u>Fracture of the distal radius: an historical perspective</u></b>	<b><u>5</u></b>
<b>1.2</b>	<b><u>Anatomy of the distal radius, and complications of fracture</u></b>	<b><u>9</u></b>
	<b>1.2.1 Osteology and arthrology</b>	<b>10</b>
	1.2.1.1 The radius	10
	1.2.1.2 The ulna	13
	1.2.1.3 The articulation between radius and ulna	13
	1.2.1.4 The distal radio-ulnar joint	14
	1.2.1.5 The radiocarpal joint	18
	<b>1.2.2 Soft tissue anatomy</b>	<b>21</b>
	1.2.2.1 Forearm rotation	21
	1.2.2.2 Wrist flexion	23
	1.2.2.3 Wrist extension	24
	1.2.2.4 Wrist abduction and adduction	24
	1.2.2.5 Soft tissue relations of the distal radius	25
	<b>1.2.3 Complications of fracture and fracture treatment</b>	<b>26</b>
	1.2.3.1 Nerve complications	26
	1.2.3.2 Tendon complications	27
	1.2.3.3 Fascial complications	28
	1.2.3.4 Complex regional pain syndrome	28
	1.2.3.5 Infection	29
	1.2.3.6 Fracture	29
<b>1.3</b>	<b><u>Fracture classification systems and radiological measurements</u></b>	<b><u>31</u></b>
	<b>1.3.1 Fracture classification</b>	<b>31</b>
	1.3.1.1 Factors used to define fractures of the distal radius	32
	1.3.1.2 The development of fracture classification	33
	1.3.1.3 The Frykman and AO-ASIF classifications	36
	<b>1.3.2 Radiological measurements</b>	<b>45</b>
	1.3.2.1 Fracture displacement	45
	1.3.2.2 Fracture comminution	50
	1.3.2.3 Carpal malalignment	50
<b>1.4</b>	<b><u>Current fracture management</u></b>	<b><u>53</u></b>
	<b>1.4.1 The evolution of management of the distal radial fracture</b>	<b>53</b>
	1.4.1.1 Anatomical and functional outcome	54
	1.4.1.2 Fracture Instability	56
	1.4.1.3 Treatment of the unstable fracture	58
	<b>1.4.2 The current fracture management protocol</b>	<b>61</b>
<b>1.5</b>	<b><u>Aims of the study</u></b>	<b><u>63</u></b>
	<b>1.5.1 Problems in the current management protocol</b>	<b>63</b>
	<b>1.5.2 Study aims</b>	<b>64</b>
	1.5.2.1 Epidemiology	64
	1.5.2.2 Fracture outcome	65
	1.5.2.3 Prediction of fracture instability and carpal malalignment	65
	1.5.2.4 Validation of prediction	65
<b>1.6</b>	<b><u>References</u></b>	<b><u>67</u></b>

## **Figures**

<b>1.2.1a:</b>	The radius	11
<b>1.2.1b:</b>	The ulna	12
<b>1.2.1.3a:</b>	The radius and ulna	15
<b>1.2.1.4a:</b>	The distal radio-ulnar joint	16
<b>1.2.1.4b:</b>	Pronosupination	16
<b>1.2.2.5a:</b>	Cross-section of the distal radius	16
<b>1.3.1.3a:</b>	The Frykman classification	39
<b>1.3.1.3b:</b>	The AO/ASIF classification, type A	40
<b>1.3.1.3b:</b>	The AO/ASIF classification, type B	41
<b>1.3.1.3b:</b>	The AO/ASIF classification, type C	42
<b>1.3.2.1a:</b>	Radiological measurements	47
<b>1.3.2.1b:</b>	Radiological measurements	47
<b>1.3.2.1c:</b>	Radiological measurements	48
<b>1.3.2.1d:</b>	Radiological measurements	48
<b>1.3.2.2a:</b>	Fracture comminution	51
<b>1.3.2.3a:</b>	Carpal malalignment	52

## 1.1 Fracture of the distal radius: an historical perspective

Fractures of the distal radius have long been recognized and documented. The earliest reference to this injury can be found in the writings of Hippocrates, in 400BC. Although Hippocrates discusses the nature and treatment of fractures of the forearm, there is no specific reference to injuries around the distal radius. However, in his treatise on articulations there is clear reference to the deformity that we now associate with fractures of the distal radius. It would seem therefore, that this fracture was considered to be a dislocation of the radiocarpal joint:

*“The whole hand is dislocated either inward, or outward, but especially inward, or to this side or that. Sometimes the epiphysis is displaced, and sometimes there is displacement (diastasis) of the one bone from the other. Powerful extension is to be made in this case; and the projecting part is to be pressed upon, and counter-pressure made on the opposite side: both modes being performed at the same time, both backward and laterally, either with the hands on a table, or with the heel. These accidents give rise to serious consequences and deformities; but in time the parts get so strong as to admit of being used. The treatment consists of bandages comprehending the hand and forearm, and splints are to be applied as far as the fingers; when put in splints, they are to be more frequently loosed than in fractures, and more copious allusions of water are to be used.”*

It was not until the late eighteenth century that this misconception was corrected. The first author to specifically describe the distal radial fracture was Claude Pouteau in 1783. However, the figure most commonly associated with the discovery of this fracture was Sir Abraham Colles. His paper in 1814 provides the classical description of the deformity of the fracture, and refutes the diagnosis of radiocarpal dislocation. He indicates how to reduce the fracture, and how to splint it to maintain the reduction

until the fracture has healed. He comments on the frequency with which he encountered the fracture, and interestingly would seem to indicate that unstable fracture was the norm:

*"If the surgeon locks his hand in that of the patient's, and makes extension, even with moderate force, he restores the limb to its natural form; but the distortion of the limb instantly returns on the extension being removed."*

It is unfortunate that the sentence from Colles' paper to which reference is most commonly made is erroneous:

*"One consolation only remains, that the limb will at some remote period again enjoy perfect freedom in all its motions, and be completely exempt from pain..."*

It is certainly not true that all patients achieve a full range of painfree motion following fracture of the distal radius.

Shortly after Colles' paper, works describing other types of distal radial fracture were published. In 1827 Barton described the fracture-dislocation in either a volar or dorsal direction, and in 1832 Goyrand described the distal radial fracture with volar angulation (commonly known as the Smith's fracture). The advent of X-rays facilitated further description of distal radial fractures. The distal radius was the perfect location for radiological study due to ease of positioning and minimal soft tissue cover. Authors in this field realised that the simple eponymous descriptions of the distal radial fracture were inadequate, and that X-rays revealed the hitherto unknown complexity of fracture morphology (Beck, 1898):

*"As far as my own experience is concerned, I must admit that I never saw a case in which the diagnosis made before skiagram (radiograph) was taken, was not more or less modified thereafter, especially when considerable effusion and swelling were present."*

However, it was not until the twentieth century that interest in the distal radial fracture was truly rekindled. This may have been due to two factors. Firstly, there was an increasing awareness of the considerable loss of function that could occur following this fracture. Secondly, as surgical techniques and equipment improved, alternative methods of treating the fracture became available.

The work of Bacorn and Kurtzke in the late 1940's comprehensively challenged the idea that the distal radial fracture was benign. By examining the records of the New York State Workmen's Compensation Board, the authors were able to outline the epidemiology of the fracture, and the degree of functional impairment suffered. In their study population, only 2.9 percent of the patients suffered no functional deficit, and the mean loss of function was 24 percent.

Gartland and Werley more closely examined this relationship between deformity and function in their 1951 paper evaluating the results of healed Colles' fracture. They defined the radiological measurements of the distal radius and devised a scoring system for the evaluation of the functional results. They showed that function was poorer with increasing residual deformity and commented that the current method of treatment of the fracture was inadequate.

A need for a new approach to fractures of the distal radius was highlighted by such research. It was apparent that simple manipulation and immobilisation in a cast was not adequate treatment for all fractures. As a result, in the second half of the twentieth century there was an explosion in research assessing new surgical methods of treatment. This was further stimulated as surgical techniques and fixation devices improved.

However, two problems remained. Firstly, fixation of the fractures failed to live up to its promise in terms of functional benefits for the patient. As a result, fracture

fixation was reserved for the young, fit patient with high functional demands, who had sustained a fracture with poor prognosis. Unfortunately, this recommendation denied surgical treatment to those patients in whom the fracture occurred most frequently and in whom prognosis was poorest, i.e. the elderly. Secondly, it was still not possible to predict which patients and fractures required surgical intervention. Jenkins demonstrated in his paper of 1989, that a fracture might collapse into a poor position well after the temporal window of opportunity for surgical fixation. Research into the first problem continues. McQueen (1998) showed significant improvement in anatomical and functional outcomes using non-bridging external fixation. Excellent results were achieved in all age groups: the surgical treatment option is no longer inappropriate in the elderly. Further advances in fracture fixation and stabilisation may reduce complications following the use of external fixation. The second problem of identifying the unstable fracture is still unanswered. It must be answered if fractures are to be treated appropriately: avoiding the complications of over- and under treatment. This thesis was designed to answer this second problem.

## **1.2 Anatomy of the distal radius, and complications of fracture**

The anatomy of the distal radius and the joints formed with the distal ulna and the carpus represent one of the most significant evolutionary advances of man. The limb pattern containing 13 carpal bones and a five-rayed extremity is seen first in the fossil record 230 million years ago, in a primitive amphibian. This early limb pattern was designed to weight-bear. Pronation and supination did not appear until 16 million years ago. This movement was essential, as the early primates took to the trees. The ulna retracted from its articulation with the triquetrum and pisiform, and the syndestmotic distal radioulnar joint became synovial. The radio-carpal joint evolved as the ulna retracted. As our ancestors became bipedal, the upper limb was freed from locomotion. The mobile rotating forearm could be put to more complex tasks eventually leading to the use of tools. Almqvist (1991) rates the development of this faculty as one of the hallmarks of the late-evolving hominids, along with the prehensile thumb and increasing brain function.

Distal radial fracture can affect both the distal radio-ulnar and radio-carpal joints.

These joints can be affected directly by fractures that involve the articular surfaces of the distal radius. The joints can also be affected indirectly: extra-articular fracture malunion can affect the orientation of the distal radial radio-ulnar and radio-carpal articular surfaces. Only by understanding the normal anatomy, will it be possible to explain the problems caused by fracture malunion. Therefore, the normal anatomy of the distal radius and its associated joints will be considered first in this chapter.

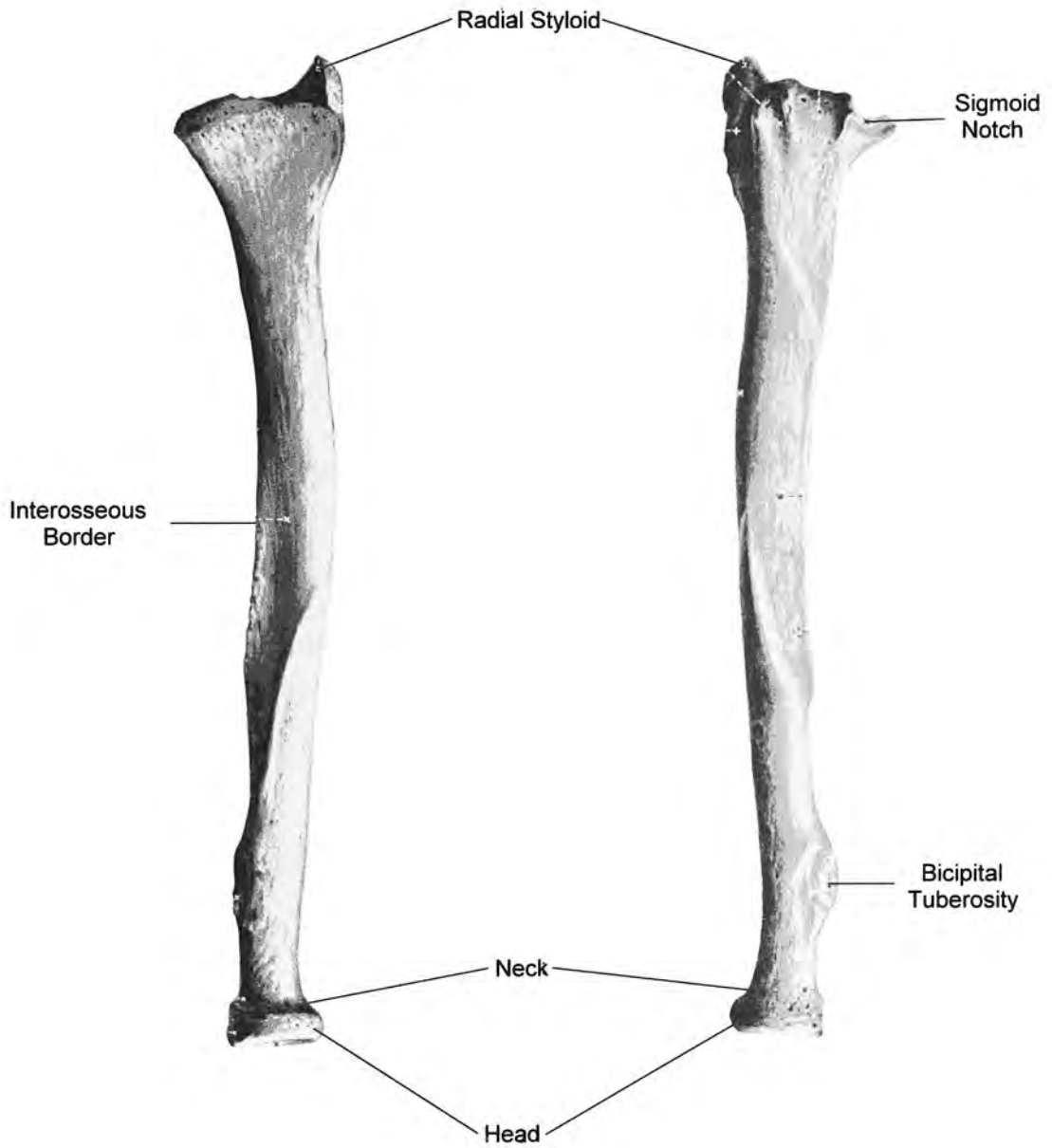


## 1.2.1 Osteology and Arthrology

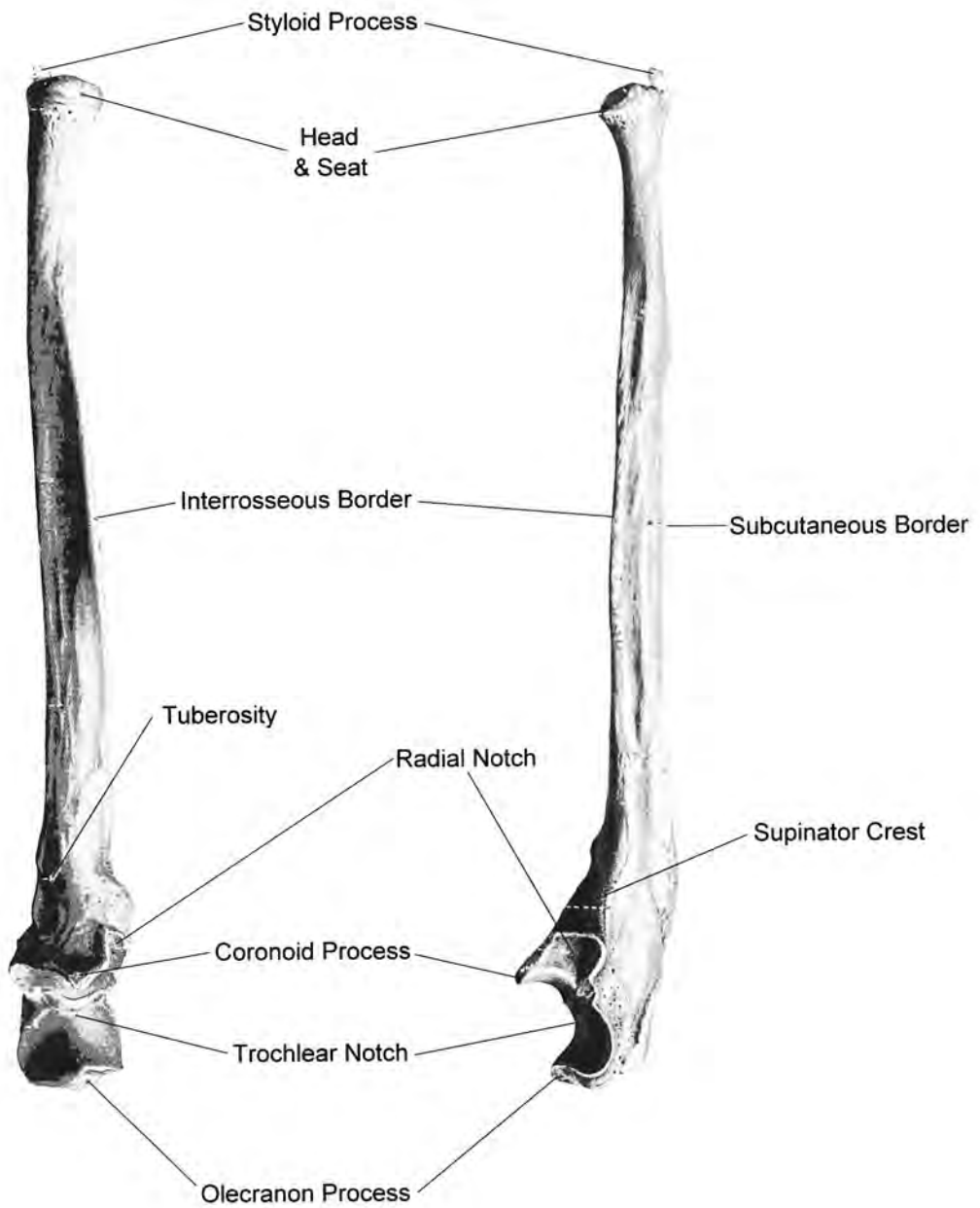
The radius and ulna are illustrated in figures 1.2.1a and 1.2.1b.

### 1.2.1.1 The radius

The radius is the lateral of the two forearm bones. Both ends of the radius are expanded, however the distal end is much larger. The proximal end of the radius consists of a head, neck, and bicipital tuberosity. The disc-shaped head articulates with the capitulum of the humerus at its slightly concave end, and with the radial notch of the ulnar at its circumference. The bicipital tuberosity lies distal to the neck of the radius on the antero-medial surface, and is the point of insertion of the tendon of biceps brachii. The distal radial shaft is slightly bowed, with its convexity facing laterally. The shaft is roughly triangular in cross-section. The medial margin is sharp, accepting attachment of the interosseus membrane; the lateral border is more curved. At the distal end, the radius is greatly expanded, and becomes four-sided in cross-section. The medial surface has a gentle concavity: this is the radial side of the distal radio-ulnar joint, known as the sigmoid notch. The lateral side projects distally forming the radial styloid. Longitudinal ridges divide the dorsal surface. Lister's dorsal tubercle is the most prominent of these ridges: it divides the dorsal surface into shallow grooves medially and laterally. Laterally, the dorsal surface is further divided into two by a smaller ridge. The distal end of the radius is the carpal articular surface. This is divided into two slightly concave facets. The slightly larger quadrangular lunate facet lies medially, and represents 53 percent of the articular surface (Mekhail 1996). The smaller lateral scaphoid facet is triangular.



**Figure 1.2.1a: The radius.**



**Figure 1.2.1b: The ulna.**

### 1.2.1.2 The ulna

In contrast to the radius, the larger of the terminal expansions of the ulna lies proximally. Here there are two processes and two articular surfaces. Anteriorly, the proximal olecranon process is divided from the coronoid process by the concave trochlear notch. The trochlear notch is divided longitudinally by a ridge, and articulates with the trochlea of the distal humerus. The brachialis tendon inserts into the ulnar tuberosity, which lies at the base of the coronoid process anteriorly. Just distal to the coronoid process on the lateral surface of the ulna is the concave radial notch, which articulates with the circumference of the radial head. The radial notch is rectangular in shape. A prominent ridge runs distally from the posterior border of the radial notch. This is the supinator crest. The ulnar shaft is triangular in cross-section proximally, but in its distal fourth becomes almost cylindrical. The apex of the triangle points laterally, and accepts insertion of the interosseous membrane. Laterally the bone is more rounded. However there is a distinct posterior border, which lies subcutaneously. The lower end of the ulna consists of a cylindrical head and a styloid process. The ulnar styloid arises from the distal surface of the ulna, postero-medially. The circumference of the head articulates with the sigmoid notch of the radius laterally. The distal surface articulates with the triangular fibrocartilage complex, which inserts into the base of the ulnar styloid.

### 1.2.1.3 The articulation between radius and ulna

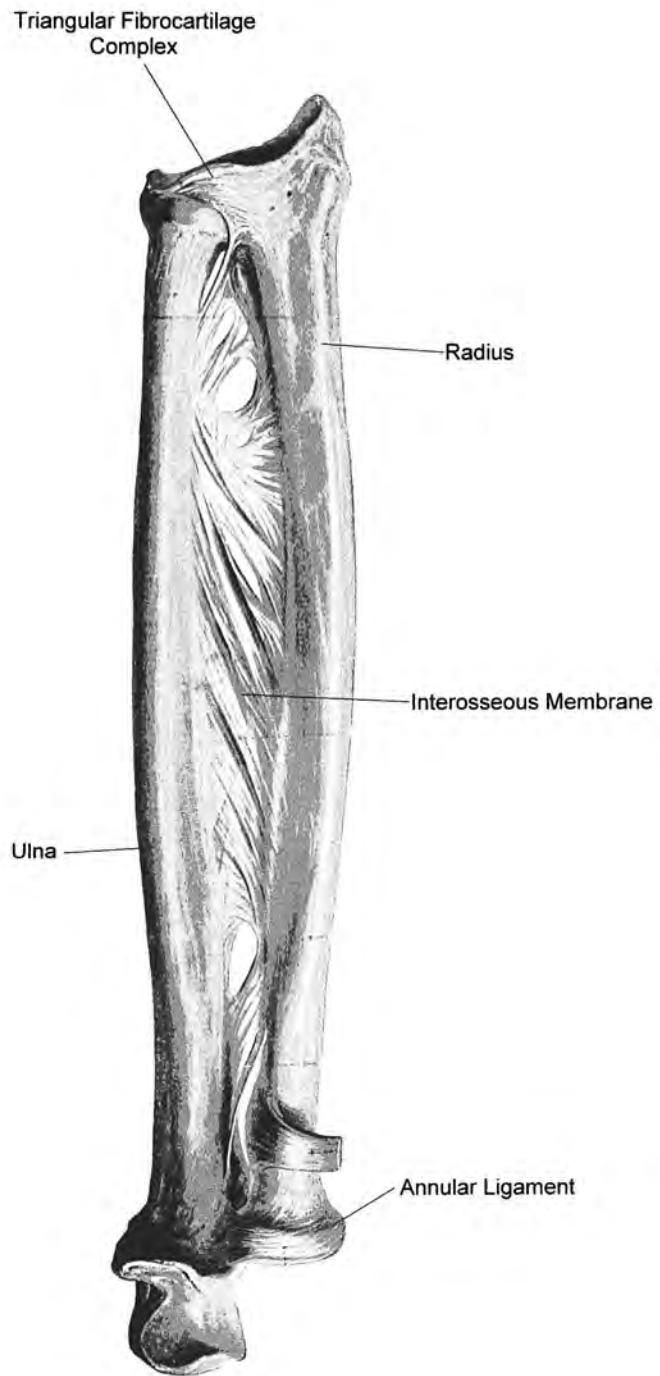
The proximal and distal radio-ulnar joints and the interosseous membrane link the radius and ulna (figure 1.2.1.3a). These can be considered as a single functional unit

allowing forearm rotation. Proximally, the annular ligament attaches to the ulna at the anterior and posterior margins of the radial notch. It passes round the radial neck and holds the radial head within the radial notch of the ulna. The interosseous membrane joins the shafts of the bones. Distally, the triangular fibrocartilage complex (TFCC) links the radius and ulna. This structure attaches to the ulna at the base of the ulnar styloid and arises from the thin margin between the radio-carpal articular surface and the sigmoid notch of the ulna. The anterior and posterior borders of the TFCC are thickened into ligaments, which merge with the ligaments of the wrist joint. The centre of the TFCC is often perforated: the incidence of perforation increases with age. Because it can be affected by distal radial fracture, the distal radio-ulnar joint is considered in greater detail below.

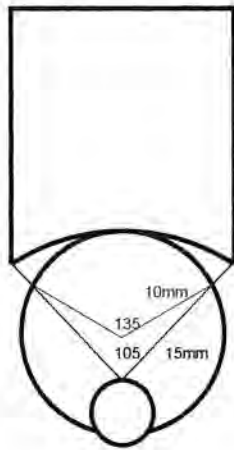
#### 1.2.1.4 The distal radio-ulnar joint

The distal radio-ulnar joint is not simply two congruent surfaces permitting rotation of the radius around the ulna. This joint is divided into two parts: between the radius (sigmoid notch) and ulna (ulnar seat), and between the proximal surface of the TFCC and the ulna (ulna pole). The joint is represented diagrammatically in figure 1.2.1.4a. The ulna seat occupies an arc of between 80 and 135 degrees of the distal ulnar circumference, facing laterally. Its mean radius of curvature is 10mm. The articular surface is broadest in its middle portion (approximately 8mm), and tapers both dorsally and volarly. It is inclined also at 20 degrees to the long axis of the ulna: this inclination varies according to the ulnar variance.

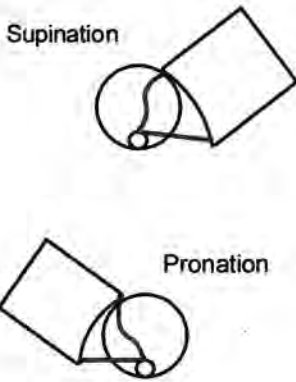
The sigmoid notch describes an arc of 47 to 105 degrees, with an average radius of 15mm. The centre of this radius of curvature lies at the base of the ulnar styloid, at



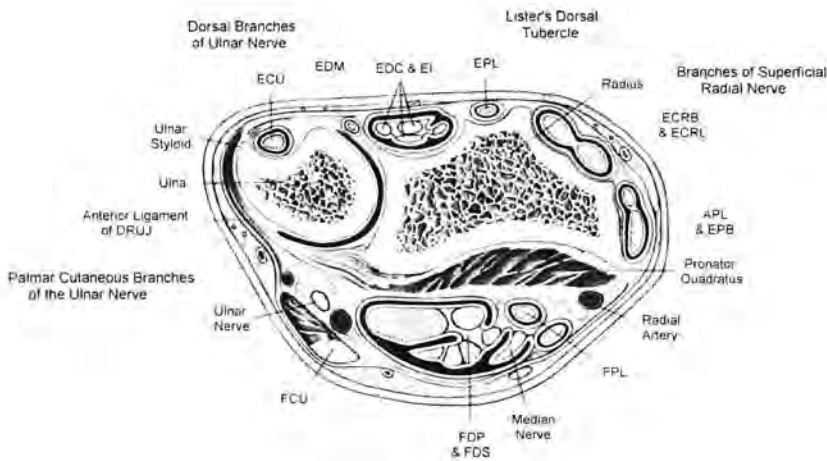
**Figure 1.2.1.3a: The radius and ulna.**



**Figure 1.2.1.4a: The distal radio-ulnar joint.** The joint is incongruent. A mismatch is seen between the radii of curvature of the sigmoid notch and ulnar seat. In addition the centres of the arcs described by the joint surfaces do not correspond.



**Figure 1.2.1.4b: Pronosupination.** A volar translation of the radius in pronation tensions the volar ligament of the TFCC, stabilizing the joint. The converse occurs in supination, with dorsal translation of the radius and tightening of the dorsal ligament.



**Figure 1.2.2.5a: Soft tissue relations of the distal radius.**

the point of insertion of the TFCC. The sigmoid notch and ulnar seat have the same inclination with respect to the long axis of the ulna.

As the radii of curvature of the ulnar seat and sigmoid notch are different, the joint is incongruent and intrinsically unstable. The radii of curvature also have different centres: the centre for the sigmoid notch is at the base of the ulnar styloid, and the centre for the ulnar seat lies laterally at the centre of the ulnar head. Maximal joint contact occurs with the forearm in neutral rotation as in figure 1.2.1.4a. The dorsal and volar ligaments of the TFCC are relaxed in this position. Pronosupination is represented in figure 1.2.1.4b. As the forearm is pronated, the radius slides volarly with respect to the ulna. Joint contact is reduced, but joint stability is maintained by increasing tension in the volar ligament. The reverse is true in supination: the radius slides dorsally, and the dorsal ligament tightens. This combination of rotation and glide in the distal radio-ulnar joint allows 180 degrees of rotation in the forearm.

The distal radio-ulnar joint can be affected by distal radial fracture in several ways. Firstly, fractures directly involving the articular surface will affect the joint. These fractures would include Frykman types 5 to 8 (section 1.3.1.3). Secondly, extra-articular distal radial fracture malunion will affect the respective alignment of the sigmoid notch and ulnar seat. Kapandji (1981) likens the proximal and distal radio-ulnar joints to hinges on a door. As long as the hinges are coaxial, then the door will open. However, if the hinges lose their co-axial alignment, then for the door to open fully, it must be sawn in half. Likewise, pronation and supination will be restricted if the proximal and distal radio-ulnar joints are no longer co-axial. Ekenstam (1992) found that measureable subluxation of the DRUJ was seen with a change in radial angulation of 10 degrees. However, he found that axial shortening of the radius (increasing ulnar variance) produced a greater effect upon DRUJ function. Thirdly,



joint function can be altered by disruption of the distal radio-ulnar joint restraints, i.e. disruption of the triangular fibrocartilage complex. Without the TFCC, the distal radio-ulnar joint is free to sublux. The secondary restraints alone (the interosseous membrane, pronator teres, and the tendon of extensor carpi ulnaris) are unable to prevent this subluxation. The TFCC is seen as a restraint to displacement of the distal radial fracture (Taylor and Parsons 1938). Disruption of the TFCC allows further displacement of the distal radial fragment, which in turn will lead to further malalignment of the distal radio-ulnar joint.

#### 1.2.1.5 The radio-carpal joint

The radio-carpal joint cannot be considered in isolation. Movements of the wrist joint involve both the radio-carpal and midcarpal articulations, and distal radial fracture affects the function of both of these joints. The normal ranges of movement of the wrist joint are 60 and 78 degrees of extension and flexion respectively, and 21 and 38 degrees of abduction and adduction respectively (Ryu et al 1991).

The distal radial joint surface is angled in two planes. There is an average tilt of 11 degrees in the sagittal plane, and 23 degrees in the coronal plane (Gartland and Werley 1951). A ridge divides the articular surface into a lateral scaphoid facet, and a medial lunate facet. This ridge is oblique, running slightly laterally from volar to dorsal edges of the articular surface. This is in line with the plane of flexion/extension at the radio-carpal joint. The scaphoid facet is approximately triangular in shape and is biconcave. Mekhail et al (1996) found that this facet was approximately 16x16x18mm in size, and constituted a little less than half of the total articular surface area (47 percent). The lunate facet is also biconcave, but shallower than the scaphoid facet. It is quadrilateral in shape, and measures approximately

10x15x14x18mm. The difference in curvature of the facets corresponds to the differences in curvature of the articular surfaces of the scaphoid and lunate. This ensures articular congruency. The proximal articular surface is completed by the distal surface of the TFCC. The convex articular facets of the proximal row of carpal bones form the distal articular surface of the radio-carpal joint. The midcarpal joint is more complex, involving three types of articulation (Garcia-Elias 1999). The joint between the scaphoid and the trapezium, trapezoid, and lateral capitate forms the lateral component. The concavity of this joint is formed by the distal row. The middle component comprises the joint between the capitate, and the scaphoid and lunate. Here the concavity of the joint is formed by the proximal row. The medial component of the midcarpal joint is helicoid, between the hamate and triquetrum. The ligaments of the wrist joint are divided into extrinsic and intrinsic. The extrinsic ligaments are those connecting the radius and ulna to the carpus. The extrinsic ligaments on the volar aspect of the wrist connect the radius to the scaphoid, capitate, and lunate, and the ulna (and TFCC) to the triquetrum, lunate and capitate. Dorsally, there is only one extrinsic ligament, connecting the radius to the triquetrum. The intrinsic ligaments are either interosseous (connecting adjacent bones in the same carpal row) or intercarpal (linking the two rows). The interosseous ligaments of the proximal row are reasonably lax, more so between the scaphoid and the lunate than between the lunate and triquetrum. This is to allow for the considerable movement that occurs in the proximal row, particularly between the scaphoid and lunate. Conversely, the interosseous ligaments of the distal carpal row are robust and tight. This effectively renders the distal row one functional unit. Medially, the palmar intercarpal ligament links the triquetrum to the hamate and capitate. On the lateral side the scaphoid is linked to the capitate, trapezoid and trapezium. Dorsally there is only

one intercarpal ligament. This runs from the triquetrum laterally, to the lunate, scaphoid, trapezoid, and trapezium.

Theories of wrist kinematics are numerous, and have involved separating the carpus into rows, and varying numbers of columns. Garcia Elias (1999) noted that no one theory is able to explain all disorders of carpal kinematics. Even in the normal wrist kinematics vary: the arrangement of the wrist ligaments is highly variable, and the ligaments can be tight or loose.

However, various concepts can be used to explain carpal collapse as a result of distal radius fracture malunion. Normal wrist movement can be explained by the anatomy.

There are no direct tendinous attachments to the proximal row of carpal bones. Thus movement in the wrist starts with the distal row: midcarpal joint motion occurs first.

Tension in the intercarpal ligaments initiates movement of the proximal row, and thus movement at the radio-carpal joint. Carpal kinematics can be described in terms of three columns (Taleisnik, 1978). The middle column, consisting of the lunate and capitate, is the load-bearing column. The distal carpal row is included in the middle column, as its tight interosseous ligaments render it a single functional unit. The

loads passing through the middle column are considerable. When the fingers are used in a pinch-grip, the loads transmitted across the corresponding carpometacarpal joint are between 1.5 and 4.2 times greater than the load at the fingertips (An et al, 1985).

Radio-carpal joint loads are approximately ten times greater than the pressure generated in the grip, as the load is transmitted through five carpometacarpal joints.

Therefore, the ability to use the hand will be impaired by any condition that affects the load-bearing characteristics of the carpus and radio-carpal joint. Kazuki et al (1991) showed that the contact area between the carpus and radius is inversely proportional to the degree of dorsal angulation of the distal radial joint surface. He

also showed that the radio-carpal contact area moves dorsally with increasing dorsal angulation. Therefore, fracture malunion shifts radio-carpal loading away from the normal longitudinal axis of the joint, and increases radio-carpal joint pressure.

Dorsally angulated malunion also affects the mid-carpal joint. In his paper analysing carpal instability, Larsen (1995) describes this phenomenon as a compensatory mechanism. Adaptive carpal instability (CIA) restores co-axial alignment of the forearm and hand. The compensatory flexion required to restore alignment occurs at the midcarpal joint. As described above, this is because movement starts with the distal row. Flexion of the capitate with respect to the lunate produces carpal malalignment, and is the radiological result of CIA. Again, the load-bearing capacity of the wrist joint is adversely affected by malunion, by disruption of the normal axis of the middle column.

## **1.2.2 Soft tissue anatomy**

The distal radius fracture can affect function with respect to forearm and wrist movement. Therefore in sections 1.2.2.1 to 1.2.2.4, the soft tissue anatomy is described with reference to the movements of the forearm and wrist. The relations of the distal radius, and the soft tissue complications of fracture and fracture treatment are described in sections 1.2.2.5 and 1.2.2.6 respectively.

### **1.2.2.1 Forearm rotation**

Forearm rotation can be significantly affected by distal radial fracture malunion, through disturbance of the DRUJ (section 1.2.1.4). The muscles primarily effecting forearm rotation are pronators and supinators. The pronators lie anteriorly in the forearm: pronator teres proximally, and pronator quadratus distally. Pronator teres

has two heads: the humeral head arising from the common flexor origin, and the deeper ulnar head arising from the coronoid process of the ulna. The common flexor origin consists of the lower third of the medial supracondylar ridge and adjacent intermuscular septum, and the medial epicondyle of the humerus. The muscle inserts into middle of the radius on its lateral aspect. Pronator quadratus arises from the distal quarter of the anterior surface of the ulnar. It inserts into the distal quarter of the anterior surface of the radius. The nerve of pronation is the median nerve. The median nerve innervates pronator teres directly, and pronator quadratus via the anterior interosseous nerve. The nerve roots supplying pronators teres and quadratus are C<sub>6</sub> and C<sub>7</sub>, and C<sub>8</sub> and T<sub>1</sub> respectively. In addition to effecting pronation, pronator quadratus acts as a secondary restraint for the distal radio-ulnar joint by holding the radius and ulna together.

The supinator muscle lies posteriorly in the forearm and has two heads. The humeral head arises from the common extensor origin (the lateral epicondyle of the humerus), the radial collateral ligament of the elbow, and the annular ligament of the proximal radio-ulnar joint. The ulnar head arises from the supinator crest of the ulna. The muscle inserts into the posterior, lateral, and anterior surface of the proximal third of the radius. The innervation of supinator is via the deep branch of the radial nerve, which runs between the two heads of the muscle. The nerve roots supplying supinator are C<sub>5</sub> and C<sub>6</sub>.

Other muscles arising proximally aid forearm rotation. Biceps brachii inserting via a thick tendon into the bicipital tuberosity, is a strong supinator with the elbow flexed. Brachioradialis and flexor carpi radialis (FCR) help in pronation, though the former only pronates the fully supinated forearm. The tendon of brachioradialis inserts into

the lateral aspect of the radius just proximal to the styloid process, and that of FCR into anterior aspect of the bases of the second and third metacarpals.

### 1.2.2.2 Wrist Flexion

Flexion of the midcarpal joint compensates for dorsiflexion of the radio-carpal joint surface of the malunited distal radius (section 1.2.1.5). Part of the normal range of wrist flexion is used to restore normal axial alignment. Thus flexion can be restricted in malunion.

Flexor carpi radialis (FCR), palmaris longus (PL), and flexor carpi ulnaris (FCU) lie anteriorly in the forearm. FCR and PL arise from the common flexor origin by single heads. The tendon of FCR inserts into the anterior aspect of the bases of the second and third metacarpals, and that of PL into the palmar aponeurosis. The median nerve innervates both muscles, though by different roots (FCR by C<sub>6</sub> and C<sub>7</sub>, PL by C<sub>8</sub>). FCU has two heads, the humeral head arising from the common flexor origin, and the ulnar head from the upper two thirds of the posterior border of the ulna. The tendon of FCU inserts into the pisiform, which in turn is connected to the hamate and the base of the fifth metacarpal. Nerve roots C<sub>7</sub> and C<sub>8</sub> innervate FCU via the ulnar nerve, which passes into the forearm between the two heads of the FCU. Flexion is effected by all of the afore-mentioned muscles. However FCR and FCU are also synergists in digital extension through stabilisation of the wrist joint.

Flexion of the wrist is aided by the long digital flexors, namely flexor digitorum superficialis (FDS) and profundus (FDP), and flexor pollicis longus (FPL). These muscles are innervated by nerve roots C<sub>7</sub>, C<sub>8</sub> and T<sub>1</sub>: FDS, FPL, and the lateral half of FDP via the median nerve, and the medial half of FDP via the ulnar nerve.

Although abductor pollicis longus and extensor pollicis brevis lie posteriorly in the

forearm, both aid in wrist flexion. This is because the axis of wrist flexion/extension lies distal and posterior to the muscles' tendons and insertions respectively. The radial nerve innervates both muscles, via its posterior interosseous branch.

### 1.2.2.3 Wrist extension

The wrist extensors lie posteriorly in the forearm. They are extensor carpi radialis longus (ECRL) and brevis (ECRB), and extensor carpi ulnaris (ECU). All three muscles arise from the common extensor origin. ECRL also takes origin from the lower one-third of the lateral supracondylar ridge, and ECU from the posterior border of the ulnar (in common with flexor carpi ulnaris). The tendons of ECRL and ECRB are inserted into the dorsal aspects of the second and third metacarpals respectively. The tendon of ECU inserts into the tubercle on the medial aspect of the base of the fifth metacarpal. Nerve roots C<sub>6</sub>, C<sub>7</sub>, and C<sub>8</sub> innervate these muscles via the radial nerve, or in the case of ECRB via the posterior interosseous branch of the radial nerve. All three muscles extend the wrist, and act synergistically in digital flexion to stabilize the wrist.

Wrist extension is aided by the digital extensors, namely extensor digitorum, extensor indicis, and extensor digiti minimi. Roots C<sub>7</sub> and C<sub>8</sub> innervate all three muscles via the posterior interosseous branch of the radial nerve.

### 1.2.2.4 Wrist abduction and adduction

Fracture malunion usually reduces radial angulation and increases ulnar variance (section 1.3.2.1). Loss of radial angulation requires compensatory adduction of the wrist to restore normal co-axial alignment of forearm and hand. Significant shortening of the radius (increased ulnar variance) can lead to impingement of the

carpus on the distal ulna. Thus wrist movement in the coronal plane can be impaired by coronal and axial deformity. Synchronous contraction of the flexor and extensors carpi radialis causes wrist abduction. The synchronous action of flexor and extensor carpi ulnaris adducts the wrist.

#### 1.2.2.5 Soft tissue relations of the distal radius

The soft tissue relations of the distal radius are shown above in figure 1.2.2.5a (page 14). Beneath the extensor retinaculum are six tunnels, each with a single synovial sheath investing the extensor (and abductor) tendons. From lateral to medial the contents of the six tunnels are as follows:

1. Abductor pollicis longus (APL) and extensor pollicis brevis (EPB) lying laterally
2. Extensors carpi radialis longus and brevis (ECRL and ECRB) lateral to Lister's dorsal tubercle
3. Extensor pollicis longus (EPL) passing round the medial aspect of Lister's tubercle
4. Extensors indicis and digitorum (EI and ED)
5. Extensor digiti minimi (EDM)
6. Extensor carpi ulnaris (ECU) lying posteromedially in the groove between the ulnar head and styloid.

The superficial branch of the radial nerve emerges from beneath brachioradialis and runs along the dorso-lateral aspect of the forearm and wrist. Anteriorly lie the flexor tendons, radial and ulnar arteries, and median and ulnar nerve. Distally, the tendons of the digital flexors and the median nerve pass into the carpal tunnel. The tunnel is created by the anterior concavity of the carpus, and the flexor retinaculum. The



tendon of FCR passes between the superficial and deep layers of the flexor retinaculum laterally.

### **1.2.3 Complications of fracture and fracture treatment**

The functional deficit associated with distal radius fracture and malunion will be discussed in section 1.4.1.1. The other complications of fracture and fracture management described below are sub-divided according to the nature of the tissue involved.

#### **1.2.3.1 Nerve Complications**

There is considerable variation in the reported incidence of nerve injury associated with distal radius fracture. Bacorn and Kurtzke (1953) found traumatic neuritis in only 0.2 percent of their study population. A similar figure was reported by Frykman (1967). Later studies have found this complication approximately fifty times more common (Cooney et al 1980, Stewart et al 1985).

After malunion, median nerve injury is the most common complication of distal radius fracture. Acutely, symptoms are due to direct trauma to the nerve, or by any cause of reduction of carpal tunnel volume such as oedema, haematoma or fracture fragments (Kozin and Wood 1993). Median nerve damage may also be iatrogenic. Application of too tight a cast or of a cast in excessive flexion (the Cotton-Loder position) will lead to nerve compression.

Prolonged symptoms may be due simply to the deformity created by the malunited fracture. The prominence in the volar cortex not only stretches the median nerve, but also compresses it as it passes into the carpal tunnel. Kwasny et al (1994) achieved

almost complete resolution of carpal tunnel symptoms by corrective osteotomy for malunion.

Ulnar nerve injury is less common. Compared to the median nerve, the ulnar nerve is less intimately related to the radius, and does not pass through the carpal tunnel.

Direct trauma to the nerve is rare. This occurs more commonly with higher energy injury with severe fracture displacement, and with concomitant distal ulnar fracture.

Nerve compression may occur in Guyon's canal, again due to reduction of volume acutely (oedema, haematoma) or chronically (malunion).

The most common cause of radial nerve injury is iatrogenic. Radial sensory neuritis can occur as a result of irritation of the superficial branch of the radial nerve by the plaster cast. This nerve can also be irritated or damaged by the pins used in fracture external fixation.

### **1.2.3.2 Tendon complications**

The most common tendinous complication following distal radius fracture is of inter- and peri-tendinous adhesions (Kozin and Wood 1993). This results in limitation of independent digital movement. De Quervain's tenosynovitis can also occur. Such complications can be avoided by careful cast application, hand elevation, and regular

full digital mobilisation. Extensor pollicis longus tendon rupture is also a well-recognised complication of distal radius fracture. This complication is due to compromise of the nutrition of the tendon, and may occur in undisplaced fractures.

The dual blood-supply of the tendon (Davies 1951) does not overlap, leaving a relatively avascular segment of the tendon at the level of Lister's tubercle. Fracture further compromises the nutrition of the tendon at this level: rupture of the tendon may result. Both internal and external fixation can cause tendon problems.

Percutaneous placement of K-wires and of external fixator pins can transfix or damage the tendons. Irritation of the tendons by internal fixation devices is a frequently reported complication necessitating implant removal, even in low profile devices such as the pi-plate.

### **1.2.3.3 Fascial complications**

Compartment syndrome is rare following fracture of the distal radius. However, this fracture is the third most common cause of compartment syndrome (McQueen 2000). This complication may occur as a result of high-energy injury, but can also be iatrogenic: Field et al (1994) reported a significant relationship between cast tightness and compartment syndrome. Although uncommon, the effects of untreated compartment syndrome are disastrous. The vicious circle of Volkmann's ischaemia leads to muscle infarction (Holden 1979). Infarcted muscle is unable to recover or regenerate, and is replaced by fibrous tissue, rendering the hand useless.

### **1.2.3.4 Complex Regional Pain Syndrome (CRPS)**

Three types of Complex Regional Pain Syndrome have been described in an attempt to rationalise the confusing nomenclature in this field. CRPS Type 1 is a well-recognised complication of fracture of the distal radius. It is defined as pain, functional impairment, autonomic dysfunction and dystrophic changes in the absence of a clinical nerve injury (Koman et al 1999). Frykman reported that 2.1 percent of patients in his study had signs of this syndrome. Later studies show that this complication occurs far more frequently: Atkins et al (1989) reported features of the syndrome in 24.8 percent of their patients. The features of this condition are related to peripheral sympathetic overactivity. Symptoms usually appear within one month

of the injury. Pain is characteristically burning in nature, constant, and worsened by movement. Vasomotor instability leads to changes in blood flow, with concomitant colour and temperature changes. Oedema is usually present. Trophic changes in the skin are seen, and sudomotor activity is affected. X-rays reveal patchy bone demineralisation. Treatment is based upon modulating the sympathetic activity in the affected limb. It can involve drugs, surgery, physiotherapy, and a range of adaptive modalities such as TENS. Unfortunately relief of symptoms is very variable.

#### **1.2.3.5 Infection**

This complication can occur in open and surgically treated fractures. The reported rates of infection following external fixation vary enormously. This variation may have two causes. Firstly, higher energy injuries have a higher rate of soft tissue complications, thus rates of infection will depend on the types of patients and fractures in the series (McQueen et al 1992). Secondly, the definition of “pin-tract infection” will vary between series, thus affecting the reported rates of infection. Treatment depends upon the severity of infection. However in most cases, scrupulous pin tract care is all that is required. McQueen et al (1996) reported infection in 12/240 external fixator pins: early removal of the fixator for persistent infection was required in only two cases.

#### **1.2.3.6 Fracture**

External fixation devices require insertion of fixator pins into the radial shaft, and in the case of bridging fixation, into the metacarpals. Fracture through the pinholes can occur whilst the fixator is in place, or after removal. Weber et al (1986) reported an iatrogenic fracture rate as high as 9 percent.



### **1.3 Fracture classification systems and radiological measurements**

This section provides an overview of the development of fracture classification systems. The classification systems and radiological measurements used in this thesis are described in greater detail.

#### **1.3.1 Fracture classification**

The concept of fracture classification is embodied in a quotation from M.E. Muller, one of the founders of the AO/ASIF Group:

*"A classification system is useful only if it considers the severity of the bone lesion and serves as a basis for treatment and for the evaluation of results."*

There have been innumerable classification systems for fractures of the distal radius. This perhaps reflects the complexity of this fracture, and the difficulty in producing a classification that fulfills Muller's criteria. In an editorial in 1993, Burstein added that a classification system must produce the same results time after time, i.e. have acceptable levels of intra- and inter-observer reliability. Each system of classification must therefore be assessed on its merits.

The use of eponymous terms in describing these fractures is of little value. This is because the scope of the eponymous fractures is limited, and there is little agreement in the literature as to the exact nature of these fractures. This creates significant difficulties when comparing the outcome of published trials. However, they were responsible for the first attempts at distal radius fracture classification. The eponymous fractures are listed below:

*Colles' fracture.* Described in 1814 by Sir Abraham Colles (1773-1843), Professor of Surgery in Dublin. The fracture is described as occurring approximately one and one half inches proximal to the radio-carpal joint, with marked posterior displacement of

the carpus. To a varying degree, the distal ulna becomes more prominent medially and anteriorly (implying radial and dorsal displacement of the distal radial fragment). *Barton's Fracture*. Described by John Rhea Barton (1794-1871) in 1838. Passing through the articular surface in the coronal plane, this fracture is accompanied by subluxation of the carpus in the direction of fracture displacement. The displacement and subluxation could be either in the dorsal or volar direction.

*Smith's fracture*. Although this fracture carries the name of Robert William Smith (1807-1873, also Professor of Surgery in Dublin), the first description of the distal radial fracture with volar displacement is attributable to Jean-Gaspar-Blaise Goyrand (1803-1866). Using cadaveric dissections, Goyrand described the anatomical features of the Colles' fracture. However, he also noted that in a few cases, displacement of the distal radial fragment could be in the volar direction.

#### 1.3.1.1 Factors used to define fractures of the distal radius

In his study published in 1967, Frykman described the factors upon which previous classification systems had been based. To the present day, almost all classification systems use these factors:

1. "*The site of the fracture in relation to the wrist joint*". This factor draws the distinction between intra- and extra-articular fractures, with reference to the radio-carpal joint surface.
2. "*The degree of joint involvement*". The classification system addresses the number of fragments into which the distal radial joint surface is divided.
3. "*The direction of displacement*". For practical purposes, the distal fragment is described as being displaced in either a dorsal or volar direction.
4. "*The degree of displacement*".

5. "*Injury to the distal radio-ulnar joint*" (DRUJ). Frykmans own system recognised the importance of involvement of the DRUJ in terms of the functional result.
6. "*The mechanism of injury*". Here classification systems recognise an association between specific fracture patterns, and the way the injury occurred (type of force, position of the wrist joint when force applied).

A notable omission from this list of defining factors is metaphyseal comminution. Both the Older and Jenkins classifications include this fracture characteristic (Older 1965, Jenkins 1989). Jenkins' study investigated the importance of various factors in the assessment of distal radius fracture. The findings of this study, along with those of Older, would indicate that comminution should be included in fracture classification for its prognostic significance.

#### 1.3.1.2 The development of fracture classification

Perhaps the earliest attempt at producing a classification of distal radial fractures was made by Auguste Nelaton. In 1844, he described fracture patterns generated in cadaveric forearm specimens, and related them to the mechanism used to create the fracture. The classification of fractures was greatly facilitated by the advent of X-rays at the end of the nineteenth century. Lidstrom remarked in his paper in 1959 that a large number of classification systems (following the discovery of X-rays) were in practice, used by their authors alone. This was probably due to their complexity. At that time only four systems had gained wider acceptance in the Orthopaedic community. Destot (1923) based his system on the direction of fracture displacement and the presence of articular involvement. His system incorporated all the eponymous fractures: the Smith's and volar Barton's fracture, and the Colles' and



dorsal Barton's fracture. It also included the Chauffeur's fracture (radial styloid fracture) under volarly displaced fractures. The classification system proposed by Taylor and Parsons (1938) was important as it drew attention to the functional problems created by disruption of the distal radio-ulnar joint. The Nissen-Lie classification system was broader, and included paediatric fractures (Nissen-Lie 1939). Adult fractures were divided into groups according to joint involvement and the direction and degree of displacement. Displacement, however, was not quantified. Gartland and Werley's classification was based upon comminution and distal radial joint surface involvement (Gartland and Werley 1951). Their paper provides an example of the confusion created by the use of eponymous terminology. All patients in this study were described as having sustained "true Colles' fractures". The authors then proceeded to classify the fractures according to the degree of intra-articular involvement of the fracture.

The deficiencies in each system limit their value. Destot failed to identify the complete articular fracture as a separate entity. Taylor and Parsons looked exclusively at the affect on the DRUJ. Nissen-Lie and Gartland and Werley classified Colles' type fractures only.

Lidstrom provided the first of the more comprehensive classification systems. It was based upon several factors: direction and degree of displacement, and involvement and degree of comminution of the distal radial articular surface. The importance of this system was that it attempted to grade the severity of the fracture, and thus indicate the mode of treatment required. However Solgaard (1984) showed that the prognostic value of the Lidstrom classification (with reference to the radiological outcome) was inferior, as fracture displacement was not quantified. The system also does not include partial articular fractures.

Older's classification was based upon the degree of fracture displacement and the degree of metaphyseal comminution (Older 1965). It was shown by Solgaard (1984) to be of prognostic value as far as the radiological outcome was concerned. Andersen (1991) showed that there was good intra- and inter-observer agreement with the Older system. However, the system is only applicable to dorsally angulated fractures, and there is little description of the morphology of the intra-articular component of the fracture. Again, partial articular fractures are not included.

Other later classification systems are directed towards specific types of fracture. For example, the Melone system (Melone 1984) is limited to the classification of intra-articular fractures. These more specialised systems are not wide enough in scope to be used in this study.

The most contemporary classification systems are designed to be a guide for fracture treatment. The simplicity of the Universal Classification (Rayhack 1990) allows it to encompass all fracture types. The fracture is classified by four factors: articular involvement, displacement, fracture reducibility (closed) and stability. The Mayo Clinic has adopted this system. Andersen (1996) found good inter- and intraobserver agreement for this classification. Unfortunately, for displaced fractures to be classified, an assessment of reducibility and stability must be made clinically, by trial reduction. Fernandez and Jupiter (1996) based their classification upon the mechanism of injury. The philosophy was that the mechanism of injury is of vital importance when deciding upon the course of treatment of the fracture. The classification is a development of Castaing's system, proposed in 1964. Castaing identified the various fracture patterns identified with compression with wrist extension, and compression in wrist flexion. Fernandez's classification is more comprehensive. It commented on fracture stability, and identified similar injury

patterns in children's fractures. Disruption of the DRUJ is also classified, as damage to this articulation affects the functional outcome. Again, the aim of the classification was to provide a general guide to fracture treatment.

For the purposes of this study, a classification system was required which could adequately define fracture morphology. At the time that data collection commenced (February 1988), the Frykman classification was widely accepted and used in the literature. In 1990, the AO/ASIF group published their system, which exhaustively defined fracture morphology. The advantage of the AO/ASIF system was that it could be applied retrospectively (i.e. to the fractures in the database prior to 1990) as the only information required for fracture classification was radiological. Therefore, all fractures in the database were classified using the AO/ASIF system: prospectively from 1990, and retrospectively prior to 1990. This could not have been done with other systems such as the Universal Classification.

### **1.3.1.3 The Frykman and AO-ASIF classifications**

Two classification systems are used in the first section of this study. The collection of data for this study commenced in 1988. At this time the most comprehensive and widely accepted system was that of Frykman (1967). Like Taylor and Parsons, Frykman addressed the importance of involvement of the DRUJ in his classification system. Frykman felt that the degree of displacement on X-ray was irrelevant, as it did not reflect the displacement at the time of injury. Likewise, fracture comminution was irrelevant, unless it involved the articular surface. Thus the factors from which the system was derived were entirely morphological. Did the fracture involve the radio-carpal or radio-ulnar joint articular surface? Was the ulnar styloid fractured?

Frykman's classification is illustrated in figure 1.3.1.3a. The fracture types are described as follows:

- I. Extra-articular fractures without fracture of the distal ulna.
- II. Extra-articular fractures accompanied by fracture of the distal ulna.
- III. Intra-articular fractures involving the radio-carpal joint but without fracture of the distal ulna.
- IV. Intra-articular fractures involving the radio-carpal joint and accompanied by fracture of the distal ulna.
- V. Intra-articular fractures involving the distal radio-ulnar joint but without fracture of the distal ulna.
- VI. Intra-articular fractures involving the distal radio-ulnar joint accompanied by fracture of the distal ulna.
- VII. Intra-articular fractures involving both the radio-carpal and distal radio-ulnar joint but without fracture of the distal ulna.
- VIII. Intra-articular fractures involving both the radio-carpal and distal radio-ulnar joint accompanied by fracture of the distal ulna.

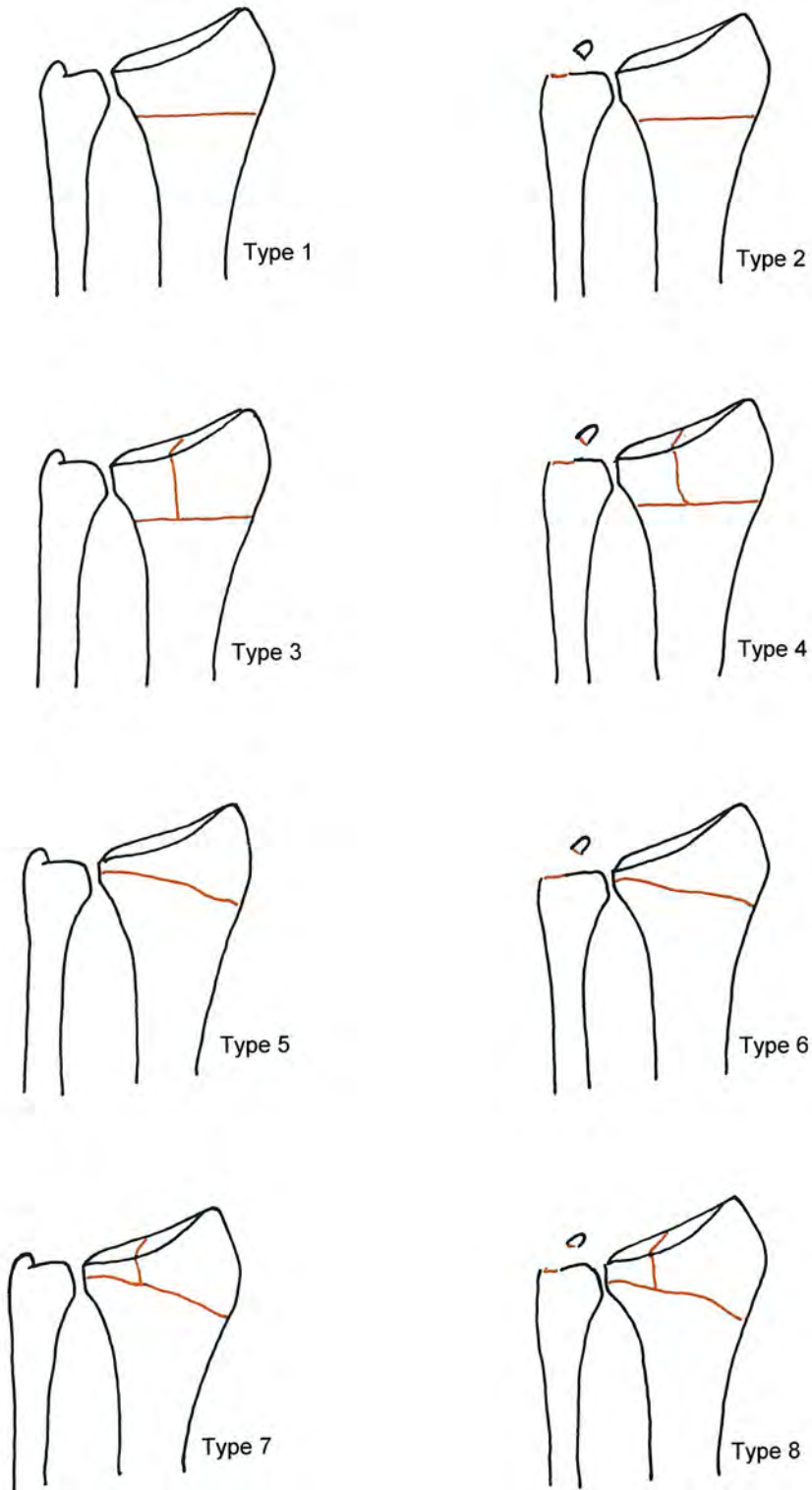
Solgaard (1984) found that the Frykman system was of some prognostic value with reference to the radiological outcome of the fracture. However, the prognostic power was inferior to that of the Older classification, and when the age of the patient and the result of fracture reduction were included in the analysis, then the Frykman classification was of no prognostic value. Andersen et al. (1996) reported that there was good intra- and inter-observer reliability of the Frykman system when assessing the presence of ulnar styloid fracture and extension into the radio-carpal articular surface. However, there was a low level of agreement when assessing radio-ulnar

articular surface involvement. As a result, the reliability of the classification system as a whole was poor.

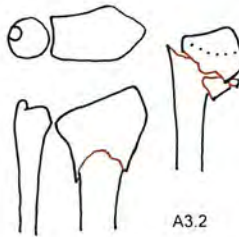
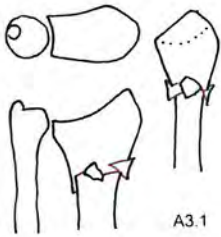
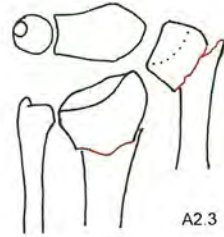
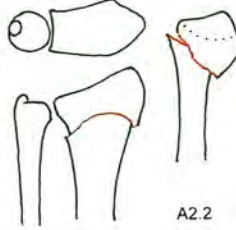
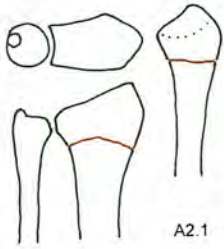
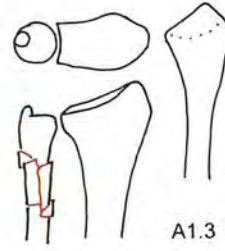
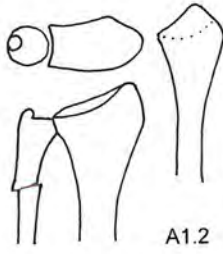
In theory, Frykman's classification system is of value as it indicates the likely nature of fracture complications by defining joint involvement. In practice the prognostic value of the classification in terms of radiological outcome is limited, and there is poor agreement between observers as to the classification of individual fractures.

The second system used in Section 1 of the study is the AO/ASIF classification (Muller et al. 1990). In Section 2 of the study, the AO/ASIF classification is used exclusively. The AO/ASIF group published their comprehensive classification of long bone fractures in 1990. This classification system was developed by analysis of a large fracture treatment database started by the authors in 1959. The system has been adopted by the OTA (Orthopaedic Trauma Association) and by SICOT (Societe International de Chirurgie Orthopedique et de Traumatologie), as its ability to communicate fracture morphology facilitates the comparison of fracture outcome studies.

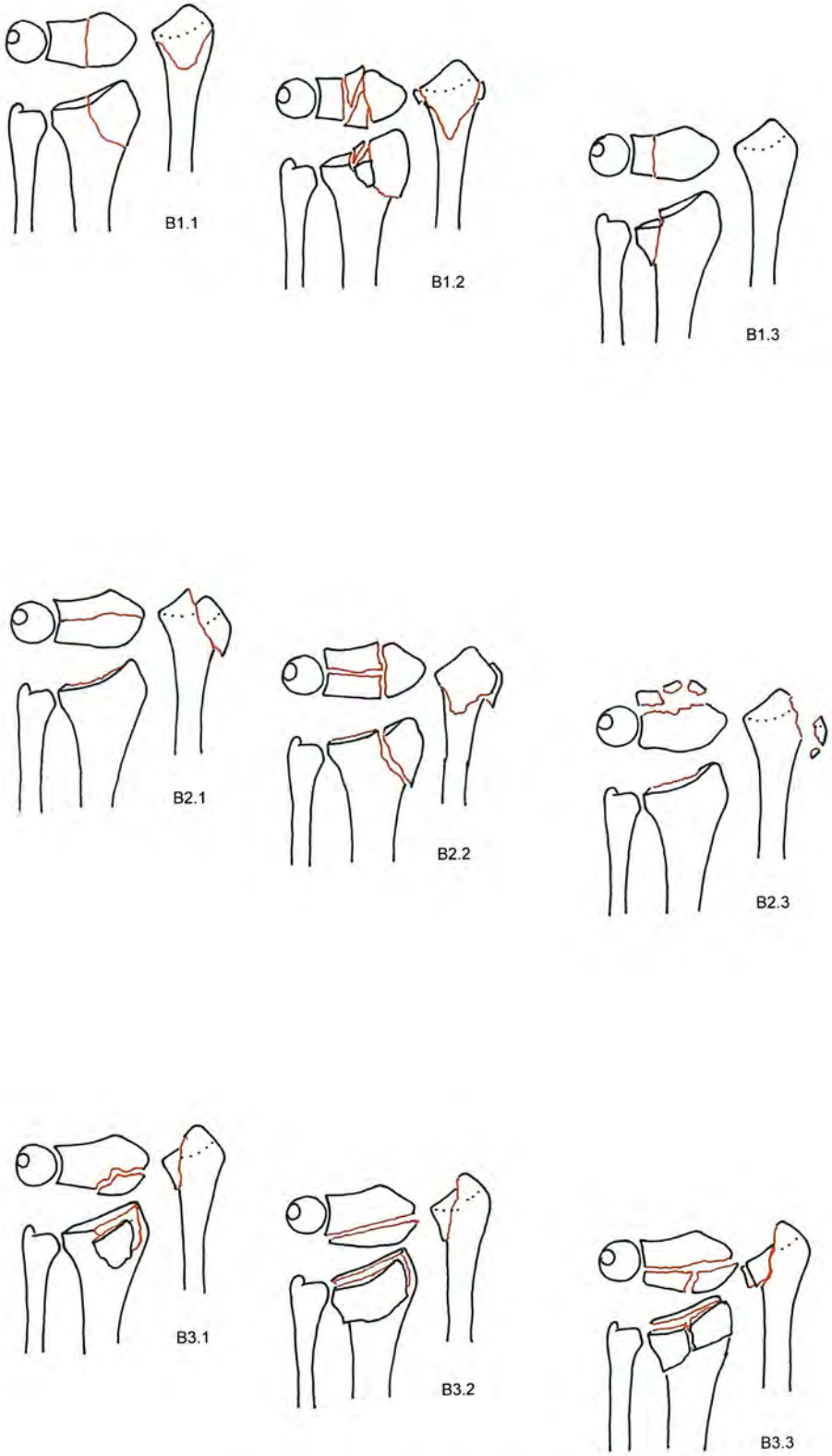
Three groups of three decisions are made when classifying a fracture according to the AO/ASIF system. Therefore there are 27 fracture types in all. The first decision is whether the fracture is extra-articular (type A) or intra-articular, and if intra-articular whether partial (type B) or complete (type C). In fractures of the distal radius, the division of each type into three groups (1 to 3) and then further into three subgroups (1 to 3) depends on factors such as fracture displacement, the orientation of fracture lines, and the degree of fracture comminution.



**Figure 1.3.1.3a: The Frykman classification.**

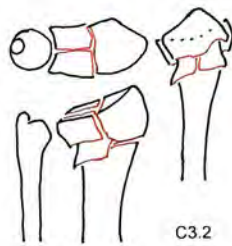
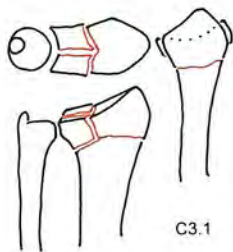
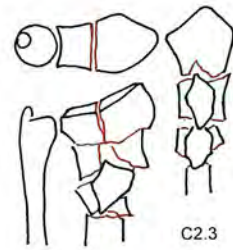
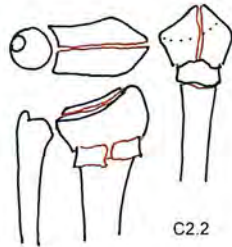
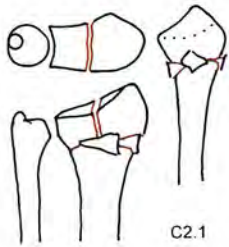
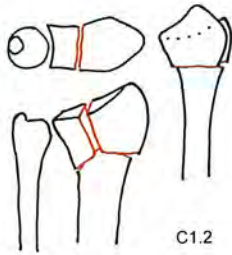
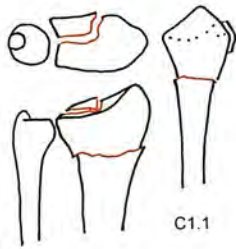


**Figure 1.3.1.3b: The AO/ASIF classification, type A.**



**Figure 1.3.1.3b: The AO/ASIF classification, type B.**





**Figure 1.3.1.3b: The AO/ASIF classification, type C.**

The system is illustrated in Figure 1.3.1.3b, and is divided as follows:

A = Extra-articular fracture

A1 Extra-articular fractures of the ulna, radius intact

- .1 styloid process
- .2 metaphyseal simple
- .3 metaphyseal multifragmentary

A2 Extra-articular fracture of the radius, simple and impacted

- .1 without any tilt
- .2 with dorsal tilt (Pouteau-Colles)
- .3 with volar tilt (Goyrand-Smith)

A3 Extra-articular fracture of the radius, multifragmentary

- .1 impacted with axial shortening
- .2 with a wedge
- .3 complex

B = Partial-articular fracture

B1 Partial articular fracture of the radius, sagittal

- .1 lateral simple
- .2 lateral multifragmentary
- .3 medial

B2 Partial articular fracture of the radius, dorsal rim (Barton)

- .1 simple
- .2 with lateral sagittal fracture
- .3 with dorsal dislocation of the carpus

B3 Partial articular fracture of the radius, volar rim (reverse Barton)

- .1 simple with a small fragment

.2 simple with a large fragment

.3 multifragmentary

C = Complete articular fracture

C1 Complete articular fracture of the radius, articular simple, metaphyseal simple

.1 postero-medial articular fragment

.2 sagittal articular fracture line

.3 frontal articular fracture line

C2 Complete articular fracture of the radius, articular simple, metaphyseal multifragmentary

.1 sagittal articular fracture line

.2 frontal articular fracture line

.3 extending into the diaphysis

C3 Complete articular fracture of the radius, multifragmentary

.1 metaphyseal simple

.2 metaphyseal multifragmentary

.3 extending into the diaphysis

This classification was used in this study as it provided the most complete morphological description of the fracture. The AO/ASIF group also meant the system to be a general guide to prognosis, as severity of the fracture increases from A1.1 to C3.3. This prognostic intent was another reason why the classification system was adopted.

However the classification has drawbacks. Perhaps due to the complexity of the classification, inter- and intra-observer agreement are poor (Andersen 1996).

Although Kreder et al (1996) concurred with this finding, they found good levels of observer agreement for fracture typing alone. To avoid the problems of inter-

observer variation, all fracture classification was undertaken by the study supervisor (M.M. McQueen).

### **1.3.2 Radiological fracture measurements**

These radiological measurements are used in two ways. Firstly, they define the fracture at presentation: fracture displacement, and comminution. Secondly, they define anatomical outcome of the fracture and fracture treatment: fracture displacement and carpal malalignment.

#### **1.3.2.1 Fracture displacement**

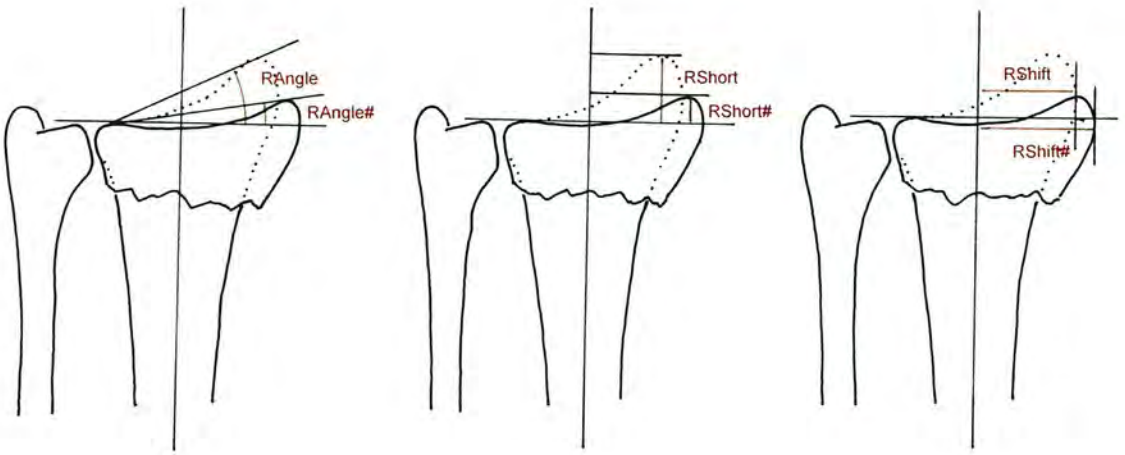
There are a number of radiological measurements described in the assessment of displacement of the distal radius fracture. These are illustrated in figures 1.3.2.1a, b, and d. Van der Linden (1981) assessed the value of a selection of radiological measurements described by previous authors. On the postero-anterior X-ray, the radial angle, radial shortening and radial shift were measured (figure 1.3.2.1a). On the lateral X-ray, dorsal angulation and dorsal shift were measured (figure 1.3.2.1b). The correlation between the two measurements of dorsal displacement (taken on the lateral film) was high. Likewise, the measurements of radial compression (radial shift, radial angulation, and shortening) were highly correlated. This close relationship of radial shift, angulation, and shortening noted by van der Linden can be explained by trigonometry (Figure 1.3.2.1c). He concluded that fracture displacement could be adequately described with two measurements only, one for dorsal displacement and one for radial compression. This conclusion is correct in that only two measurements are required to define displacement in two planes. Measurement of the distal radius in the third dimension had been described some

time earlier (Hulten 1928). This measurement looked at the relative length of the two forearm bones, and was termed ulnar variance. This measurement is illustrated in figure 1.3.2.1d.

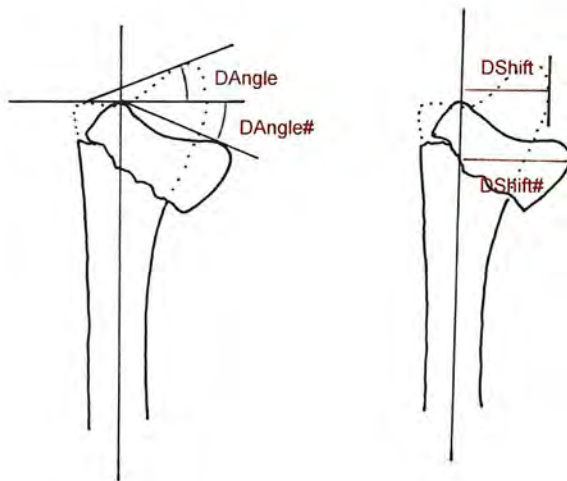
To adequately describe the displacement of the distal fragment of the distal radius fracture, we have therefore employed three measurements. These are dorsal angulation, radial shift, and ulnar variance. The dorsal angulation is measured on the lateral X-ray, and the radial shift and ulnar variance are measured on the antero-posterior X-ray. These three measurements define the deformity in all three dimensions: antero-posterior (dorsal angulation), medio-lateral (radial shift), and axial (ulnar variance).

Dorsal angulation is defined as the angle subtended between the articular surface and a line perpendicular to the long axis of the radius. It is an absolute measurement.

Volar angulation is negative, and dorsal angulation positive. The radial shift is defined as the distance in millimetres between the most radial point of the styloid process and the long axis of the radius. It is a relative measurement. Therefore the radial shift of the fractured radius is expressed as a positive or negative difference from the radial shift of the contralateral uninjured radius. The ulnar variance is defined as the distance in millimetres between the distal cortical surfaces of the ulnar pole and the lunate fossa as measured along the long axis of the radius. The ulnar variance is described as negative, when the cortical surface of the lunate fossa is distal to the cortical surface of the ulnar pole. Again this is a relative measurement, expressed as the difference from the ulnar variance measured on the uninjured side.



**Figure 1.3.2.1a: Radiological measurements.** Displacement in the coronal plane measured on the postero-anterior radiograph: radial angulation, shortening, and shift.

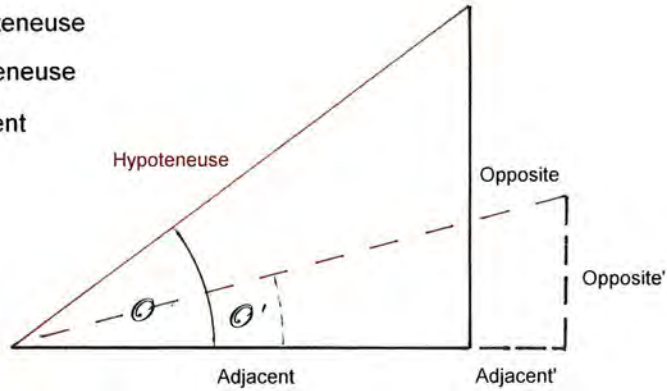


**Figure 1.3.2.1b: Radiological measurements.** Displacement in the sagittal plane measured on the lateral radiograph: dorsal angulation and shift.

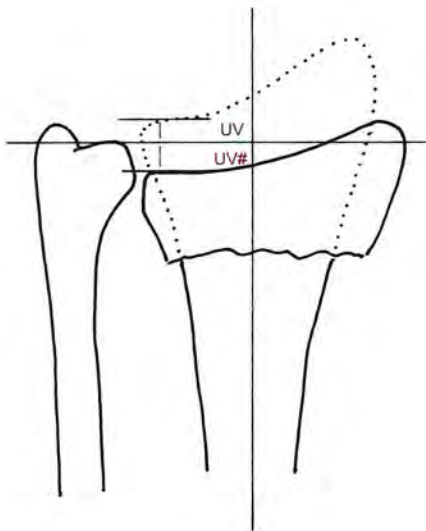
$\sin \theta = \text{Opposite}/\text{Hypoteneuse}$

$\cos \theta = \text{Adjacent}/\text{Hypoteneuse}$

$\tan \theta = \text{Opposite}/\text{Adjacent}$



**Figure 1.3.2.1c: Radiological measurements.** The trigonometrical relationship of angulation (theta), shortening (opposite side), and shift (adjacent side). The hypoteneuse is constant and is the width/depth of the distal radial joint surface.



**Figure 1.3.2.1d: Radiological measurements.** The measurement of ulnar variance is made with respect to the distal ulnar. Ulnar variance can be negative (radius longer than ulna), or positive (ulna longer than radius).

There are considerable differences in opinion as to what constitutes a displaced fracture in terms of radiological measurement. The displaced fracture has usually been defined by the relationship between anatomy and function. Thus displaced fractures are those fractures following which the functional result is significantly poorer. Depalma (1952) advocated a watershed value of 5 degrees of dorsal angulation and 3 millimetres of ulnar variance. He found that greater displacement was incompatible with acceptable functional results. However, Kelly et al (1997) concluded that a displacement of up to 30 degrees of dorsal angulation and 5mm of ulnar variance would be acceptable in selected elderly patients. Older's classification groups fractures in part by the degree of displacement. An undisplaced fracture had to have a dorsal angulation of less than 5 degrees, and minimal radial shortening. Unfortunately, in clinical practice, there is often no indication of the nature of the displaced fracture. In the study by Dias et al (1987), a displaced fracture was defined as a fracture that required manipulation (in the opinion of the admitting Junior Orthopaedic Staff). For the purposes of our statistical analysis, this approach was unacceptable. The anatomical outcome needed to be expressed in binary terms: was the fracture displaced, yes or no? In the Edinburgh Orthopaedic Trauma Unit, a fracture is termed "displaced", if the dorsal angulation exceeds 10 degrees, or if the ulnar variance exceeds 3 millimetres. If the radiological measurements do not exceed these values, then the fracture is termed "minimally displaced" (McQueen et al 1996).



### **1.3.2.2 Fracture comminution**

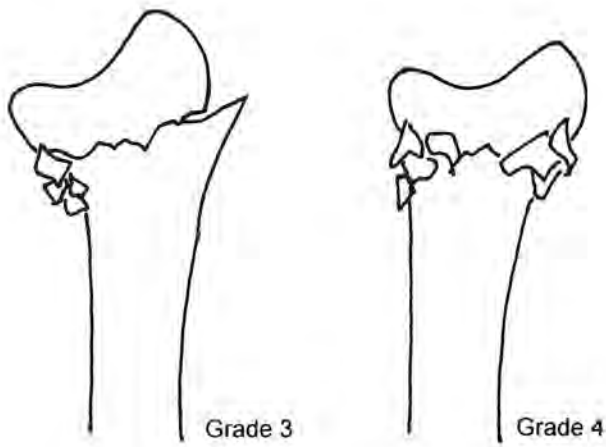
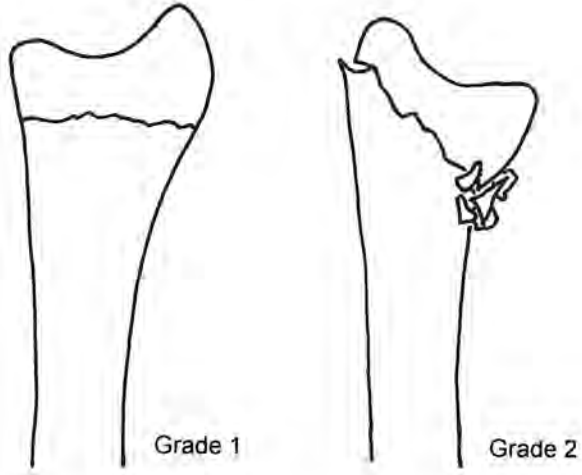
The importance of fracture comminution in the assessment of distal radius fracture is considered to be sufficient to include it in classification systems (Older 1965, Jenkins 1989). The use of these systems has been avoided in this study, as they are based on more factors than metaphyseal comminution alone. Older's classification includes fracture displacement, and both Jenkins' and Older's systems include articular surface involvement. For the purposes of this study, comminution is a qualitative measurement defined by its presence or absence, and by its location (figure 1.3.2.2a).

The four grades of metaphyseal comminution are as follows:

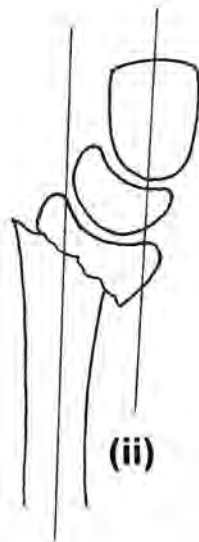
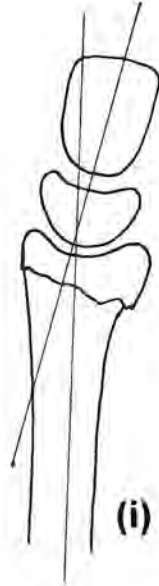
1. no comminution present
2. comminution of the dorsal cortex only
3. comminution of the volar cortex only
4. comminution of both dorsal and volar cortices.

### **1.3.2.3 Carpal malalignment**

As described in section 1.2.1.5, symptoms are related to the derangement of the load-bearing middle column of the carpus. The radiological finding is compensatory flexion of the capitate on the lunate. The radiological measurement of this carpal derangement is seen in figure 1.3.2.3.a. Carpal malalignment is present when the long axes of the capitate and radius fail to intersect within the confines of the carpus, as measured on the lateral X-ray (McQueen 1996).



**Figure 1.3.2.2a: Fracture comminution.** Fracture comminution graded on the lateral radiograph as either: 1 – none; 2 – dorsal; 3 – volar; 4 – dorsal + volar.



**Figure 1.3.2.3a: Carpal malalignment.** Assessment of carpal malalignment is made using the lateral radiograph. Malalignment is present when the intersection of the long axes of the capitate and radius does not lie within the carpus. Carpal alignment is satisfactory in (i); malalignment is demonstrated in (ii).

## **1.4 Current fracture management**

In this section of the introduction, distal radial fracture management is examined. This thesis has been directed towards answering some of the questions raised by failings in the current management protocol.

### **1.4.1 The evolution of management of the distal radial fracture**

The treatment rationale advocated by Sir Abraham Colles remains unaltered: the deformity of the fracture should be corrected, and then the fracture immobilised until union. However, three important observations have stimulated considerable research into this fracture in the latter half of the last century. Firstly, there is a relationship between anatomical and functional outcome following the fracture. Secondly, fractures are either stable, or unstable. Thirdly, unstable fractures cannot be treated effectively by immobilisation in a plaster cast.

Plaster cast immobilisation (following closed reduction if required) is the treatment of choice in two groups of patients. Patients with stable fractures can be treated effectively in this way. The maintenance of fracture position is reliant on patient and fracture characteristics, rather than on the plaster cast. Some authors have suggested that rigid immobilisation (in a cast) can be avoided in the stable fracture, without compromising the anatomical result (Abbaszadegan 1989). Cast immobilisation is also acceptable in those patients with little or no functional requirement from the wrist.

However, this approach is unsatisfactory for patients with unstable fractures and high functional demands. The majority of distal radius fracture research has been directed toward the satisfactory treatment of these patients.

#### 1.4.1.1 Anatomical and functional outcome

Bacorn and Kurtzke (1953) retrospectively reviewed the findings of the New York Workmen's Compensation Board in 2047 cases of distal radial fracture. They observed that the mean permanent loss of function of the hand and wrist following fracture was 24 percent (range: 0 – 100 percent). Only 2.9 percent of patients were deemed to have no functional impairment. They also found a relationship between the functional deficit and the degree of residual deformity. There was a statistically significant increase in the mean functional deficit with each grade of the four grades of deformity (none, mild, moderate, severe). The study by Gartland and Werley (1951) looked at 60 patients a year or more after fracture. It used more precise measurements of radiological deformity and functional outcome. The authors showed that functional deficit was related to all three radiological measurements, namely dorsal angulation, radial deviation, and radial shortening. The scoring system for the assessment of functional and anatomical outcome produced by Gartland and Werley is widely accepted and used as a research tool in its modified form (Sarmiento, 1980). The mean interval between fracture and assessment in Frykman's study (1967) was 2 years and 7 months. Radiological measurement at union was not available for all of the patients in his study (224/430). However, he found that severe deformity was incompatible with an excellent functional result, and that radial shortening was the most likely reason for this. Dorsal angulation had a less profound effect on the functional outcome.

More specific relationships between anatomy and function are described. Villar et al (1987) noted that grip strength was adversely affected by radial shortening. This was the most significant finding. There was also a significant correlation between dorsal

angulation and loss of wrist flexion and supination. Jenkins and Mintowt-Czyz (1988) also observed the relationship between dorsal angulation and wrist flexion, but found that radial angulation was the most significant factor affecting grip strength. They found that radial shortening was significantly greater in those patients complaining of wrist pain. McQueen and Caspers (1988) undertook perhaps the most comprehensive assessment of the relationship of anatomy and function. Although only thirty patients were examined (17 with an acceptable anatomical result, and 13 with malunion), the functional assessment was exhaustive. Hook, cylinder, key chuck, pinch and mass grip strengths were measured. Wrist range of motion was recorded using a goniometer. Pain was measured using an analogue scale, and the degree of cosmetic deformity graded. Finally, various activities of daily living (lifting weights, turning a key, using scissors etc.) and manual dexterity were assessed. The functional outcome was significantly poorer in patients with malunion, though there was no significant increase in the incidence of pain.

Long-term studies show that the detrimental effect of malunion persists. Warwick et al (1993), showed that the radial shortening was significantly greater in patients with an unsatisfactory functional result at 10 years. Altissimi et al (1986) assessed their patient cohort up to 6 years post injury. They were able to define a radiological watershed: functional results were significantly poorer when the radial angle was less than 5 degrees, the dorsal angle greater than 15 degrees, and the ulnar variance greater than 5 millimetres.

There appear to be inconsistencies in the conclusions of these studies. For example, authors differ as to the factor that affects grip strength most significantly, and as to how long the detrimental effect of malunion persists. The explanation for these differences may be the differences in methodology. Villar et al (1987) found a

correlation between grip strength and radial shortening at one week, whereas Jenkins and Mintowt-Czyz (1988) found that grip strength correlated with radial angulation at union. As described in section 1.3.2.1, there is a direct relationship between these measurements. Stewart et al (1985) found that the significant difference in function related to the degree of malunion had disappeared by six months, whereas Warwick et al (1993) found that the detrimental effect of radial shortening persisted for 10 years. Stewart compared functional outcome between different anatomical grades of fracture. Warwick on the other hand compared the radial shortening between different grades of functional outcome.

The importance of these studies must not be obscured by these inconsistencies. The theoretical reasons for functional impairment are described in section 1.2, and the weight of evidence indicates a close relationship between anatomy and function.

#### **1.4.1.2 Fracture Instability**

Jenkins in 1989 was the first author to discuss explicitly two forms of fracture instability. He identified acute instability as the macroscopic movement at the fracture site of reduced fractures, occurring within the first week of injury. Acute instability is therefore a product of the morphology of the fracture. He also described late deterioration of the fracture position, which occurs slowly and progressively. This he termed chronic instability. This entity had previously been described by Charnley (1961), and was felt to be as a result of the gradual collapse of uniting cancellous bone.

Most work examining the causes of fracture malunion has not made the distinction between early and late collapse of the fracture. In addition, fracture instability has not been examined with reference to the position of the fracture at presentation. The

subsequent heterogeneity of study populations may explain the disagreement between authors as to the most important factors determining fracture stability. Hove et al (1994) analysed data for 645 conservatively managed distal radius fractures. Using multiple regression analysis, the authors found that the initial dorsal angulation and radial length, and the patient's age were significant predictors of malunion. It was not possible to determine whether these factors may have been different for early and late instability, as all fractures which requiring treatment for redisplacement at one week were excluded from the analysis. Jenkins (1989) found that the position of the fracture at presentation (as measured by dorsal angulation, radial length, and radial angulation) was a good indicator of fracture position at union. He also found that the absence of dorsal cortical comminution was protective against malunion in dorsal angulation. However, Jenkins did not calculate the independent significance of these factors. He also only analysed radiological data. All the patients in his study had displaced fractures at presentation, but displacement was not defined other than by the need for reduction. Lafontaine et al (1989) reported independent significant predictors of fracture instability: age (greater than 60 years), dorsal angulation (greater than 20 degrees), dorsal comminution, intra-articular fracture (radio-carpal joint surface), and associated ulnar fracture. Again, all fractures in the study were initially displaced. Abbaszadegan et al analysed 267 cases of distal radius fracture in their study in 1989. They calculated the independent significance of a range of factors. Ulnar variance, Lidstrom class, and patient age were the most important predictors of fracture instability. The authors also quantified the risk of instability with respect to ulnar variance, but not with respect to any of the other factors. Adolphson et al (1993) used computerised analysis to quantify the risk of



fracture instability. Unfortunately this method of predicting fracture behaviour has not been validated.

A list of significant predictors of fracture instability is available (Ruedi et al 2000). The presence or absence of these predictors will facilitate management decision-making. However, fracture instability cannot be quantified using this information, and the assessment is ultimately based upon clinical judgement.

#### **1.4.1.3 Treatment of the unstable fracture**

Traditional methods of treatment (manipulation and casting) are inadequate when managing the unstable fracture (McQueen 1986). Studies showed that extension of the cast above the elbow (Pool 1973), and altering the position of wrist immobilisation (Gupta 1991) had little effect on outcome. Bohler suggested the pins and plaster technique in 1929. Several variations of the technique have been described, however the underlying principle is of fixed traction. Pins are placed proximal (into radius and/or ulna) and distal (into one or more of the metacarpals) to the fracture, the fracture is reduced, and the position is maintained by including the pins in the plaster cast. Chapman et al (1982) concurred with previous authors in their study, stating that reasonable anatomical results were achieved. However, they recommended that use of this technique should be highly selective, due to the incidence of pin-related complications. They reported serious pin site infection in 20 percent of cases, osteomyelitis in 9 percent, and iatrogenic fracture in 9 percent. Percutaneous pin fixation of the fracture has been popularised by Kapandji. He describes a technique using two intrafocal wires, one directed lateral to medial, the other from posterior to anterior (Kapandji 1988). He reported excellent and good radiological results in 70 percent of patients. However, Kapandji had strict and

limited indications for the use of this technique. Intrafocal wiring was considered ideal in extra-articular fractures, where the cortical gap due to dorsal comminution was less than 4mm. Previously, De Palma (1952) had reported a wiring technique for those severely comminuted intra-articular fractures not indicated for the Kapandji technique. The fracture was reduced, and reduction maintained by a wire passed through the ulna into the distal radial fracture fragments. However, De Palma's series was small (28 patients), and did not compare the technique with any other.

It has been suggested that bone cement or bone graft could be used to fill the cortical defect in comminuted fractures. There is little agreement in the literature as to the efficacy and indications for these treatments. Kofoed (1983) had good anatomical and functional results following the use of bone cement, however he felt this method of treatment should be reserved for highly comminuted intra-articular fractures in the elderly. Conversely, Schmalholz (1989) reported poor personal experience with bone cement used in just such patients. McQueen et al (1995) achieved good results with bone grafting and wire fixation. The anatomical results were unpredictable in severe metaphyseal comminution, as over-correction of the dorsal angulation could occur. However, when compared to other methods of treatment, bone grafting and wiring conferred no functional benefit (McQueen et al 1996). The authors felt that there was thus no indication for this technically demanding procedure.

Ombredanne first described external fixation of distal radius fracture in 1929.

Interestingly, he used a non-bridging fixator for injuries in adolescents. Bridging external fixation in the distal radius became the subject of much research, after Vidal et al described the concept of ligamentotaxis in 1979. McQueen et al (1996) studied four different methods of fixation of the unstable fracture. This paper was uncommon within the body of literature for two reasons. It compared the outcome of bridging

external fixation with other types of fixation, and was restricted to patients with proven fracture instability. The study was able to show no significant improvement in anatomical or functional outcomes with the use of bridging external fixation. In 1998, McQueen identified a reliable treatment method for unstable fractures. Non-bridging external fixation produced significantly superior anatomical and functional results when compared with bridging fixation.

Other more invasive methods of distal radial fracture reconstruction have been described in the literature. These include the use of devices such as the pi-plate. This type of surgery is directed towards the reconstruction of severely comminuted higher energy injuries. Open reduction and internal fixation using these methods is probably inappropriate for the common low energy injury, as the exposure required is extensive, and the rates of complication high. However recent work has shown good results in the elderly patient with internal fixation using a fixed angle device through a volar approach (Orlay and Fernandez 2004). Discussion of these methods of treatment is beyond the scope of this thesis.

The literature available on the treatment of distal radius fracture is enormous, however analysis of this information has proved difficult. The review produced by the Cochrane Library (Handoll, 2001), found only 44 trials that met its selection criteria. The review concluded that:

*"The randomised trials do not provide robust evidence for most of the decisions necessary in the management of these fractures. Although in particular there is some evidence to support the use of external fixation or percutaneous pinning, their precise role and methods are not established. It is also unclear whether surgical intervention of most fracture types will consistently better long term outcomes."*

#### 1.4.2 The current fracture management protocol

The current management protocol is described in detail in Section 2.1.2. However the essence of the protocol is to provide timely surgical treatment. The decision to treat the fracture surgically can be taken at three points:

1. At the time of presentation, surgical treatment will be indicated for those patients with:
  - i. open fractures
  - ii. compartment syndrome
  - iii. nerve compression symptoms
  - iv. severe intra-articular fractures requiring reconstruction.
2. At 7 to 10 days, when fracture stability is radiologically assessed. If the fracture has collapsed into an unacceptable position, then fixation is undertaken (as patient and fracture characteristics dictate). This is realistically the latest time that stability assessment is worth performing prior to union. After this time, fracture healing renders surgical treatment difficult, and therefore stability assessment irrelevant.
3. Late. If fracture malunion has occurred and the patient remains symptomatic despite physiotherapeutic measures, then a variety of corrective surgical procedures are available.



## **1.5 Aims of the study**

Section 1.5.1 details the problems with the current fracture management protocol. Other than those cases identified at presentation, the indications for surgical treatment in the protocol are reactive rather than proactive. Surgery is for collapse of the fracture, and the presence of symptomatic malunion, rather than for the prevention of these outcomes. Section 1.5.2 provides a brief outline of the research projects in the thesis.

### **1.5.1 Problems in the current management protocol**

The aims of fracture treatment have been outlined by the AO/ASIF group (Muller et al 1991). These are anatomical reduction and stable fixation of the fracture, and adequate mobilisation of the adjacent joints to maintain function. These principles apply to the distal radius fracture in all patients whose functional requirements demand good functional outcome. Following reduction, the stable fracture does not require fixation, and can be adequately protected by a plaster cast. In fact, Abbaszadegan (1989) suggested that casting was not required in stable fractures. The unstable fracture can be treated successfully in the majority of cases by non-bridging external fixation (McQueen 1998). This method of treatment not only maintains reduction, but also permits full mobilisation of the wrist joint in line with the AO/ASIF principles.

The choice of treatment depends upon the nature of the fracture. Currently, decision-making is based upon an assessment of early instability. Fractures that maintain an acceptable position for 7 to 10 days are deemed stable. Those fractures that do not are deemed unstable. Stability assessment is performed at the latest possible moment, before fracture healing renders surgical treatment of the fracture impossible.

Unfortunately this assessment is not performed late enough to detect all unstable fractures. Jenkins (1989) stated that the majority of fracture collapse was due to 'chronic instability'. Thus malunion rate is a reflection of chronic instability, when all fractures displaying early instability are treated appropriately. All flaws in the current management of distal radius fracture are due to the inability to accurately assess the risk of malunion, at the time the patient presents. Patients with early instability undergo what is often an ineffective closed reduction under regional anaesthesia. They then wait 7 to 10 days for appropriate treatment of their fracture. Patients with late instability suffer the same ineffective closed reduction. They do not receive the treatment they require, and their fracture malunites.

### **1.5.2 Study aims**

The aims of this study were twofold. Firstly it was necessary to assess the size of the problem. To this end, we looked at the epidemiology and natural history of distal radius fracture. Secondly, we addressed the problem of prediction of fracture instability.

#### **1.5.2.1 Epidemiology**

Over a period of approximately 5 years, data were collected for all patients presenting to the Orthopaedic Trauma Unit of the Royal Infirmary of Edinburgh. Data included demographic details, information about the mode of injury, and radiological measurements of the fracture from presentation until union. For reasons discussed in section 2.1.5, not all of this data could be used for epidemiological study. Therefore using a part of this database we aimed to define the characteristics of the fracture and patient sustaining the fracture. By comparing the epidemiological

data from the initial study period with data collected from 1999 to 2000, we hoped to identify any trends in patient and fracture characteristics.

### **1.5.2.2 Fracture outcome**

We also planned to examine the differences in fracture anatomical outcome produced by factors such as patient age and fracture type. This section of the study was undertaken using the same data described in section 1.5.2.1 above. In this way, the findings with respect to fracture outcome could be directly related to the epidemiological findings. This would not have been possible if different sets of data had been used. In addition, future study looking at trends in fracture epidemiology and outcome will be able to use this descriptive data for direct comparison.

### **1.5.2.3 Prediction of fracture instability and carpal malalignment**

Data for approximately 4000 patients recorded patient and fracture characteristics, and the outcome of the fracture. As alluded to above, treatment choices are based upon the clinician's assessment of fracture instability, and the presence or absence of early instability. This section of the study involved the statistical analysis of recorded patient and fracture characteristics with respect to fracture outcome. The aim was to identify those factors which predicted outcome, and with this information to devise a method of prospectively quantifying the risk of poor outcome (i.e malunion and carpal malalignment) in the individual fracture. With the emphasis on identifying the significance of the relationship between predictors and outcome, in contrast to sections 1.5.2.1 and 1.5.2.2, the complete database was used for this analysis. By maximising the amount of data used, we hoped to minimise type II statistical error.



#### 1.5.2.4 Validation of prediction

Producing a method of predicting fracture instability is of little use unless it can be shown to be accurate. Two studies were devised, to test not only the predictive accuracy of our method, but also to assess the difference that the method would make in accuracy of prediction in clinical practice. Thus the validation of prediction comprised:

1. Prospective testing of the accuracy of prediction using a new cohort of patients.  
Data was to be collected for patients presenting with distal radial fracture in the clinic. The standard treatment protocol was used, and the outcome for each fracture was recorded. Blinded to the outcome, the percentage risks of early and late instability, the risk of malunion, and the risk of carpal malalignment were calculated. By comparing the predictions with recorded outcomes, the accuracy of the formulae was to be ascertained
2. Comparison of the predictive accuracy of the formulae with that of the clinician.  
A group of clinicians were asked to predict the outcome of 40 fractures. They performed this task firstly using only their clinical experience, and then using the formulae. The aim was to compare the accuracy of these two sets of predictions, to see if the use of the formulae improved upon predictive ability. The clinicians were also asked to identify those factors that in their usual practice, they thought important in the assessment of fracture instability.

## 1.6 References

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## **2. MATERIALS AND METHODS**



<b>2.1</b>	<b><u>Study section 1</u></b>	<b><u>75</u></b>
2.1.1	Data	75
2.1.2	Fracture management protocol and data collection	78
2.1.3	Inclusion and exclusion criteria	80
2.1.4	Data validation	82
2.1.5	Epidemiology of fractures of the distal radius in the Lothian Region	84
2.1.6	Radiological outcome of fracture of the distal radius	85
2.1.7	Prediction of fracture instability	87
2.1.8	Prediction of carpal malalignment	88
<b>2.2</b>	<b><u>Study section 2</u></b>	<b><u>89</u></b>
2.2.1	Prospective validation of the prediction of fracture instability and carpal malalignment	89
2.2.2	Prediction of fracture instability: a comparison of the predictive formulae and clinical experience	93
<b>2.3</b>	<b><u>Statistical analysis and study design</u></b>	<b><u>97</u></b>
<b>2.4</b>	<b><u>References</u></b>	<b><u>103</u></b>



## **Figures**

<b>2.2.1a:</b>	Clear Perspex measuring device	91
<b>2.2.1b:</b>	Measurement of dorsal angulation and ulnar variance	92

## **2.1 Study section 1**

Data on all distal radial fracture patients were collected between June 1988 and December 1993. During this period, 28,376 new patients presented to the Fracture Clinic. Of these patients, 4024 presented with fracture of the distal radius. These patients therefore constituted 14.2 percent of the new referrals.

The distal radius fracture occurred four times more frequently in females: 3173 fractures were in females (79 percent), and 851 fractures in males (21 percent). The mean age of all patients was 58 years. The mean age for females was 64 years (range 14 to 100 years), and 42 years for males (range 15 to 92 years).

Standardisation of the data was possible as fracture management followed a protocol. As outlined above, this section of the study examined the epidemiology and outcome of the fractures of the distal radius. The database was then used to generate a mathematical method of predicting fracture instability, and carpal malalignment.

### **2.1.1 Data**

Patient name, hospital number and study number identified individual patient data.

The following data were collected for each patient:

#### **1. Input data:**

##### **1. Demographic information**

- i. date of birth
- ii. age at the time of injury
- iii. sex
- iv. dominance
- v. premorbid level of function as measured by the patient's ability or inability to do their own shopping

2. Mode of injury
  - i. side of injury
  - ii. exact mode of injury
  - iii. injury code:
    - 1 = fall from a standing height
    - 2 = fall from a height (greater than 3 feet)
    - 3 = sporting injury
    - 4 = road traffic accident: pedestrian
    - 5 = road traffic accident: driver or passenger
    - 6 = other mode of injury
3. Additional injuries sustained. Any other bony or soft tissue injury sustained by the patient was recorded.
4. Radiological measurements of the normal, uninjured wrist
  - i. dorsal angulation
  - ii. ulnar variance
  - iii. radial shift
5. Radiological information at presentation
  - i. fracture type according to the Frykman Classification (Frykman 1967)
  - ii. fracture type, group, and sub-group, according to the AO/ASIF classification (Muller et al 1990)
  - iii. fracture comminution
  - iv. dorsal angulation
  - v. ulnar variance
  - vi. radial shift
  - vii. displacement (minimally displaced or displaced)

6. Radiological measurements post-reduction (if reduction performed)
  - i. dorsal angulation
  - ii. ulnar variance
  - iii. radial shift
  - iv. post-reduction displacement

## 2. Output data:

1. Radiological measurements at 7 to 10 days post injury
  - i. dorsal angulation
  - ii. ulnar variance
  - iii. radial shift
  - iv. displacement
2. Radiological measurements at fracture union (approximately 6 weeks post injury)
  - i. dorsal angulation
  - ii. ulnar variance
  - iii. radial shift
  - iv. displacement
  - v. carpal malalignment (present or absent)

## 3. Additional data:

1. Operative intervention undertaken: all surgery undertaken for the fracture or for complications of the fracture was recorded. The date of surgery was also noted. This did not include the initial reduction (if performed) in the Accident & Emergency Department.

2. Post-operative radiological measurements (when surgery for fracture displacement was undertaken)
  - i. dorsal angulation
  - ii. ulnar variance
  - iii. radial shift
  - iv. displacement
3. Complications following fracture and/or surgery.

### **2.1.2 Fracture management protocol and data collection**

A standard protocol for management of the distal radial fractures was used. Initially, fracture management was by the Accident & Emergency Department. A routine fracture clinic appointment was made the next day. Subsequently review was solely by the research team in a specialist interest clinic. Review was maintained in this clinic until patient discharge.

The protocol for fracture management was as follows:

1. The initial assessment and treatment were in the Accident & Emergency Department. Minimally displaced fractures had a Plaster-of-Paris dorsal slab applied. Displaced fractures were reduced under intravenous regional anaesthesia, and a dorsal Plaster-of-Paris slab was applied. Patients admitted for primary surgical treatment were excluded from the study, as this precluded assessment of the natural history of the fracture. The following patients were therefore excluded: patients with open fractures, with compartment syndrome, with associated severe nerve compression symptoms, and with comminuted displaced intra-articular fractures requiring reconstruction.

2. The patients were reviewed in the fracture clinic the day after presentation to Accident & Emergency Department. At this visit, the patient was assessed for plaster complications, and taught exercises to maintain joint mobility in the hand and upper limb. If severe digital swelling or stiffness were present, the patient was referred immediately to the physiotherapist.

3. Between 7 and 10 days after injury, all patients were reviewed at a special interest clinic. Demographic information and details of the mode of injury were recorded. X-rays of the normal uninjured wrist were taken, to allow calculation of the ulnar variance and radial shift of the fractured radius. Repeat X-rays of the injured wrist were taken at this clinic visit, to assess fracture stability. Those patients whose fracture had maintained an acceptable position (i.e. minimal displacement at 7-10 days) had the dorsal slab completed. Patients with redisplaced fractures incompatible with their functional requirements were admitted to the Orthopaedic Trauma Unit for further intervention. If the patient continued to have, or had developed problems with digital swelling and/or stiffness, then clinical review was undertaken on a weekly basis with input from the physiotherapist.

4. All patients underwent further clinical and radiological review at fracture union (approximately 6 weeks). Further clinical review was arranged according to the needs of the individual patient. Therefore the review period could be extended by the need for physiotherapy, or for the treatment of complications.

All radiographs (taken at presentation, reduction, 7 to 10 days, post-surgery, and six weeks) were measured to provide values for the dorsal angle, ulnar variance, radial shift, and fracture displacement. In those cases where normal values were

unavailable, mean values for the normal side were employed (Abbaszadegan 1989).

The fractures were classified using both AO/ASIF and Frykman classifications, using

the radiographs taken at presentation. Fracture comminution was also categorised using these films. The AO/ASIF classification of fractures sustained between 1988 and 1990 was performed retrospectively, as the AO/ASIF classification was not published until 1990. X-rays taken at the six weeks review were assessed for carpal malalignment (figure 1.3.2.3a, p50). Malalignment was defined as the long axes of the radius and capitate failing to intersect within the carpus, measured on the lateral radiograph (McQueen 1996). To avoid the introduction of inter-observer error, the project supervisor alone was responsible for fracture classification according to the AO/ASIF and Frykman systems, and for recording the degree of comminution and carpal malalignment. Details of, and references for fracture measurement, classification, and the assessment of carpal collapse, are found in section 1.3. The definitions of fracture displacement are found below, in section 2.1.6.

All data was stored using a Microsoft<sup>R</sup> Spreadsheet. Statistical analysis was performed using either Microsoft<sup>R</sup> Excel, or SPSS Version 9.0 for Windows.

### **2.1.3 Inclusion and exclusion criteria**

As mentioned above, patients who were admitted immediately for surgical intervention were excluded from the study. These patients included the following:

1. Patients with open fractures of the distal radius requiring debridement and fracture stabilisation.
2. Patients with compartment syndrome related to the distal radial fracture, requiring compartment decompression and fracture stabilisation.
3. Patients with nerve compression syndromes due to the distal radial fracture, requiring nerve decompression and fracture stabilisation.

4. Patients with severely comminuted intra-articular fractures of the distal radius requiring articular reconstruction.

Depending on the nature of the missing data, certain patients were excluded from certain statistical analyses:

1. Patients with missing input data.
  - i. No radiological measurements at presentation. These patients were excluded from all analyses, as fracture outcome is meaningless without being able to define the nature of the fracture at presentation.
  - ii. Patients with other missing input data were excluded from the analysis of the predictive significance of that data. For example, patients with no details of mode of injury were excluded from the analysis of mode of injury as a factor predictive of fracture instability.
2. Patients with missing output data.
  - i. No output data. If radiological measurements were not available for 7 to 10 days or for six weeks, then available data were used only for the epidemiological part of the study.
  - ii. No radiological measurements available at 7 to 10 days. This meant no output data was available for the prediction of early instability, and that input data for the prediction of late instability were missing. These patients' data were excluded from these analyses.
  - iii. No radiological measurements available at six weeks (fracture union). No output data was available for the prediction of late instability, malunion, or carpal collapse. The patient's data was therefore excluded from these analyses.



#### 2.1.4 Data Validation

Once the data had been collected and recorded in spreadsheet format, validation of the data was performed. The hospital number of every thirtieth patient in the database was taken. The notes and X-rays of these patients were then re-examined, without reference to the original database. The following data were recorded, and checked prior to entry on a new spreadsheet:

1. date of birth
2. age at the time of injury
3. side of injury
4. injury code
5. radiological measurements: normal uninjured side
  - i. dorsal angulation
  - ii. radial shift
  - iii. ulnar variance
6. radiological measurements: fracture at presentation
  - i. dorsal angulation
  - ii. radial shift
  - iii. ulnar variance
7. radiological measurements: fracture post-reduction
  - i. dorsal angulation
  - ii. radial shift
  - iii. ulnar variance
8. radiological measurements: fracture at 7 to 10 days
  - i. dorsal angulation
  - ii. radial shift

- iii. ulnar variance
9. radiological measurements: fracture at six weeks
- i. dorsal angulation
  - ii. radial shift
  - iii. ulnar variance

Thus 19 categories of data were examined in 116 patients. There were 331 items of data missing, leaving 1808 items available for comparison between the two databases. No difference was allowed between items of data in the two databases when examining the non-radiological parameters. However, because of expected inter- and intra-observer variation a difference was permitted when comparing the radiological data in the two databases. Therefore a difference of 5 degrees was allowed in the measurements of dorsal angulation, and a difference of 2 millimetres in the measurement of radial shift and ulnar variance. The percentage agreement, and correlation between the two databases were calculated, as a measure of the validity of the original database.

### **2.1.5 Epidemiology of fractures of the distal radius in the Lothian Region**

When data collection started in February 1988, there were two hospitals in the Lothian region providing Trauma Orthopaedic care. These separate services were merged in May 1991. The merger is reflected in the number of fractures presenting to the Fracture Clinic at the Royal Infirmary of Edinburgh:

February to December 1988: 326 fractures  
January to December 1989: 400 fractures  
January to December 1990: 482 fractures  
January to December 1991: 787 fractures  
January to December 1992: 878 fractures  
January to December 1993: 922 fractures  
January to mid March 1994: 231 fractures

The epidemiology of the distal radius fracture was calculated using data after the merger, as one unit became the sole provider of Orthopaedic Trauma care for a defined population of approximately 650,000 (the Lothian Region). Analysis of the data collected between January 1992 and December 1993 was performed for this purpose. Due to incomplete data in the original database, only 1797 fractures were available for this analysis (876 in 1992, and 921 in 1993). Thus data for three fractures were missing (0.17 percent). Fracture incidence was calculated using data for the Lothian Region from Scottish Health Statistics (The NHS in Scotland, 1996 and 2001). The distribution of fractures was described according to the following factors:

1. Patient age
2. Patient sex
3. Month of injury
4. Premorbid level of function
5. Mode of injury
6. Fracture AO/ASIF classification
7. Fracture displacement
8. Fracture comminution

## 9. Fracture reduction

We also wished to identify trends in fracture epidemiology. To this end, data were collected retrospectively for fractures of the distal radius seen in the Edinburgh Orthopaedic Trauma Unit between January and December 1999. During this period there had been no ongoing data collection for distal radius fractures. Therefore the items of data that could be consistently recorded were limited:

1. Patient age at presentation
2. Patient sex
3. Month of injury
4. AO/ASIF fracture classification

Fracture comminution was also recorded, either directly, or by the identification of comminution in the AO/ASIF fracture classification. As a result, examination of epidemiological trends was restricted to these five criteria.

All statistical analysis was performed using Microsoft<sup>R</sup> Excel, or SPSS Version 9.0 for Windows. Graphical illustrations were produced using Microsoft<sup>R</sup> Excel.

### **2.1.6 Radiological outcome of fracture of the distal radius**

Fracture outcome was assessed using the data from January 1992 until December 1993. By using the same data used for the epidemiological study, direct comparisons could be drawn.

The fracture outcomes were defined as follows:

1. Early instability. The fracture displacement recorded at 7 to 10 days was used as the outcome variable. Early instability was present if the fracture was displaced on radiological assessment at 7 to 10 days, and had been minimally displaced at presentation. Early instability was also present if redisplacement was noted

radiologically at 7 to 10 days, following reduction of a displaced fracture in the Accident & Emergency Department. It was not possible to comment on early instability of the fracture, if the fracture were displaced on presentation and no reduction had been performed.

2. Late instability. Late instability was present if the fracture was malunited (displaced at week six radiological review), and had been minimally displaced at 7 to 10 day radiological review. Therefore late instability was only assessed in those fractures that did not demonstrate early instability.

3. Fracture malunion. Malunion was recorded as the fracture outcome if fracture displacement (or redisplacement) was recorded radiologically at any time up to and including six weeks. By recording data in this way, the natural history of all fractures could be assessed regardless of whether surgical intervention had been undertaken or not.

Fracture displacement is based upon radiological measurements. For the purposes of this study, the definition of displacement is that outlined by McQueen et al (1996):

- Minimally displaced: dorsal angulation less than or equal to 10 degrees, and ulnar variance less than or equal to 3 millimetres.
- Displaced: dorsal angulation greater than 10 degrees, *and/or* ulnar variance greater than 3 millimetres.

The parameters of displacement were more stringent when assessing the fracture position post-reduction. Therefore reduction was considered satisfactory if the dorsal angulation were less than or equal to zero degrees, and the ulnar variance were less than or equal to 3 millimetres. Conversely, the reduction was deemed unsatisfactory if dorsal angulation were greater than zero degrees, and/or the ulnar variance greater than 3 millimetres.

Fracture outcomes were described according to the following parameters:

1. Patient age
2. Patient sex
3. Mode of injury
4. Fracture displacement
5. Fracture AO/ASIF classification
6. Fracture comminution
7. Fracture reduction

All analysis was performed using Microsoft<sup>R</sup> Excel or SPSS Version 9.0 for Windows. Graphical illustrations were produced using Microsoft<sup>R</sup> Excel.

### **2.1.7 Prediction of fracture instability**

The database containing 4024 fractures was transferred to SPSS Version 9.0 for Windows. This required coding of various data fields as described in section 2.3. Dr R Elton PhD performed the statistical analysis for this part of the study.

Fractures were divided into two groups according to displacement at presentation, i.e. minimally displaced or displaced. The predictive significance of the input data was then calculated, with respect to the fracture displacement at 7 to 10 days, between 7 to 10 days and six weeks, and at six weeks. In this way, the significance of each factor in the prediction of early and late instability, and malunion was ascertained. The statistical test for each factor depended upon the nature of the data. The chi-squared test was used in calculating the significance of discrete variables, such as patient sex. The Mann-Whitney test was used for continuous variables, such as patient age.

Multiple logistic regression analysis (MLRA) used those factors of significant predictive value following the univariate analysis above. Thus the independent significance of each factor in the prediction of each outcome was calculated. The MLRA also produced weighting of the independent significance of each factor. From this information, predictive mathematical formulae were produced, from which the probability of a particular outcome could be calculated.

Thus the results of this part of the study are divided into the following six groups:

1. The prediction of early instability in minimally displaced fractures
2. The prediction of early instability in displaced fractures
3. The prediction of late instability in minimally displaced fractures
4. The prediction of late instability in displaced fractures
5. The prediction of malunion in minimally displaced fractures
6. The prediction of malunion in displaced fractures

### **2.1.8. Prediction of carpal malalignment**

As in section 2.1.7 above, the database was transferred to SPSS Version 9.0 for Windows. The database was examined as a whole when looking for factors predictive of carpal malalignment. The significance of the input data was calculated using the chi-squared and Mann-Whitney tests. Again, the independent significance of each predictive factor was ascertained using MLRA. A mathematical formula was generated, from which the probability of carpal malalignment could be calculated for the individual patient and fracture.

## **2.2 Study section 2**

This section of the study comprised an assessment of the value of the predictive formulae generated in Section 1. To make a comprehensive assessment, the answers to two questions were sought:

1. How accurate are the mathematical formulae in prospectively predicting individual fracture outcome?

A database was constructed using prospectively gathered data on 139 fractures. The data collected, and fracture management protocol followed those outlined above in sections 2.1.1 and 2.1.2. The prediction of fracture outcome was compared with the observed outcome.

2. Is the mathematical prediction of individual outcome more accurate than prediction based on clinical experience?

The performance of the predictive formula (malunion in displaced fractures) was compared with the performance of clinicians with varying levels of experience in the field.

### **2.2.1 Prospective validation of the prediction of fracture instability and carpal malalignment**

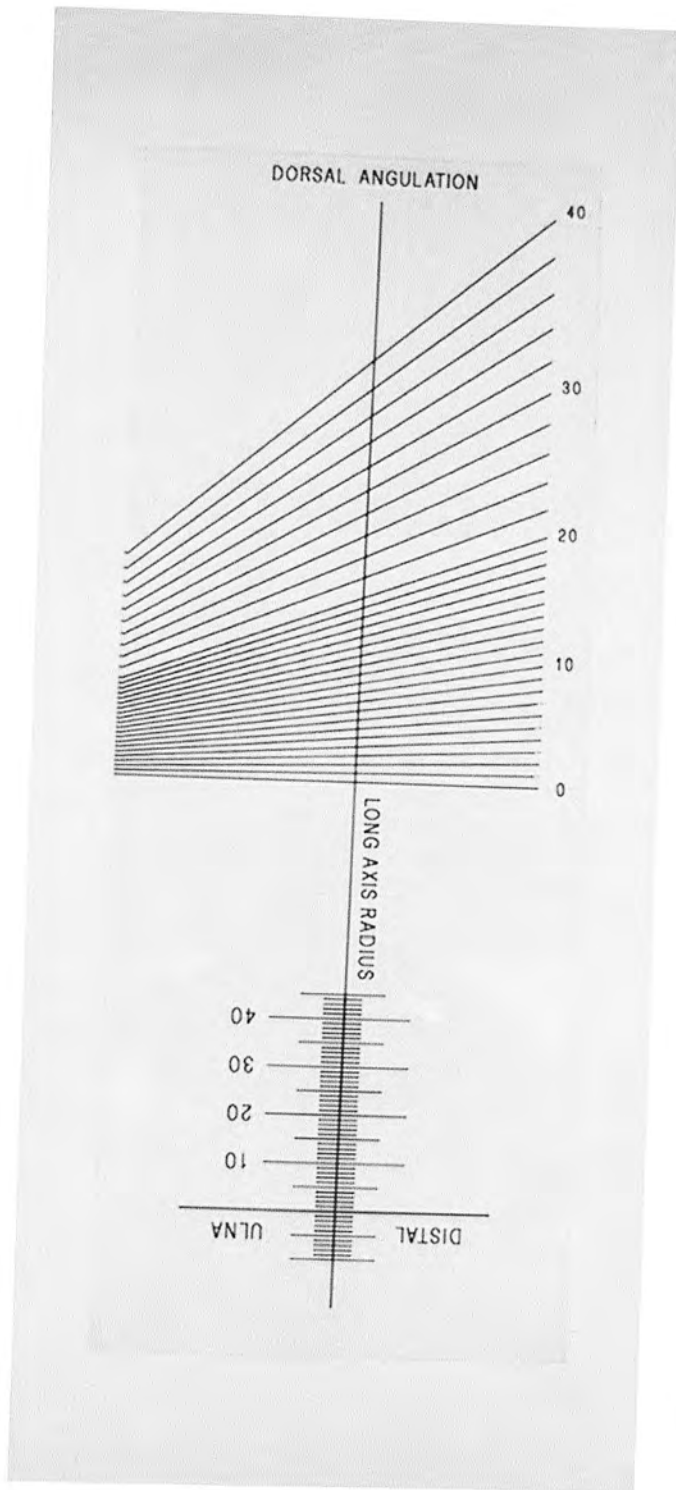
Between September and December 2000, data were collected on all patients presenting to the fracture clinic with fracture of the distal radius. The data collected was as outlined in section 2.1.1 above. One hundred and forty six patients were recruited into the study. Seven patients were lost to follow-up, leaving 139 patients for statistical analysis. One hundred and fifteen or 82.7 percent of the patients were female. The mean age of all patients was 59.7 years, of females was 61.5 years, and of males was 51.2 years. The fracture management protocol and timing of data



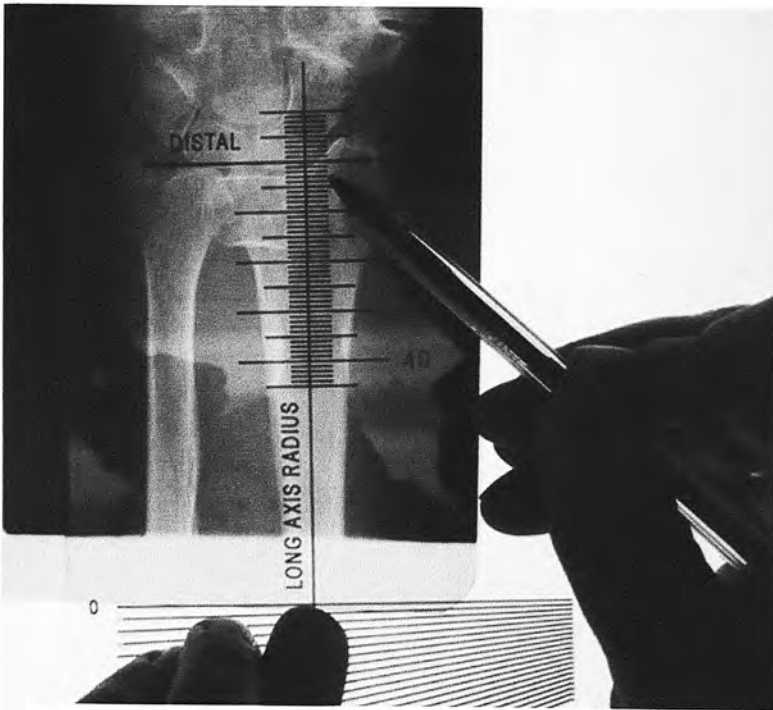
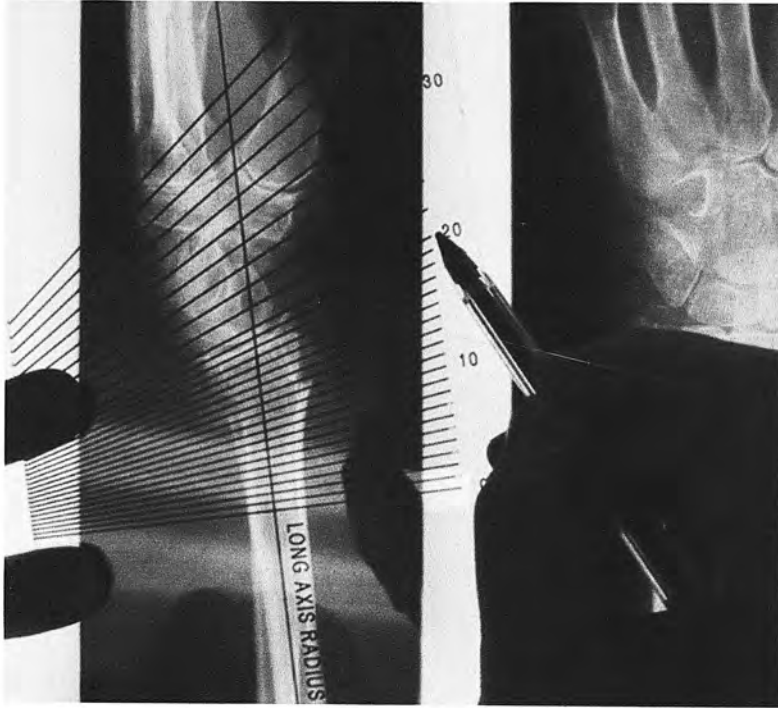
collection are described in section 2.1.2. A specially manufactured device facilitated the collection of standardised radiological measurements (figures 2.2.1a and 2.2.1b). The following exclusion criteria were applied:

1. Patients unavailable for local review.
2. Patients unwilling or unable to consent to study participation.
3. Patients requiring immediate surgical intervention (compound injuries, nerve compression, compartment syndrome).
4. Patients requiring additional reconstructive procedures for complex fractures (for example open reduction and fixation of displaced intra-articular fractures).

Data were collected and stored in spreadsheet format. Once data collection was completed, a separate database was constructed, containing only that information required for the prediction of fracture instability and carpal malalignment. This allowed the blinded mathematical calculation of the probability of fracture instability and carpal malalignment. By performing these calculations once data collection was complete, bias in taking radiological outcome measurements was also avoided. The databases were then recombined to allow compare predicted and actual outcomes. The sensitivity and specificity of the predictive formulae were then calculated. The sensitivity of the predictive formula was defined as the ability to predict which fractures would be unstable, and which fractures would produce carpal malalignment. The specificity was defined as the ability to predict which fractures would remain stable, and in which cases carpal malalignment would be absent. To make these calculations, the percentages produced by the predictive formulae had to be converted into a binary response: is the fracture unstable or not/ is carpal



**Figure 2.2.1a: Clear Perspex measuring device.**



**Figure 2.2.1b: Measurement of dorsal angulation and ulnar variance.**

malalignment present or not? A variable cut-off percentage for fracture outcome was used to undertake this conversion. The conversion is illustrated as follows:

1. Early instability present, probability of early instability calculated as 45 percent
  - i. Cut-off percentage set at 40 percent. At 45 percent, the prediction is that the fracture will display early instability. Therefore, a true positive prediction is made.
  - ii. Cut-off percentage set at 50 percent. At 45 percent, the prediction is that the fracture will not display early instability. Therefore a false negative prediction is made.
2. Early instability absent, probability of early instability calculated as 45 percent.
  - i. Cut-off percentage set at 40 percent. At 45 percent, the prediction is that the fracture will display early instability. Therefore a false positive prediction is made
  - ii. Cut-off percentage set at 50 percent. At 45 percent, the prediction is that the fracture will not display early instability. Therefore a true negative prediction is made.

For each of the seven formulae generated (see sections 2.1.7 and 2.1.8), sensitivity and specificity curves were plotted, using a range of cut-off percentages. The optimum cut-off percentage was taken as the intersection of the two curves. This choice attached equal importance to false positives and false negatives.

## **2.2.2 Prediction of fracture instability: a comparison of the predictive formula and clinical experience**

Forty cases of distal radial fracture were selected. All data required for the calculation of the risk of malunion was available from the previously constructed

database. In each case, the fracture was severely displaced at presentation, with a dorsal angulation measured at greater than 15 degrees. All patients had undergone a manipulation of the fracture, with satisfactory radiological results: in all cases, dorsal angulation was measured as zero degrees or less, and ulnar variance was less than 3 millimetres. The radiological outcome was known for all the fractures: in 16 cases the fracture remained stable until union, and in 24 cases fracture instability was present. The risk of malunion was calculated using the previously recorded data. The percentage was converted into a binary response using a cut-off of 70 percent. The sensitivity and specificity of the formula was calculated.

Fourteen clinicians participated in this section of the study. There were 6 members of staff from the Orthopaedic Department (two consultants and four trainees), and 8 from the Accident & Emergency Department (three consultants and five trainees). The Orthopaedic Consultants both had a specialist interest in the wrist, and one was the study supervisor (M.M. McQueen). The participants were asked to predict the anatomical outcome of each of the forty fractures: which fractures would remain in a minimally displaced position until fracture union, and which fractures would lose position? They were provided with the X-rays taken at presentation, details of the age and sex of the patient, and details of the mode of injury. Once they had assessed the fractures, they were asked to comment upon the relative importance to their assessment of the following factors:

1. Patient age
2. Patient sex
3. Mode of injury
4. Dorsal angulation
5. Radial angulation

6. Fracture comminution

7. Bone quality

The first three items of information were provided with the x-rays of each fracture taken at presentation. The participants were free to measure or estimate the last four factors using the x-rays. Relative importance was graded as follows: 0 – no importance; 1 – some importance; 2 – great importance. They were also asked to record any other items of information they would take into account in their assessment of fracture instability. Each participant performed the task individually, with no opportunity to confer with others. The sensitivity and specificity in predicting fracture outcome was calculated for each participant, in order to allow comparison with the predictive formula.

The exercise was then repeated. However, on this occasion the 14 participants were asked to calculate the risk of malunion for each fracture, using the mathematical formula. They were provided with the X-rays taken at presentation, a device for measuring ulnar variance and probability tables to calculate the percentage risk of malunion. Details of patient age and level of function (as measured by ability to do one's own shopping) were also provided. The clinician had therefore to measure ulnar variance, and decide on the degree of fracture comminution. Contra-lateral normal X-rays were not provided. Therefore ulnar variance was determined using the mean normal value of –1 millimetre, as calculated from the original database (section 2.1.2). The percentage risk of malunion was converted into a binary variable using a cut-off of 70 percent. The sensitivity and specificity of each participant using the formula was calculated. Thus the potential benefits of using the formula could be identified. It also allowed the identification of those fractures in which mathematical prediction of outcome was poor.

All data were stored and analysed using Microsoft<sup>R</sup> Excel. The same software was used to produce the graphical illustrations.

### **2.3 Statistical analysis**

All statistical analysis in the study was performed using either Microsoft<sup>R</sup> Excel, or SPSS Version 9.0 for Windows. The calculation of the mathematical formulae (to predict fracture instability and carpal collapse) was undertaken by Dr R Elton PhD. Dr Elton also provided invaluable statistical advice in all other areas of the study, and in the writing of this thesis.

The analysis of the data described in sections 2.1.7 and 2.1.8 required standardisation and coding of the data. In order that appropriate statistical tests be used, the nature of the data had to be recognised. Coding and data types are in italics:

#### 1. Input Data

##### 1. Demographic information

- i. age at the time of injury (*age in years: quantitative continuous*)
- ii. sex (*1=male, 2=female: qualitative binary*)
- iii. dominance (*1=right-handed, 2=left-handed, 3=ambidextrous: qualitative discrete*)
- iv. premorbid level of function (*1=able to do own shopping, 2=unable to do own shopping: qualitative binary*)

##### 2. Mode of injury

- i. side of injury (*1=right, 2=left: qualitative binary*)
- ii. injury code (*1 = fall from a standing height, 2 = fall from a height greater than 3 feet, 3 = sporting injury, 4 = road traffic accident: pedestrian, 5 = road traffic accident: driver or passenger, 6 = other mode of injury: qualitative discrete*)



### 3. Radiological measurements

- i. dorsal angulation (*angle in degrees: quantitative continuous*)
- ii. ulnar variance (*distance in millimetres, N.B. ulnar variance in the fractured radius is expressed relative to the measurement of the uninjured side: quantitative continuous*)
- iii. radial shift (*distance in millimetres, N.B. radial shift in the fractured radius is expressed relative to the measurement of the uninjured side: quantitative continuous*)

### 4. Radiological information at presentation

- i. fracture type according to the Frykman Classification (*types 1 to 8: qualitative discrete*)
- ii. fracture according to the AO classification (*divided into three subsections: types, groups, and sub-groups. Type 1=A, type 2=B, type 3=C. Groups 1 to 3. Sub-groups 1 to 3. Qualitative discrete*)
- iii. fracture comminution (*1=no comminution, 2=dorsal comminution, 3=volar comminution, 4=dorsal + volar comminution: qualitative discrete*)
- iv. dorsal angulation (*angle in degrees: quantitative continuous*)
- v. ulnar variance (*distance in millimetres, N.B. ulnar variance in the fractured radius is expressed relative to the measurement of the uninjured side: quantitative continuous*)
- vi. radial shift (*distance in millimetres, N.B. radial shift in the fractured radius is expressed relative to the measurement of the uninjured side: quantitative continuous*)

### 5. Intervention data

- i. reduction under Biers block (*1=reduction performed, 2=reduction not performed: qualitative binary*)
- ii. reduction satisfactory (*1=post-reduction position satisfactory, 2=post-reduction position unsatisfactory: qualitative binary*)
- vii. surgical intervention 1 (*1=surgical intervention undertaken prior to union, 2=no surgical intervention prior to union: qualitative binary*)
- viii. surgical intervention satisfactory (*1=post-surgical position satisfactory, 2=post-surgical position unsatisfactory: qualitative binary*)

2. Output data:

- 1. Early fracture instability, based upon radiological measurements at 7 to 10 days post injury (*1=displaced and therefore early instability present, 2=minimally displaced and therefore stable: qualitative binary*)
- 2. late fracture instability, based upon radiological measurements at fracture union, and assuming no early instability present (*1= displaced at union and therefore late instability present, 2= minimally displaced at union and therefore stable: qualitative binary*)
- 3. presence of malunion, based upon radiological measurements and intervention data (*1=malunion present: early or late instability present, or surgery performed prior to union for displacement of the fracture, 2= no malunion present:no early or late instability present, and no surgery performed prior to union for displacement: qualitative binary*)

4. presence of carpal malalignment, based upon assessment of radiographs at union, or of radiographs taken before surgical intervention prior to union  
(1=carpal malalignment present, 2=carpal malalignment absent: qualitative binary)

If any item of data were absent, it was coded appropriately to prevent inclusion in statistical analysis (code = 999). This code was also used if data were to be excluded for other reasons. For example, if early instability were present, then the code for late instability was “999”. This was because calculation of late instability was dependent upon the fracture remaining in a minimally displaced position for the first 7 to 10 days.

Univariate analysis was performed to identify those input factors had an effect upon outcome. The frequency or magnitude of the input variables was compared with respect to the outcome. Quantitative continuous variables, such as patient age and radiological measurements, were assessed using the Mann-Whitney test. Qualitative variables were assessed using the chi-squared test.

Those variables that were significant predictors of outcome in univariate analysis were then used in multiple logistic regression analysis. This analysis provides the solution to the equation (Armitage & Berry 1994):

$$y = a + b_1x_1 + b_2x_2 + b_3x_3 + \dots + b_nx_n$$

where y is the outcome, a and b<sub>1</sub> to b<sub>n</sub> are constants, and x<sub>1</sub> to x<sub>n</sub> are the input variables. Logistic regression is used as the outcome is binary: fracture instability or

carpal malalignment is either present or absent. This involves the transformation of the probability  $p$  of each outcome using the logistic function:

$$y = \log(p/1-p)$$

The 'best fit' solution is found where the difference between observed and expected values are minimised. The analysis was performed in a forward stepwise fashion.

Thus input variables are added to the equation one at a time, in an order based upon their significance adjusted for those already added. Those variables significantly reducing the difference between observed and expected outcomes are retained in the equation; those that have no significant effect are deleted.

The comparison of groups of data in sections 2.1.5 and 2.1.6 was performed using either the chi-squared or Mann-Whitney test. These sections of the study used data from January 1992 to December 1993, and provided epidemiological and outcome information. Again the data were coded and categorised to facilitate analysis and the correct choice of test.

There is no recognised method of validation of databases. Validation of the database (used in sections 2.1.5 to 2.1.8 of this study) also needs to take into account the size of the database and the nature of the data. It was not feasible purely in terms of time for re-examination of data for approximately 4000 patients. Therefore a sample of the data was selected for validation, both in terms of number of patients, and the variables examined. Every thirtieth patient in the database was selected. The variables chosen for validation were those that could be readily retrieved from the patients' notes or radiographs, and were those most pertinent to the study. Therefore the exact mode of injury was not chosen, as in the study the mode of injury was

coded for the purpose of analysis. Likewise, the patients' premorbid level of function was not selected as a validation variable, as this information was rarely recorded in the patients' notes.

With respect to variables such as the date of birth, age at presentation, the side of the fracture, and the mode of injury, the data recorded could be deemed either correct or incorrect. The recorded data could be directly compared to information contained in the patients' notes and radiographs. However, the phenomenon of inter-observer variation meant that radiological measurements in the database could not be considered correct or incorrect. Thus with respect to radiological measurements, a range for each measurement had to be chosen. If the original and validation measurements fell within these ranges, then agreement between the measurements was said to have occurred. Therefore for the purposes of validation of the database, the level of agreement between the original and validation databases was calculated for each variable. This level of agreement was expressed as a percentage and a correlation coefficient, and no further statistical analysis was performed.

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## **3. RESULTS**





<b>3.1</b>	<b><u>Study Section 1</u></b>	<b><u>111</u></b>
3.1.1	<b>Validation of the database</b>	<b>111</b>
3.1.2	<b>Epidemiology of fractures of the distal radius in the Lothian Region</b>	<b>112</b>
3.1.2.1	Age and sex distribution	112
3.1.2.2	Seasonal variation	114
3.1.2.3	Premorbid level of function	115
3.1.2.4	Mode of injury	116
3.1.2.5	Additional injuries	117
3.1.2.6	Fracture displacement	119
3.1.2.7	Fracture classification	120
	<b>3.1.2.7.1</b> A3.2 fractures	122
	<b>3.1.2.7.2</b> C2.1 fractures	123
	<b>3.1.2.7.3</b> A2.1 fractures	124
	<b>3.1.2.7.4</b> C1.2 fractures	125
	<b>3.1.2.7.5</b> C3.2 fractures	126
	<b>3.1.2.7.6</b> B1.1 fractures	127
3.1.2.8	Fracture comminution	128
	<b>3.1.2.8.1</b> Comminuted fractures	129
	<b>3.1.2.8.2</b> Fractures without comminution	131
3.1.2.9	Fracture reduction	132
3.1.2.10	Fracture trends with time	132
3.1.3	<b>Radiological outcome of fractures of the distal radius</b>	<b>134</b>
3.1.3.1	Patient age and sex	135
3.1.3.2	Mode of injury	136
3.1.3.3	Premorbid level of function	137
3.1.3.4	AO/ASIF classification	138
3.1.3.5	Fracture displacement	139
3.1.3.6	Fracture comminution	140
3.1.3.7	Fracture reduction	140
3.1.4	<b>Prediction of fracture instability</b>	<b>141</b>
3.1.4.1	Prediction of early instability in fractures minimally displaced at presentation	141
3.1.4.2	Prediction of early instability in fractures displaced at presentation	148
3.1.4.3	Prediction of late instability in fractures minimally displaced at presentation	149
3.1.4.4	Prediction of late instability in fractures displaced at presentation	150
3.1.4.5	Prediction of malunion in fractures minimally displaced at presentation	150
3.1.4.6	Prediction of malunion in fractures displaced at presentation	151
3.1.5	<b>Prediction of carpal malalignment</b>	<b>152</b>
3.1.6	<b>Predictive formulae</b>	<b>152</b>

<b>3.2</b>	<b><u>Study Section 2</u></b>	<b><u>157</u></b>
3.2.1	<b>Prospective validation of the prediction of fracture instability and carpal malalignment</b>	<b>157</b>
3.2.1.1	Minimally displaced fractures	157
3.2.1.2	Displaced fractures	161
3.2.1.3	Carpal malalignment	164
3.2.2	<b>Prediction of instability: comparison of predictive formulae and clinical experience</b>	<b>166</b>
3.2.2.1	Prediction of malunion using clinical experience	167
3.2.2.2	Importance of predictive factors	168
3.2.2.3	Prediction of malunion using the formula	170
3.2.2.4	Sensitivity and specificity of prediction	171
<b>3.3</b>	<b><u>References</u></b>	<b><u>176</u></b>

<b>Figures</b>		
3.1.1a:	Validation of the dataset	111
3.1.2.1a:	Age and sex related fracture incidence	113
3.1.2.2a:	Seasonal variation in fracture numbers	114
3.1.2.3a:	Percentage of patients able to do their own shopping according to age and sex	115
3.1.2.4a:	Percentage of fractures according to mode of injury and sex	116
3.1.2.4b:	Patient age according to mode of injury and sex	117
3.1.2.5a:	Additional injuries	118
3.1.2.6a:	Percentage of displaced fractures according to age and sex	120
3.1.2.7a:	Percentage of fractures according to the AO/ASIF classification	121
3.1.2.7b:	Incidence according to most common AO/ASIF fractures and age	121
3.1.2.7.1a:	Incidence of A3.2 fractures according to age and sex	122
3.1.2.7.3a:	Incidence of A2.1 fractures according to age and sex	124
3.1.2.7.4a:	Incidence of C1.2 fractures according to age and sex	126
3.1.2.7.6a:	Incidence of B1.1 fractures according to age and sex	127
3.1.2.7.6b:	Incidence of B1.1 fractures according to mode of injury and sex	128
3.1.2.8.1a:	Incidence of fractures according to comminution, sex and age	129
3.1.2.8.1b:	Fracture frequency according to mode of injury, sex and comminution	130
3.1.2.10a:	Fracture incidence in 1999 and 1992/3 according to age and sex	133
3.1.3.1a:	Frequency of malunion according to age	135
3.1.3.2a:	Frequency of malunion according to mode of injury	137
3.1.3.4a:	Frequency of malunion in the six most common AO/ASIF fractures	138
3.1.4a:	Prognostic factors for early instability in fractures minimally displaced at presentation	142
3.1.4b:	Prognostic factors for early instability in fractures displaced at presentation	143
3.1.4c:	Prognostic factors for late instability in fractures minimally displaced at presentation	144
3.1.4d:	Prognostic factors for late instability in fractures displaced at presentation	145
3.1.4e:	Prognostic factors for malunion in fractures minimally displaced at presentation	146
3.1.4f:	Prognostic factors for malunion in fractures displaced at presentation	147
3.1.5a:	Prognostic factors for carpal malalignment	153
3.2.1a:	Percentage of fractures according to the AO/ASIF classification	158
3.2.1.1a:	Minimally displaced fractures: sensitivity and specificity of prediction of early instability	159
3.2.1.1b:	Minimally displaced fractures: sensitivity and specificity of prediction of late instability	159
3.2.1.1c:	Minimally displaced fractures: sensitivity and specificity of prediction of malunion	160
3.2.1.2a:	Displaced fractures: sensitivity and specificity of prediction of early instability	162
3.2.1.2b:	Displaced fractures: sensitivity and specificity of prediction of late instability	162
3.2.1.2c:	Displaced fractures: sensitivity and specificity of prediction of malunion	163
3.2.1.3a:	Sensitivity and specificity of prediction of carpal malalignment	165
3.2.2.1a:	Correct prediction of fracture outcome using clinical experience	167

3.2.2.2a:	Relative importance of information used in the prediction of fracture outcome: Orthopaedic staff	169
3.2.2.2b:	Relative importance of information used in the prediction of fracture outcome: Accident & Emergency staff	169
3.2.2.3a:	Correct prediction of outcome using the predictive formula	170
3.2.2.4a:	Prediction of outcome using clinical experience	171
3.2.2.4b:	Sensitivity and specificity of the predictive formula according to cut-off percentage	173
3.2.2.4c:	Prediction of malunion with and without predictive formula	173
3.2.2.4d:	Variation about the mean of predicted probabilities of malunion	174
3.2.2.4e:	Variation from the mean measurement of ulnar variance	175
3.2.2.4f:	Agreement in the assessment of comminution	175

### 3.1 Study section 1

The first section of the results is based predominately upon the distal radius fracture database created in the Edinburgh Orthopaedic Trauma Unit between February 1988 and March 1994. Primary investigations were to validate the database in section 3.1.1. Analysis of this database provided epidemiological and natural history descriptions of this fracture (sections 3.1.2 and 3.1.3). Section 3.1.2.9 required the collection of additional fracture data for 1999. The database analysis also produced equations predictive of fracture instability and carpal malalignment.

#### 3.1.1 Validation of the database

Analysis was performed using data for 116 patients, each patient having 19 categories of data re-recorded. However data were missing in 331 cases, leaving 1808 pairs of data for comparison. The results are shown in figure 3.1.1a.

Category [ <i>missing data</i> ]	Number in agreement	Number in disagreement	Percentage agreement	Correlation coefficient	
Date of birth [13]	100	3	97.09	-	
Age [12]	104	0	100	-	
Side of injury [13]	100	3	97.09	-	
Injury code [13]	101	2	98.06	-	
Normal side	dorsal angle [13]	101	2	98.06	0.91
	radial shift [13]	103	0	100	0.96
	ulnar variance [13]	102	1	99.03	0.94
Presentation	dorsal angle [13]	99	4	96.12	0.97
	radial shift [13]	100	3	97.09	0.91
	ulnar variance [13]	99	4	96.12	0.91
Post reduction	dorsal angle [20]	91	5	94.79	0.61
	radial shift [20]	93	3	96.87	0.82
	ulnar variance [20]	91	5	94.79	0.63
Week one	dorsal angle [20]	90	6	93.75	0.94
	radial shift [20]	94	2	97.92	0.76
	ulnar variance [17]	94	5	94.95	0.75
Week six	dorsal angle [29]	81	6	93.1	0.85
	radial shift [29]	87	0	100	0.95
	ulnar variance [27]	78	11	87.65	0.75
Total [331]	1808	65	96.52	-	

Errors in demographic data were infrequent. These were due mainly to typographical error. With respect to radiological data, the error in angular measurement was no greater than the error in linear measurement. There was not a consistent trend with respect to displacement of the fracture.

### **3.1.2 Epidemiology of fractures of the distal radius in the Lothian Region**

Fractures of the distal radius are the most common fracture seen in Orthopaedic trauma. During the period of data collection for this study (February 1988 to March 1994), approximately 14 percent of all new outpatient consultations were for this fracture. In this section of the study, we more closely examined the type of fractures sustained and characteristics of the patients in whom the fractures are sustained. For the reasons explained in section 2.1.5, only data collected between January 1992 and December 1993 were used for the description of fracture epidemiology. During this two-year period, data were collected for 1800 fractures. Data pertinent to this section of the study were incomplete for three patients, leaving 1797 fractures for analysis. Subsequently data were collected retrospectively for distal radial fractures occurring between January and December 1999. Comparison of the two data sets provided details of epidemiological trends in distal radius fracture.

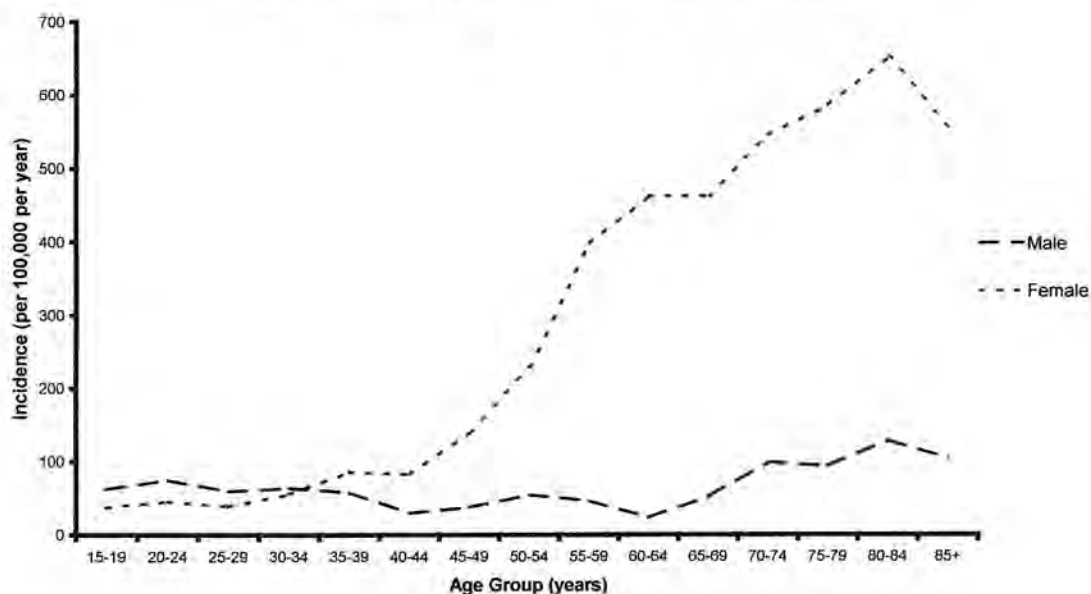
#### **3.1.2.1 Age and sex distribution**

Of the 1797 fractures recorded, 876 occurred in 1992 and 921 in 1993. The overall incidence of this fracture was 145 per 100,000 per year. Females accounted for 1454 fractures (80.9 percent), and males 343 fractures (19.1 percent). The sex specific incidences were 224 and 58 per 100,000 per year for females and males respectively. The mean age of the study group was 59.2 years, and the median age 63 years. There

was a marked difference between the sexes: the mean and median ages for females were 63.2 and 65 years, and for males 42.5 and 37 years. These figures implied that age and sex distributions were skewed, toward elderly females and younger males.

These trends can be seen in figure 3.1.2.1a. Age and sex specific incidences

**Figure 3.1.2.1a: Age and sex related fracture incidence**



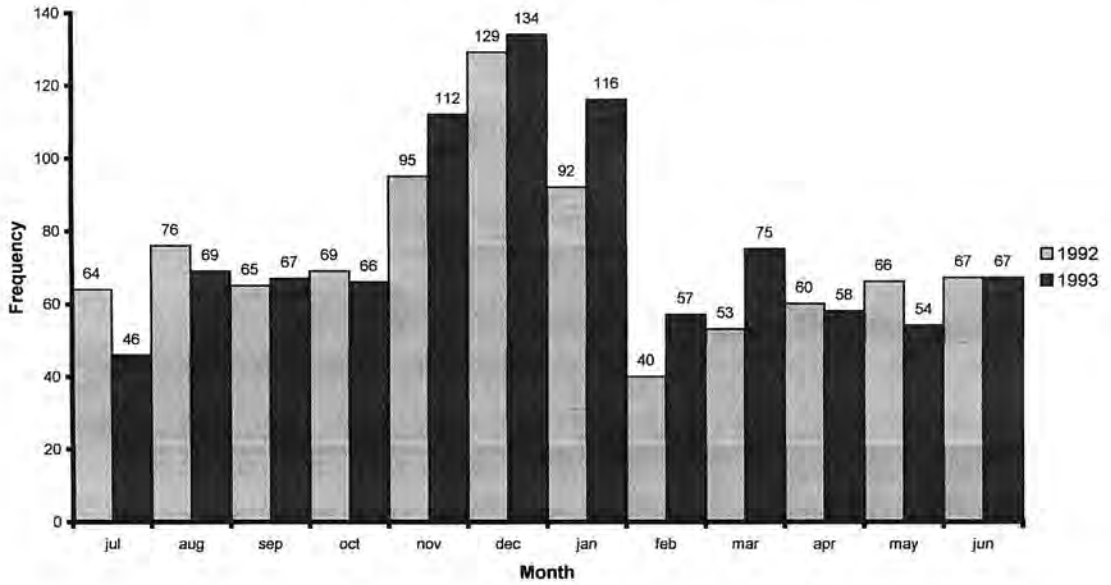
followed the distribution curves described by Buhr and Cooke (1959). A J-shaped curve was seen in females, and bimodal distribution curve in males. In females, fracture incidence rose by approximately 120 per 100,000 per year each decade after the age of 40 years. This trend continued until the age of 80 to 84 years. In males, incidence peaks occurred early in the third and ninth decades. The peak incidence in females early in the ninth decade was 657 per 100,000 per year: this was more than five times greater than the peak value in males of this age (130 per 100,000 per year).



### 3.1.2.2 Seasonal variation

An obvious seasonal variation can be seen in figure 3.1.2.2a. Fracture numbers almost doubled in the winter months, peaking in December. Thus 678 fractures (37.7 percent) occurred in the three months of November, December, and January.

Figure 3.1.2.2a: Seasonal variation in fracture numbers



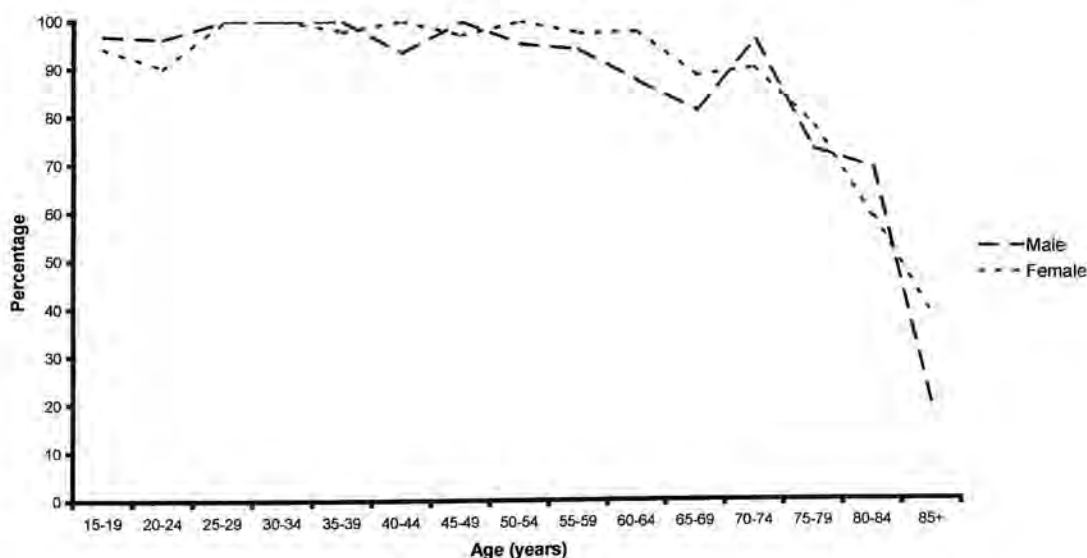
There was no significant difference in sex distribution: in males 121 fractures (35.3 percent) occurred in the winter months, and 557 fractures in females (38.3 percent) in the winter months. There were no significant differences in the age distribution of fractures with regard to season. However, the majority of fractures occurred in the winter months in only one age group: 55.2 percent of 40-44 year olds sustained their fracture in winter compared with a mean of 37.5 percent. A fall from standing height was significantly more common as the mode of injury during the winter (chi-squared test  $p < 0.001$ ). Thus 40.4 percent of winter fractures were caused in this way, compared with 25.7 percent of fractures during the rest of the year. Those patients who sustained their fractures during the winter also had a better premorbid level of

function (chi-squared  $p < 0.001$ ). Ninety-one percent of winter fracture patients were able to do their own shopping versus 85.2 percent of non-winter fracture patients. Despite the difference in mode of injury there was no difference in the proportion of patients with displaced fractures in the winter months (53.7 percent) and the non-winter months (53.2 percent)

### 3.1.2.3 Premorbid level of function

The premorbid level of function of the study population was good. Therefore 87.5 percent of the patients were sufficiently fit both physically and mentally to do their own shopping. The level of function was slightly better in males, with 93.3 percent able to do their own shopping, as opposed to 86.1 percent in females. As can be seen in figure 3.1.2.3a, the level of function only deteriorates in the very elderly, with well over half of patients in their early eighties (69.2 percent of males and 59 percent of females) able to do their own shopping.

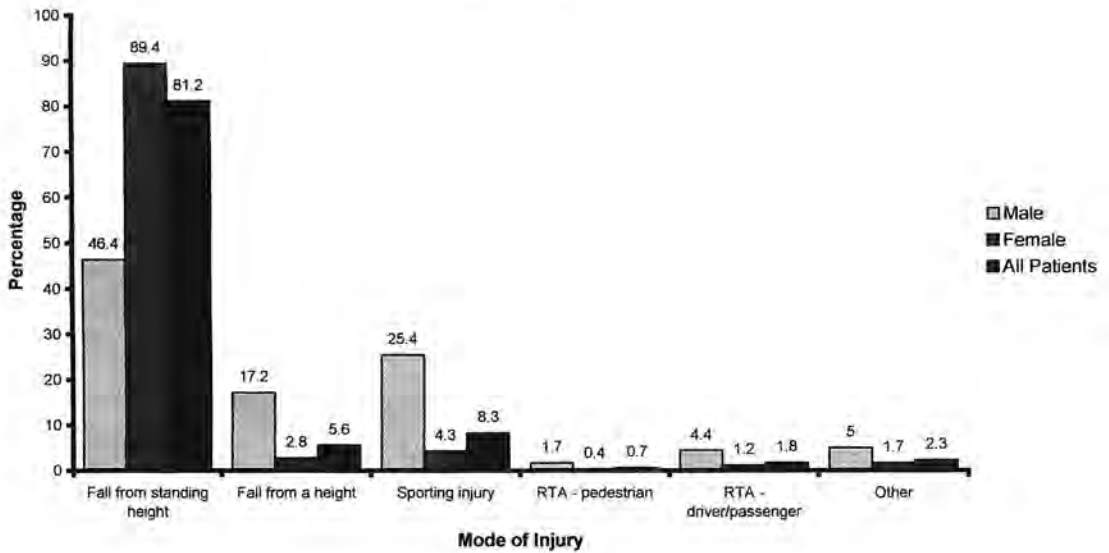
**Figure 3.1.2.3a: Percentage of patients able to doing their own shopping according to age and sex**



### 3.1.2.4 Mode of injury

The majority of fractures (81.1 percent) were caused by a fall from standing height, as seen in figure 3.1.2.4a. The proportion of females sustaining their injury in this way was far greater: 89.4 percent of fractures in females as opposed to only 46.4 percent in males.

**Figure 3.1.2.4a: Percentage of fractures according to mode of injury and sex**

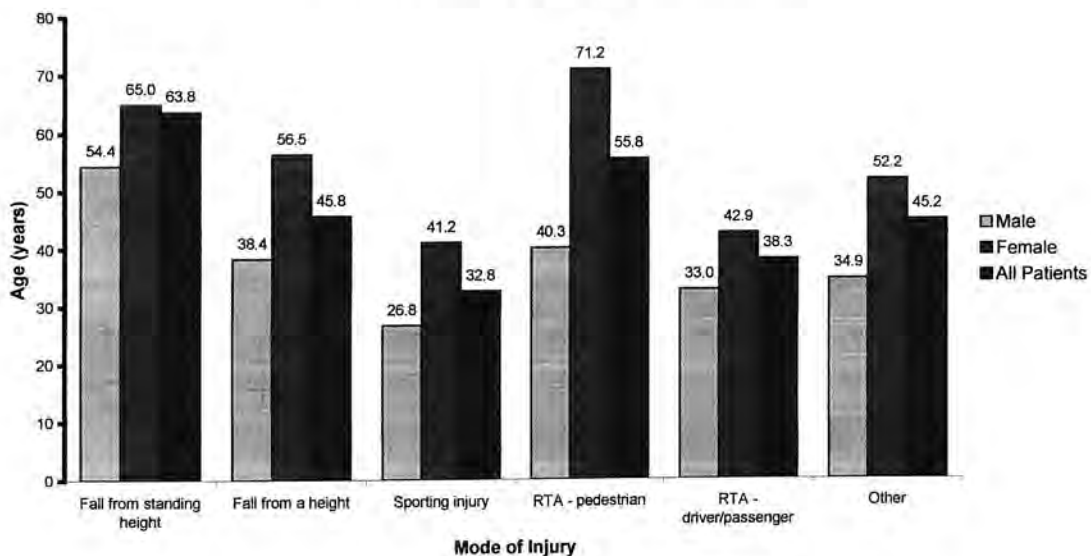


The incidence of fractures due to this mechanism of injury showed strong age and sex differences. The incidence in females began to rise sharply after the age of 40, and reached a peak of 634 per 100,000 per year, at the age of 80 to 84. The increase in incidence in males occurred later in life (after the age of 60), and was much less marked. The male peak incidence occurs at a similar age of 80 to 84 years, but is less than 20 percent of the peak in females at 120 per 100,000 per year.

The remaining 18.9 percent of fractures was caused by higher energy injuries. These injuries occur far more frequently in males: although males accounted for 19.1

percent of all fractures, 53.7 percent of higher energy fractures occurred in males. The sex difference in these higher energy fractures was most marked in those fractures caused by sporting endeavours. Not surprisingly the peak incidence of these fractures occurred in young males. The mean ages for the different modes of injury are shown in figure 3.1.2.4b. Using the Mann-Whitney test for non-parametric data, patients sustaining their fracture through a simple fall were significantly older than those whose fracture was caused by a higher energy injury ( $p < 0.001$ ). The only exception was pedestrians sustaining their fractures in road traffic accidents: there was no significant difference in age between these patients and those who had sustained their fracture through a simple fall.

**Figure 3.1.2.4b: Patient age according to mode of injury and sex**



### 3.1.2.5 Additional Injuries

One hundred and ninety two patients, or 10.7 percent of the study population, sustained 211 additional injuries (figure 3.1.2.5a). Additional injuries were slightly

**Figure 3.1.2.5a: Additional injuries**

upper limb		male	female	lower limb		male	female	axial		male	female
carpal dislocation		2		ankle STI			1	C spine fracture			1
clavicular fracture		2	2	NOF fracture		1	11	coccygeal fracture			1
DRUJ dislocation		2		CPN palsy			1	head/neck STI		1	11
elbow dislocation			1	Gtr trochanter fracture		1		head injury		2	
humeral fracture		1	2	leg STI			3	pubic rami fracture		1	6
Laceration to arm		1		Metatarsl fracture(s)			2	rib fracture			6
Metacarpal fracture(s)		1	5	patellar fracture			3	skull fracture		1	
olecranon fracture			6	TA rupture		1		sternal fracture			6
distal radial fracture		10	25	tibial fracture		1		T/L spine fracture		2	4
phalangeal fracture(s)		1	2								
radial head fracture		2	6								
scaphoid fracture		8	6								
scapular fracture		1									
shoulder STI			1								
SNOH fracture		2	7								
thumb MC fracture		1									
ulnar fracture		5	57								
wrist STI			2								
<b>total</b>		<b>50</b>	<b>115</b>	<b>total</b>		<b>4</b>	<b>21</b>	<b>total</b>		<b>7</b>	<b>25</b>
<b>more than two additional injuries:</b>											
			<b>mode of injury</b>				<b>age</b>				
<b>male</b>											
ulnar + scapular fractures			RTA pedestrian				59				
clavicular fracture + TA rupture			sport				26				
distal radial + T/L spine fractures			fall from > 3ft				39				
NOF + pubic rami fractures			fall from > 3ft				36				
<b>female</b>											
distal radial + T/L spine fractures			fall from > 3ft				39				
distal radial + scaphoid fractures			fall from standing height				67				
ulnar + humeral shaft + T/L spine fractures			fall from > 3ft				73				
ulnar + humeral shaft fractures			fall from standing height				68				
distal radial + Metatarsal + pubic rami fractures			fall from standing height				69				
clavicular + T/L spine + C spine fractures			RTA driver/passenger				54				
CPN palsy + pubic rami fractures			fall from standing height				70				
multiple injuries			RTA pedestrian				68				

more common in males (13.4 percent), than in females (10 percent). Fifty additional injuries occurred in 46 male patients, with a mean age of 39.6 years. The majority of these injuries in males occurred in the upper limb (78 percent), the commonest being a fracture of the contralateral distal radius. Only 17 percent of these male patients sustained their injuries through a fall from standing height. The commonest cause of injury in these males was a fall from a height (43.5 percent). Four male patients sustained two or more additional injuries with an average age of 40 years. Higher

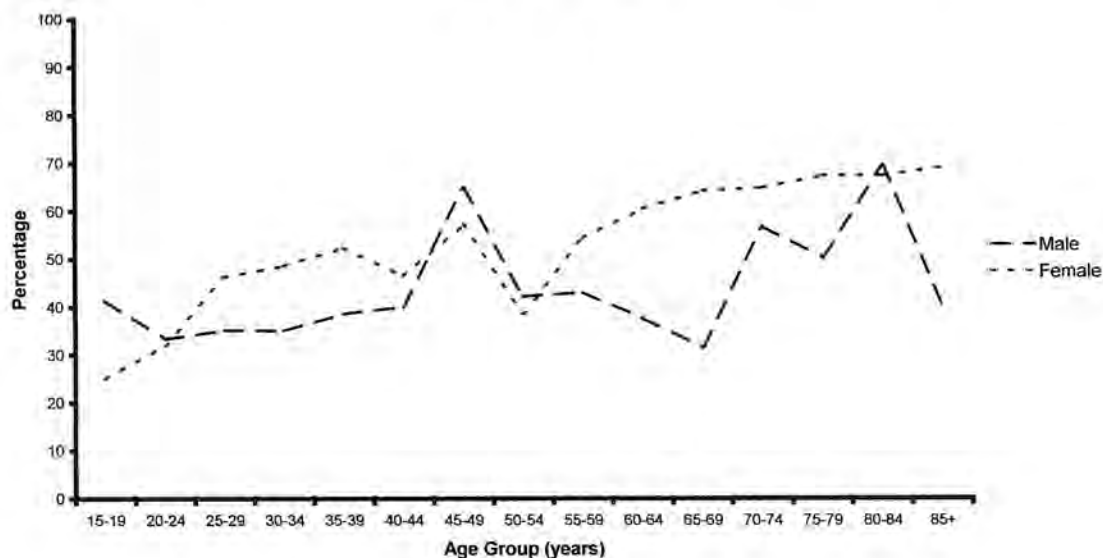
energy accidents caused the injuries in these four males: two fell from a height, one sustained the injury through sport, and one was a pedestrian in a road traffic accident. One hundred and sixty one additional injuries occurred in 146 female patients, with a mean age of 66.6 years. Again the majority of these injuries occurred in the upper limb (71 percent), the most common injury being a fracture of the ulna shaft. In contradistinction to males, there were a number of osteoporotic fractures: 11 fractures of the femoral neck, and 7 fractures of the surgical neck of humerus. The majority of female patients (85 percent) sustained their injuries through a fall from standing height. Eight females sustained two or more additional injuries (average age 63.5 years). Three sustained a fall from standing height, 2 fell from a height, and two were involved in road traffic accidents, one as a pedestrian.

#### **3.1.2.6 Fracture displacement**

The mean ages of patients with minimally displaced fractures were 40.5 years for males, 59.9 years for females, and 55.1 years overall. For patients with displaced fractures the mean ages were 45.6, 65.5, and 62.7 years for males, females, and all patients respectively. Therefore patients with displaced fractures were significantly older, and this difference was more pronounced in females (Mann-Whitney tests, significance values were  $p=0.03$  for males,  $p<0.001$  for females, and  $p<0.001$  for all patients). At presentation, 41.6 percent of males had a displaced fracture.

Displacement at presentation was more common in females, occurring in 58.9 percent of cases. The relationship between age, sex, and displacement is demonstrated in figure 3.1.2.6a. Displaced fractures were more likely

**Figure 3.1.2.6a: Percentage of displaced fractures according to age and sex**



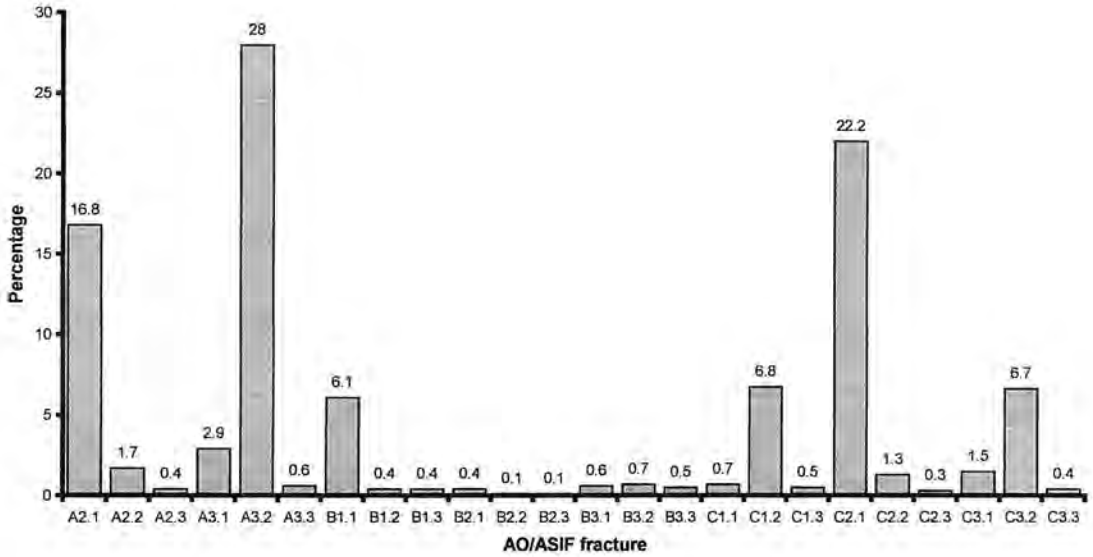
to be caused by a low energy injury: 85.4 percent of displaced fractures were caused by a fall from standing height, as opposed to 77 percent of minimally displaced fractures.

### 3.1.2.7 Fracture classification

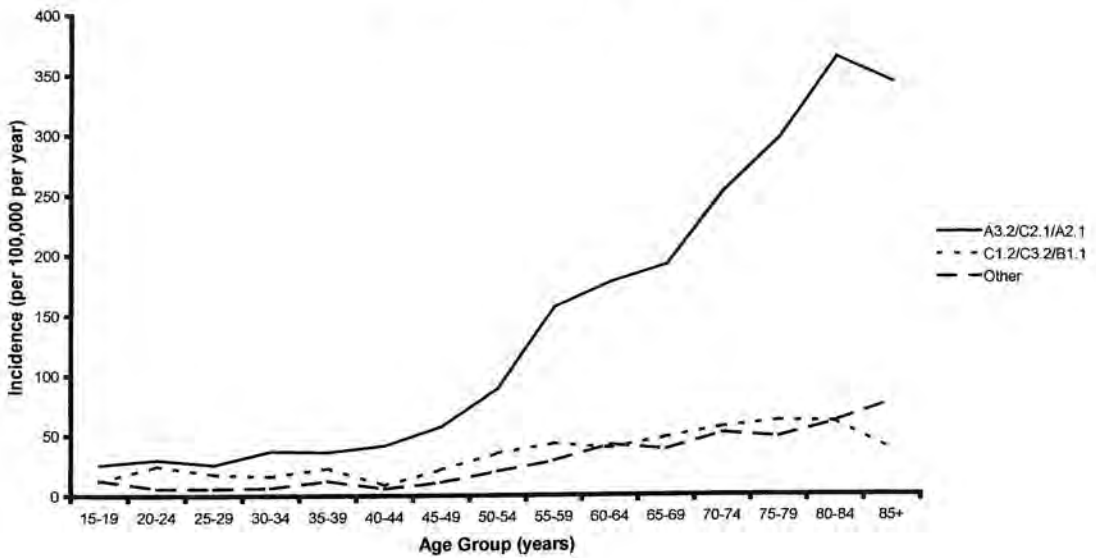
Six of the 1797 (0.3 percent) could not be classified according to the AO /ASIF system. This was due to missing radiographs. Therefore epidemiological analysis of fractures according to the AO/ASIF system was based on 1791 fractures. The percentage of fractures according to the AO/ASIF classification is shown in figure 3.1.2.7a. The majority of patients presented with one of three types of fracture, according to the AO/ASIF classification. The A3.2, C2.1, and A2.1 fractures constituted 66.7 percent of the study population. The increased incidence of distal radial fracture after the age of 40 years was almost entirely due to the A3.2, C2.1, and A2.1 fractures (figure 3.1.2.7b). Three other types occurred with some

regularity, namely the C1.2, C3.2, and B1.1 fractures. Together, these six fracture types constituted 89.2 percent of the fractures seen.

**Figure 3.1.2.7a: Percentage of fractures according to the AO/ASIF classification**



**Figure 3.1.2.7b: Incidence according to most common AO/ASIF fractures and age**

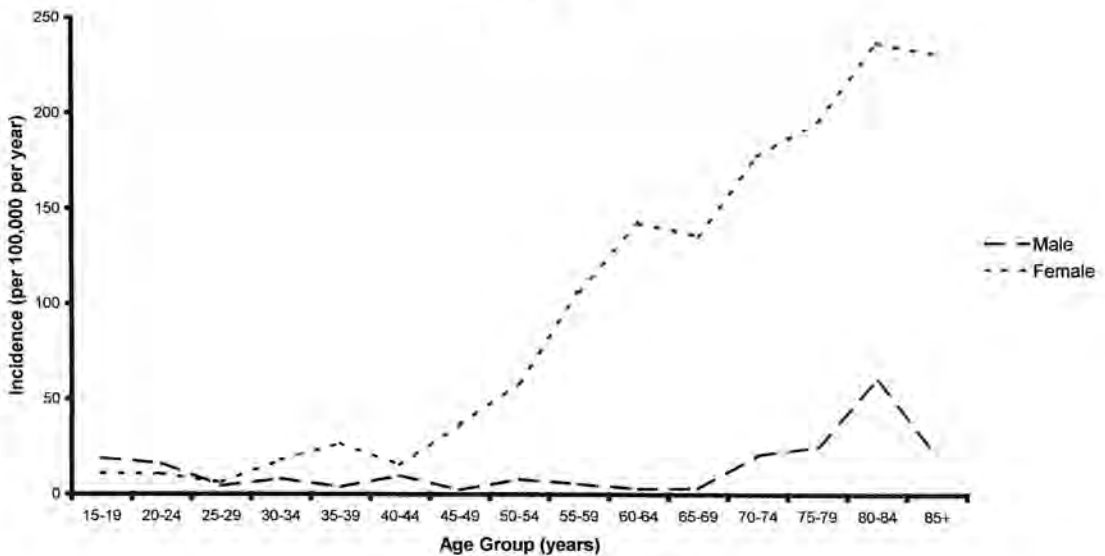




### 3.1.2.7.1 A3.2 Fractures

The A3.2 fractures were the most common type (27.9 percent), with an incidence of 40.4 per 100,000 per year. The incidence in females (68 per 100,000 per year) was approximately seven times greater than the incidence in males (10 per 100,000 per year). The mean age was 62.8 years: for males 44.3 years and for females 65.3 years. The median age was 66 years: for males 36 years and for females 68 years. The females with this fracture were significantly older than the rest of the study population (Mann-Whitney test,  $p=0.001$ ), whereas there was no difference for males. There was a significantly higher percentage of females (88.2 percent) in this subgroup of patients, than in the study population as a whole (chi-squared test  $p<0.001$ ). The incidence of this fracture (figure 3.1.2.7.1a) showed similar age and sex related trends as the population as a whole.

**Figure 3.1.2.7.1a: Incidence of A3.2 fractures according to age and sex**



In males there was a bimodal distribution with peaks in the 20-24 and 80-84 age groups. In females there was a sharp increase in incidence after the age of 40 years, until a peak in the 80-84 years age group. Again, the peak in female incidence (236 per 100,000 per year) was approximately five times that in males (60 per 100,000 per year). Compared to the study population as a whole, a significantly higher percentage of patients with the A3.2 fracture (87.6 percent) sustained their fracture through a fall from standing height (chi-squared test  $p < 0.001$ ). Fewer patients with A3.2 fractures (8.2 percent) sustained additional injuries than in the study population as a whole. Just over four-fifths (83.6 percent) of the fractures were displaced at presentation, which was a significantly greater proportion than in the remainder of the study group (chi-squared test  $p < 0.001$ ). Between the ages of 65 and 85, 79.9 percent of males and 79 percent of females in the study population had a good level of function. These figures were similar for patients with A3.2 fractures: 82.1 percent in males and 81 percent in females.

#### **3.1.2.7.2 C2.1 Fractures**

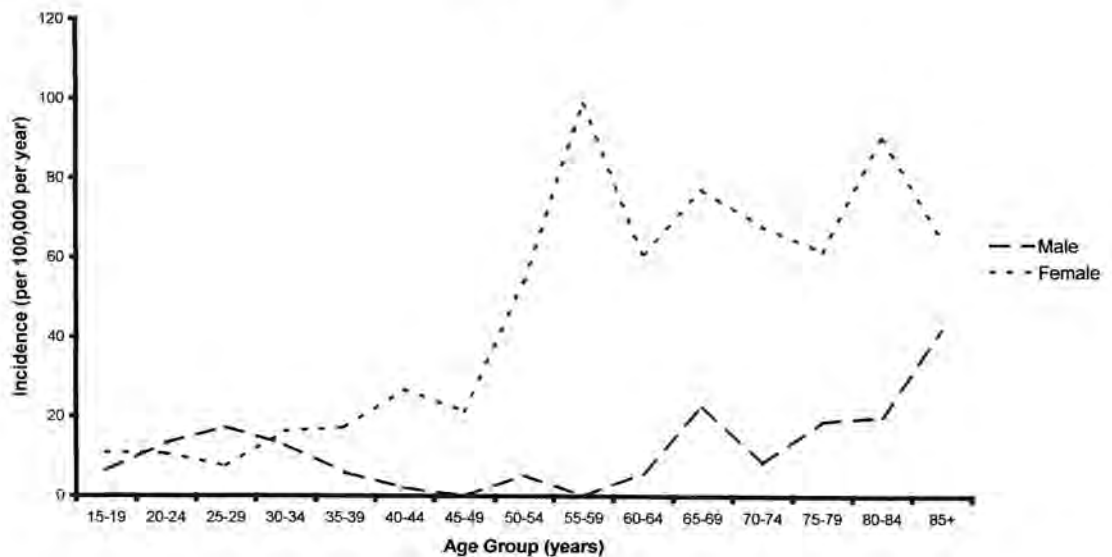
Almost identical trends were seen in the C2.1 fractures. This fracture was less common than the A3.2 type (22.1 percent of the study population), with an incidence of 32 per 100,000 per year. There was no statistical difference in the age distribution between the A3.2 and C2.1 fractures. Mean ages were 46.8 years in males, 65.3 years in females, and 63.2 years overall. Median ages were 46 for males, 67 for females, and 66 years overall. The female incidence began to rise at an earlier age of 35 years, but peaked at a similar age of 80-84 years (peak value 175 per 100,000 per year). In males the peak incidence of 33 per 100,000 per year occurred at an earlier age of 70-74 years. Additional injuries were slightly, but not significantly more common in this group, occurring in 11.6 percent of patients. These fractures were

displaced in similar proportion (81.7 percent) to the A3.2 fractures, and a similar proportion was caused by a fall from standing height (86.6 percent). Between the ages of 65 and 85 years there was a large proportion of patients who had an excellent premorbid level of function (78.9 percent).

### 3.1.2.7.3 A2.1 Fractures

The incidence of the A2.1 fracture was 24.2 per 100,000 per year. Just over four-fifths (81.3 percent) were female. Compared to the A3.2 fractures, there were differences in the age and sex distribution of this fracture. Although there was no difference in the proportion or age of males, females were significantly younger (Mann-Whitney test  $p < 0.001$ ). The mean age was 43 years for males and 59 years for females. This difference is seen clearly in the age and sex related incidence figures (figure 3.1.2.7.3a). The incidence in females rose at a similar age (45-49 years), but the peak incidence (98.7 per 100,000 per year) occurred at the age of 55-59 years.

**Figure 3.1.2.7.3a: Incidence of A2.1 fractures according to age and sex**



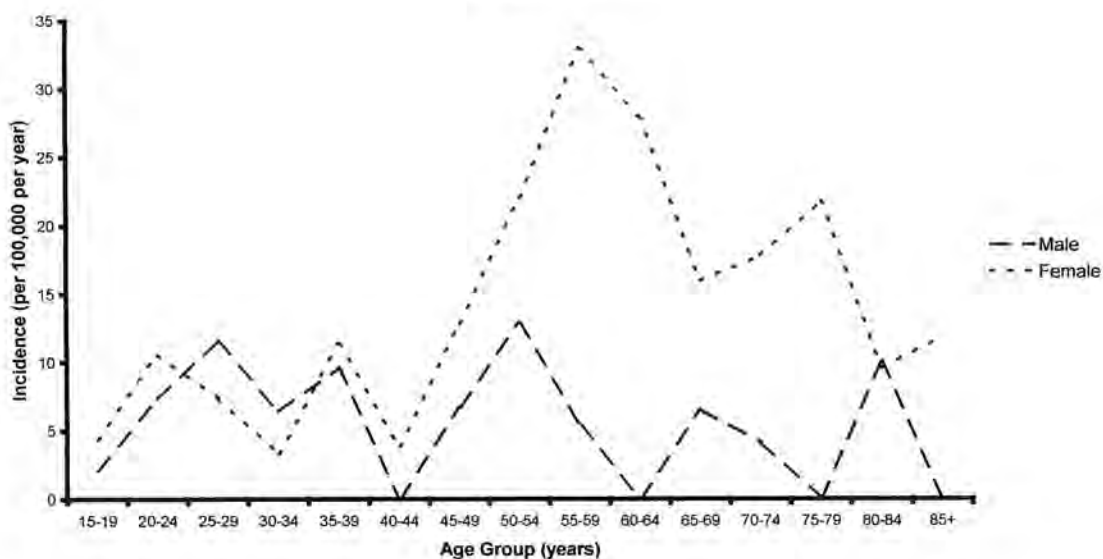
The incidence thereafter remained more or less constant. A similar, though slightly lower proportion of patients had additional injuries (6.3 percent). The fracture was caused by low energy injury in 83.7 percent of cases, but a significantly higher proportion was caused by sport (10.7 percent). This fracture was a great deal more benign than the A3.2 and C2.1 types: only 5.7 percent of the fractures were displaced at presentation.

#### **3.1.2.7.4 C1.2 Fractures**

The incidence of C1.2 fractures was 9.8 per 100,000 per year. Again comparing these fractures to the A3.2 fractures, the age and sex distributions were significantly different. A significantly greater proportion of this subgroup was male at 30.3 percent (chi-squared test  $p < 0.001$ ). With a mean age of 39.4 years, males were not significantly younger. However, females were significantly younger (Mann-Whitney test  $p = 0.008$ ), with a mean age of 52.9 years. Amongst females, those with C1.2 fractures were the youngest by a significant margin (Mann-Whitney test  $p = 0.009$ ). With respect to age, the incidence of this fracture in females peaked at 55-59 years (32.9 per 100,000 per year), and fell steeply with increasing age (figure 3.1.2.7.4a). The male incidence was fairly constant with respect to age (mean value of 6.3 per 100,000 per year). Additional injuries occurred in 13.9 percent of patients. A larger number of patients sustained their fracture through higher energy injuries, with only 68 percent of fractures caused by a fall from standing height. Compared to A3.2 fractures, a significantly higher percentage of fractures are caused by a fall from a height (13.1 percent: chi-squared test  $p < 0.001$ ), and by driver or passenger involvement in a road traffic accident (4.8 percent: chi-squared test  $p = 0.003$ ). Sporting injuries were responsible for 11.5 percent of fractures. These fractures like

the A2.1 fractures were relatively benign, with 16.7 percent of fractures displaced at presentation.

**Figure 3.1.2.7.4a: Incidence of C1.2 fractures according to age and sex**



### 3.1.2.7.5 C3.2 Fractures

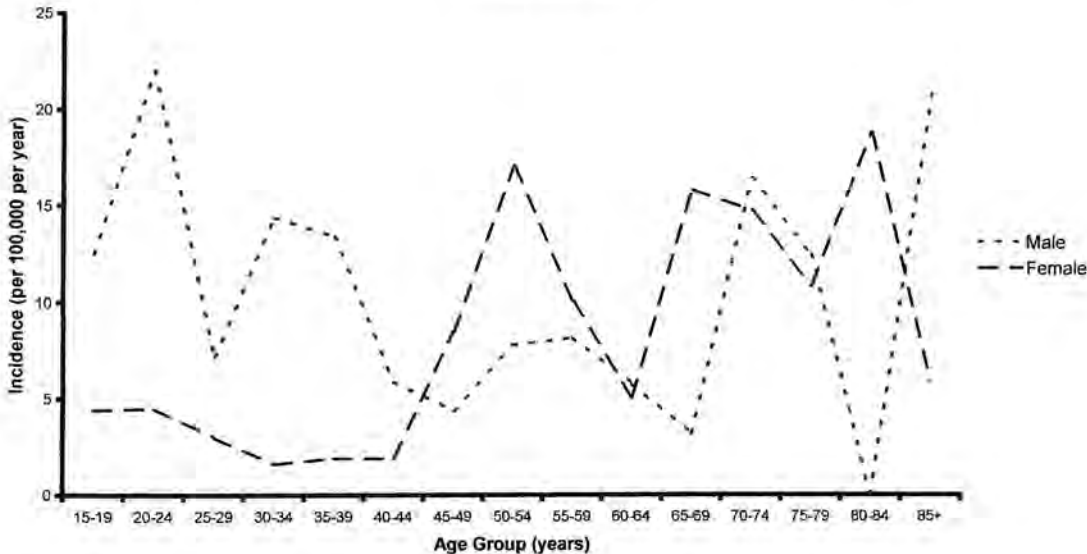
The incidence of C3.2 fractures was 9.68 per 100,000 per year. There was no significant difference between the age and sex distribution of this group and that of the A3.2 fractures. Females constituted 81.7 percent of this group. The mean ages were 42.7 years for males, 67.4 years for females, and 62.9 years overall. The female incidence started to rise after the age of 50 years, reaching a peak of 58 per 100,000 per year at 75-79 years. The male incidence remains low with a mean value of 3.7 per 100,000 per year. However, compared to the A3.2 fractures there was a significant increase in the number of fractures caused by high energy injuries: only 77.5 percent of fractures were caused by a fall from standing height (chi-squared test  $p=0.005$ ). This was almost entirely due to an increase in the percentage of fractures caused by a fall from a height. Additional injuries occurred in a significantly greater

number of patients (16.7 percent). However, the majority of these occurred in females falling from a standing height (71.4 percent). Rates of displacement at presentation (84.2 percent) were not significantly different from those of the A3.2 fractures.

**3.1.2.7.6 B1.1 Fractures**

The incidence of B1.1 fractures was 8.79 per 100,000 per year. The incidence in males was bimodal: the highest incidence of 22 per 100,000 per year occurring in the 20-24 year olds (figure 3.1.2.7.6a). The patients with B1.1 fractures were the

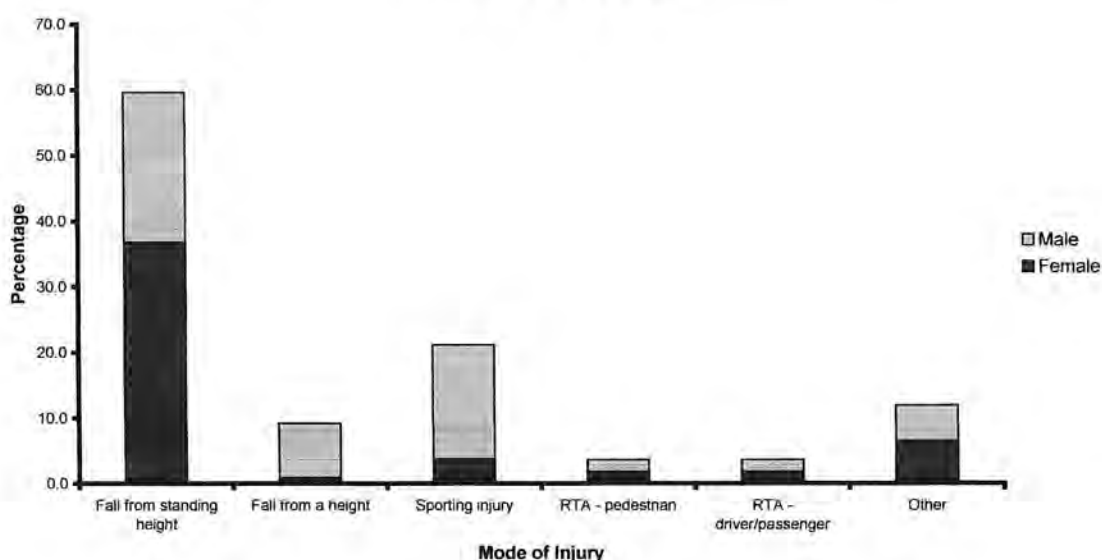
**Figure 3.1.2.7.6a: Incidence of B1.1 fractures according to age and sex**



youngest, though not significantly. The mean ages were 37.8 years for males, 56.0 years for females, and 45.5 years overall. It was the only commonly occurring fracture with a higher proportion of males at 57.8 percent. The female incidence peaked at 19 per 100,000 per year in the 80-84 year olds. Although the commonest

cause of this fracture was a fall from standing height (59.6 percent), a significantly greater proportion of the B1.1 fractures was due to higher energy injuries (chi-squared  $p < 0.001$ ). This difference is illustrated in figure 3.1.2.7.6b. Just over half of

**Figure 3.1.2.7.6b: Percentage of B1.1 fractures according to mode of injury and sex**



these higher energy fractures (21.1 percent), were due to sporting injury. These sporting fractures were for the greater part in males (82.5 percent). Despite the large proportion of higher energy injuries, there was not an increase in the number of patients with additional injuries (10.1 percent). Just over a third (36.4 percent) of these patients with additional injuries were males involved in sporting activities.

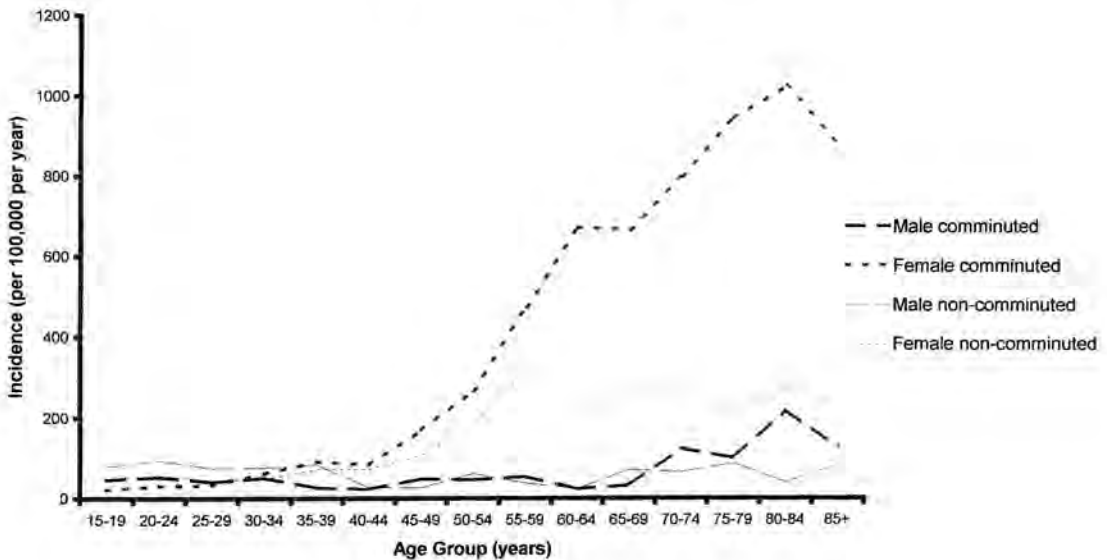
### 3.1.2.8 Fracture comminution

Striking differences were seen when patients were grouped according to fracture comminution. For epidemiological purposes, fractures were grouped according to the presence, or absence of metaphyseal comminution.

### 3.1.2.8.1 Comminuted fractures

Metaphyseal comminution was present in 64.3 percent of fractures. The majority of these fractures (87 percent) were in females. The mean age was 63.4 years: 47.3 years for males and 65.8 years for females. The median age was 66 years: 45 years for males and 68 years for females. The incidence of the comminuted fracture was 92 per 100,000 per year (25 per 100,000 per year for males and 153 per 100,000 per year for females). The age and sex specific incidence can be seen in figure 3.1.2.8.1a.

**Figure 3.1.2.8.1a: Incidence of fractures according to comminution, sex, and age**

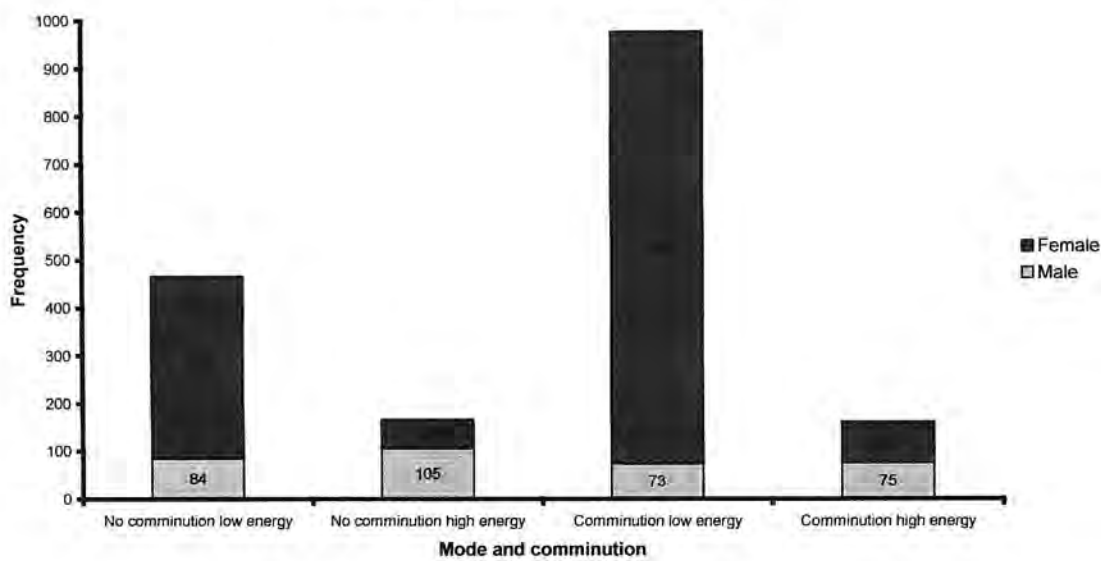


After the age of 40 years, the incidence in females rose by approximately 120 per 100,000 per year, until a peak of 516 per 100,000 per year at 80-84 years. The male incidence did not rise until the age of 60 years, and the peak incidence at 80-84 years was far lower (109 per 100,000 per year). The premorbid level of function of this group was good in 87.5 percent of patients. Eighty percent of the 65 to 85 year olds were able to do their own shopping. Fracture displacement at presentation was found in the majority of patients (80.1 percent). The most common cause of the



comminuted fracture was a low energy injury: 87.6 percent of patients sustained a fall from standing height. The difference in the mode of injury between males and females is illustrated in figure 3.1.2.8.1b. Just over half of males sustained a higher energy injury (50.7 percent), as opposed to 8.9 percent of females. The majority of

**Figure 3.1.2.8.1b: Fracture frequency according to mode of injury, sex, and comminution**



the higher energy injuries in both males and females (82.4 percent and 70.8 percent respectively) were caused by a fall from a height, or by sport. Additional injuries occurred in 10.6 percent of patients with comminuted fractures, and 83 percent were female. The mean age was 65.6 years. Three-quarters of these patients sustained their injury through a simple fall, and 13.2 percent by falling from a height. The most common additional injury was an ulnar shaft fracture. Of the 21 ‘osteoporotic’ fractures (9 fractures of the surgical neck of humerus, 12 femoral neck fractures), 13 occurred in patients with comminuted distal radial fractures. The presence of comminution in the metaphysis was closely related to fracture position. Thus 80.1 percent of comminuted fractures were displaced at presentation.

### 3.1.2.8.2 Fractures without comminution

In contrast, fractures without comminution of the metaphysis occurred in significantly younger patients (Mann-Whitney  $p=0.001$ ), and were more likely to occur in males. The mean age was 52.3 years: 39.2 years for males and 57.9 years for females. The proportion of fractures without metaphyseal comminution occurring in females (70.1 percent) was significantly lower. The age and sex specific incidences can be seen above in figure 3.1.2.8.1a. As in the comminuted fractures, the female incidence began to rise after the age of 40 years, however the peak incidence of 159 per 100,000 per year occurred far earlier at 55-59 years. The age specific incidence curve in males was obviously bimodal, and the peak incidence of 47 per 100,000 per year occurred in the 20-24 year olds. A significantly higher percentage (91.2 percent) of patients had a good premorbid level of function. A similar proportion of the 65 to 85 year olds were able to do their own shopping. Only 12.7 percent of fractures were displaced at presentation. The causes of the fracture without comminution are seen above in figure 3.1.2.8.1b. In males, there was no significant difference in the distribution of mode of injury between fractures with or without comminution. However there was an increase in the number of fractures caused by sport. In females, there were significant differences. A greater proportion of fractures were due to higher energy injuries (14 percent: Mann-Whitney  $p=0.002$ ), and this was caused by a significant increase in the number of sporting injuries (6.8 percent: Mann-Whitney  $p=0.002$ ). Additional injuries occurred in 11.8 percent of patients, with a mean age of 50.8 years. Significantly fewer females were in this group, and only 68.8 percent of patients sustained a lower energy injury. In comparison with the 80.1 percent of comminuted fractures, only 12.1 percent of fractures without

metaphyseal comminution were displaced at presentation. This difference was highly significant (chi-squared  $p < 0.001$ ).

### **3.1.2.9 Fracture reduction**

Although not strictly part of fracture epidemiology, it is interesting to comment on trends in initial treatment of the fracture. The initial fracture treatment is based upon the clinical assessment of the patient's functional demand, and the displacement of the fracture.

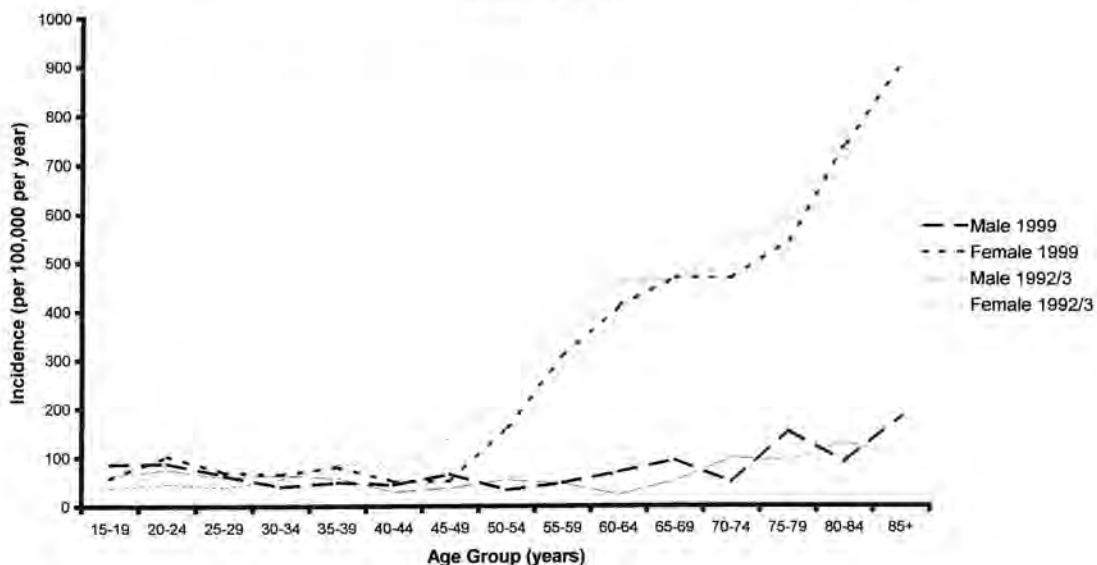
Manipulative reduction was undertaken in 841 of the 964 displaced fractures. By our definitions of displacement therefore, 123 displaced fractures were not manipulated. Interestingly, this was the same number of minimally displaced fractures that were manipulated. The mean age of manipulated fractures was 62.1 years, and of unmanipulated fractures was 66.5 years. With increasing age there was a significant increase in the proportion of displaced fractures that were left unmanipulated (Mann-Whitney  $p = 0.012$ ). Patients unable to do their own shopping constituted 13.4 percent of those whose displaced fracture was manipulated. This rose significantly (chi-squared  $p = 0.03$ ) to 23.6 percent in those whose fracture was not manipulated. Interestingly with respect to age, there was no significant difference in the proportion of manipulations that were successful.

### **3.1.2.10 Fracture trends with time**

Due to the retrospective collection of data for 1999, only certain items of information were available. Between 1<sup>st</sup> January and 31<sup>st</sup> December 1999, there were 911 fractures of the distal radius seen in the Edinburgh Orthopaedic Trauma Unit. The incidence of the fracture was therefore 143 per 100,000 per year. Seven hundred and

thirteen of these fractures were in females (78.3 percent), and 198 in males (21.7 percent). The mean age of all patients was 59.2 years. The mean ages according to sex were 63.3 years for females, and 44.3 years for males. For the patient population as a whole, there were no significant differences in the age and sex distributions between 1992/1993 and 1999. However, there was no decrease in incidence of the fracture in the eldest age group as seen in figure 3.1.2.10a. The incidence peaked over 85 years of age in both males and females (186 and 911 per 100,000 per year respectively) and in the population as a whole (721 per 100,000 per year). These peak values were greater than those recorded in 1992-1993.

**Figure 3.1.2.10a: Fracture incidence in 1999 and 1992/3 according to age and sex**



The seasonal variation in fracture presentation was comparable in 1999. The percentage of fractures occurring in November, December, and January (32.9 percent) was similar to that seen in the data from 1992 to 1993. The distribution of fractures according to the AO/ASIF classification 1999 was similar to that seen in

1992/1993. The six commonest fractures were the same, and accounted for 88.8 percent of fractures.

However, there were significant differences in age and sex distribution in certain fracture types:

1. The age of females with A3.2 fractures rose significantly (Mann-Whitney  $p=0.038$ ): the mean age in 1992/1993 was 65.2 years, and 67.5 years in 1999
2. The proportion of C2.1 fractures occurring in males rose by 6 percent to 17.6 percent in 1999 (chi squared  $p<0.05$ ).
3. Males with C2.1 fractures were also significantly older (Mann-Whitney  $p=0.042$ ): the mean age in 1992/1993 was 46.6 years, and 56.6 years in 1999
4. In 1992/1993, males accounted for 57.8 percent of B1.1 fractures: in 1999 57.7 percent of B1.1 fractures occurred in females (chi squared  $p<0.05$ ).
5. The females with B1.1 fractures were significantly younger in 1999( Mann-Whitney  $p=0.011$ ): the mean age in 1992/1993 was 56.6 years, and 44.4 years in 1999.

### **3.1.3 Radiological outcome of fractures of the distal radius**

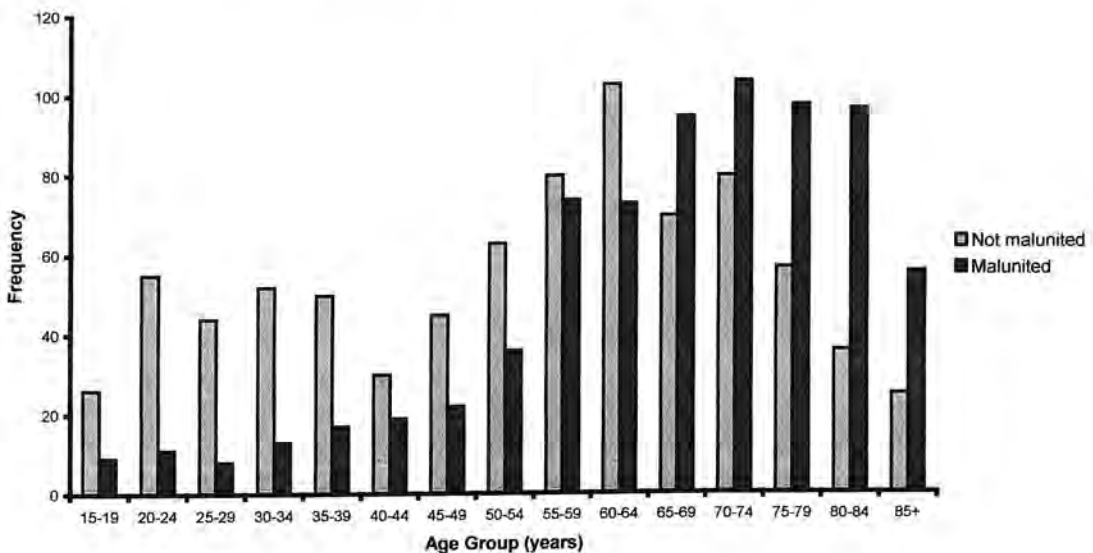
As outlined in section 2.1.6, fracture outcome was analysed using data collected in 1992 and 1993. Thus direct comparison of the epidemiological and outcome study results was permitted, as both used the same data. Fracture outcomes were described with respect to patient age and sex, mode of injury, the AO/ASIF classification, fracture displacement and comminution. The inter-dependence of these factors with respect to their influence upon outcome was not examined statistically in this section of the study.

### 3.1.3.1 Patient age and sex

There were 1728 patients with sufficient data to comment upon the relationship between age and early instability. Significantly higher rates of early instability were found with increasing age (Mann-Whitney  $p < 0.001$ ). Below the age of 45 years, approximately 10 percent of fractures displayed early instability. Over the age of 75 years, this figure was approximately 50 percent. Just fewer than 15 percent of data were incomplete, leaving 1039/1218 patients for analysis of late instability. Late instability increased with age significantly (Mann-Whitney  $p < 0.001$ ). In the older age groups, early and late instability were present in similar proportions.

Interestingly, the proportion of fractures with late instability in patients under the age of 45 years (20 percent) was double that proportion with early instability. Of the 1797 patients in the database, 1548 had outcome data at union. Figure 3.1.3.1a indicates anatomical outcome with reference to age.

**Figure 3.1.3.1a: Frequency of malunion according to patient age**



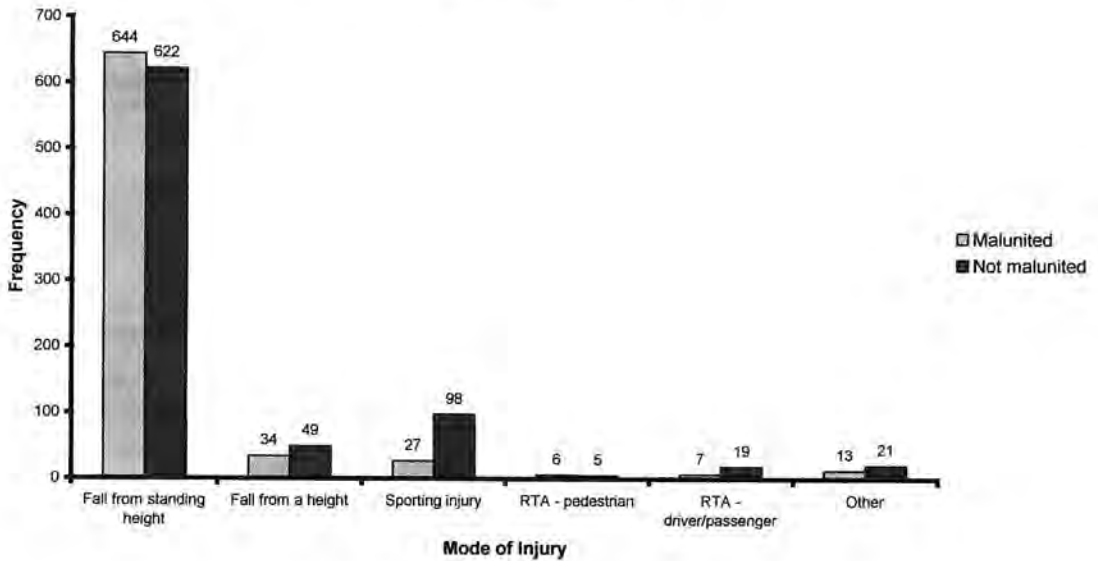
Although the percentage of missing data was high, a definite trend can be seen. Of the 66 fractures in the 20-24 age group with known outcome, 55 healed in an anatomically acceptable position. However, in the 80-84 age group, the proportion is almost reversed, with 56/81 fractures maluniting. If all fractures with unknown outcome in these age groups were to defy the trend, the trend still would be noticeable. In the younger group 55 percent of fractures would heal in an acceptable position and, in the older group 56 percent would malunite. Confounding factors were noted in the epidemiological section of the study, particularly fracture displacement and initial fracture treatment. The older patient was more likely to have a displaced fracture, but was less likely to have manipulative reduction of this displaced fracture.

The relationship between sex and outcome was highly significant (chi squared  $p < 0.001$  for early instability and risk of malunion, and chi squared  $p = 0.001$  for late instability). The numbers of patients with data available for sex versus outcome were the same as the numbers for age versus outcome. In males the percentages of fractures with early and late instability were 17.4 and 26.5 respectively. In females, the percentages were greater: 32.3 percent for early instability and 38.2 percent for late instability. Sixty-five percent of fractures in males united in a satisfactory position. Only 50 percent of fractures in females healed in a satisfactory position.

### **3.1.3.2 Mode of injury**

The influence of the mode of injury upon radiological outcome of the fracture was highly significant as seen in figure 3.1.3.2a. Early and late instability occurred in

**Figure 3.1.3.2a: Frequency of malunion according to mode of injury**



38.6 percent and 32.6 percent of low energy injuries, and in 25.5 percent and 15.8 percent of higher energy injuries respectively. The rate of malunion in low energy fractures (a fall from standing height) was 51 percent, but was only 31 percent in the higher energy injuries. The results seem counter-intuitive. This was almost certainly because of the effect of age of the patient as noted in section 3.1.2.4: the elderly patient was more likely to sustain the fracture through a simple fall, and was more likely to have a poor anatomical outcome from the fracture. The numbers of patients with sufficient data were 1726/1797 for early instability, 1037/1218 for late instability, 1546/1797 and for malunion.

### 3.1.3.3 Premorbid level of function

The numbers of patients with sufficient data were: early instability 1728/1797, late instability 1039/1218, and malunion 1548/1797. Late instability again proved to be more common than early instability in all patients. Those patients who were able to

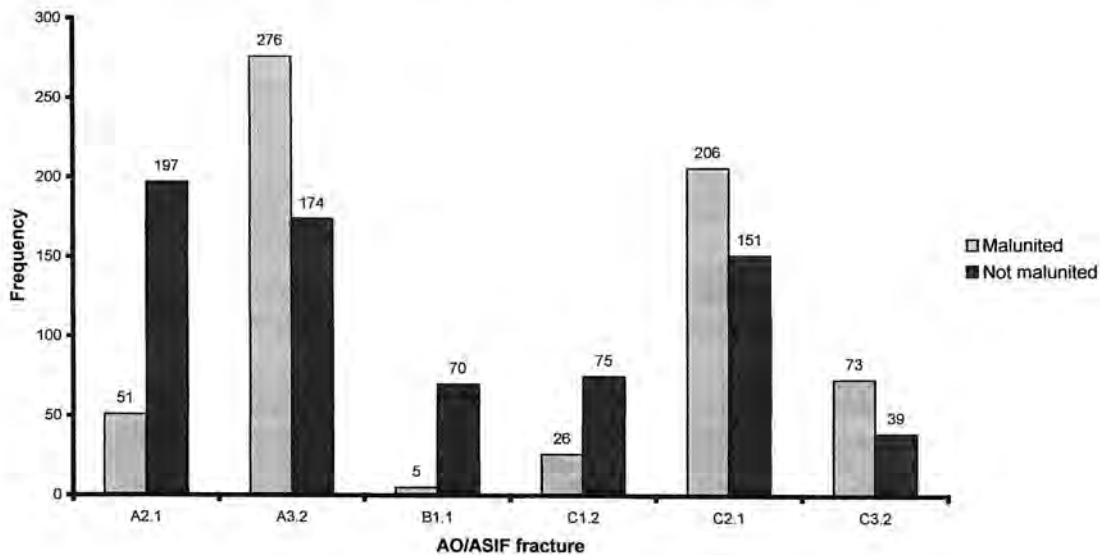


do their own shopping prior to the fracture had early instability in 402/1513 cases (26.6 percent) and late instability in 326/954 cases (34.2 percent). The equivalent percentages in patients unable to do their own shopping were 50.2 and 52.9 percent. The biggest difference between the two groups was seen in the rate of malunion. Being mentally and physically fit reduced the risk of fracture malunion by 27 percent to 41 percent.

### 3.1.3.4 The AO/ASIF classification

As described in section 3.1.2.7, six AO/ASIF fractures represent nearly 90 percent of the fractures recorded. Of the 1797 fractures in the database, 1547 were coded for final outcome and AO/ASIF classification, or 86.1 percent. The corresponding numbers for early and late instability were 1724/1797 and 1039/1218 respectively. The outcome of the six major fracture types is seen in figure 3.1.3.4a.

**Figure 3.1.3.4a: Frequency of malunion in the six most common AO/ASIF fractures**



The prognosis of the fracture is related to the severity of the fracture, and thus should worsen through the classification from A2.1 to C3.2. This was not the case in this study. The most common fracture, the A3.2, had early and late instability and malunion rates of 44, 49.8 and 62 percent respectively. These rates were significantly greater than the B1.1 (3, 4.8 and 5 percent) and the C1.2 (11.7, 19.5 and 26 percent) fractures. However, within the AO/ASIF fracture types, there appeared to be a relationship with outcome. Thus the malunion rate in the A3.2 fractures was nearly three times that in the A2.1 fractures (62 versus 21 percent), and a similar ratio was seen between the C3.2 and C1.2 fractures (65 versus 26 percent).

### **3.1.3.5 Fracture displacement**

The effect of fracture displacement at presentation upon anatomical outcome was highly significant (chi-squared  $p < 0.001$ ). Data for analysis were as follows: early instability 1675/1797, late instability 1013/1218, and malunion 1504/1797. Malunion occurred in 541 (62 percent) of displaced fractures, but in only 169 (27 percent) of minimally displaced fractures. Similar results were seen in the data for early and late instability. The rate of early instability was four times greater in displaced fractures, and the rate of late instability was two-and-one-half times greater in displaced fractures. Again, the rates of late instability were greater than the rates of early instability: 51.6 percent and 43.4 percent for displaced fractures respectively. The percentages of data missing for early and late instability were 6.8 percent and 16.8 percent respectively.

### 3.1.3.6 Fracture comminution

Eighty-seven and 190 patients had missing data for early and late instability respectively (4.8 percent and 15.6 percent) Thus 1710 and 1028 fractures were coded for early and late instability calculations respectively. Only 9.3 percent of fractures without comminution demonstrated early instability, a figure that rose to 40.4 percent in fractures with comminution. The corresponding figures for late instability were 16 percent and 49.4 percent. Fracture comminution was also highly significant (chi-squared  $p < 0.001$ ) in its relationship with final outcome. Metaphyseal comminution was present in 1028 fractures, and absent in 501 fractures: 85.1 percent of the data were coded for comminution and outcome. If metaphyseal comminution were present then the rate of malunion was 60 percent. However, if there were no comminution, then the malunion rate was 21 percent.

### 3.1.3.7 Fracture reduction

The effect of reduction upon outcome is only relevant in displaced fractures. The 123 manipulations undertaken in minimally fractures have been ignored here. Reduction was performed in 766 displaced fractures with sufficient data for analysis. The effect of reduction seems not to have had a significant effect upon malunion (chi-squared  $p = 0.146$ ): 61 percent of reduced fractures malunited as opposed to 69 percent of unreduced fractures. If the reduction were successful when performed, then the effect of the reduction upon final anatomical outcome was highly significant (chi-squared  $p < 0.001$ ). Of the 766 reductions performed in displaced fractures, 356 were successful. The malunion rate in these fractures was 55.5 percent. In those 410 fractures where reduction was unsuccessful, the malunion rate was 67 percent. Similar results are seen for early instability (chi-squared  $p < 0.001$ ). Of the 381

fractures with a good reduction, 106 (27.8 percent) demonstrated early instability; this figure nearly doubled (229/449 fractures or 51 percent) in poorly reduced fractures. A good reduction had far less effect upon late instability (chi-squared  $p=0.041$ ). Thus 120/251 fractures with a good reduction and 115/200 fracture with a poor reduction demonstrated late instability (47.8 percent and 57.5 percent).

### **3.1.4 Prediction of fracture instability**

For this section of the study, the entire database was used for statistical analysis. The results of the analysis are found in figures 3.1.4a to f. Results are divided according to the displacement of the fracture at presentation, and according to the outcome. The outcome measures as described in section 2.1.7 were early instability, late instability, and the risk of malunion.

#### **3.1.4.1 Prediction of early instability in fractures minimally displaced at presentation**

Early instability occurred in 159/1486 fractures, or 11 percent. All factors in this analysis were of statistically significant prognostic value using univariate analysis (Mann-Whitney or chi-squared test). Increasing patient age, female sex, and low premorbid level of function all significantly increased the risk of early instability. Early instability was also significantly increased in patients whose fractures were sustained either through a simple fall, or through being a pedestrian in a road traffic accident. The AO/ASIF type was significant as early instability was greatly reduced in type B fractures. Increasing fracture severity indicated by AO/ASIF group and

**Figure 3.1.4a: Prognostic factors for early instability in fractures minimally displaced at presentation**

	LEVEL	NUMBER	NUMBER DISPLACED AT ONE WEEK [%]	SIGNIFICANCE		
				UNIVARIATE	MLR	
AGE	1486	<30	250	4 [2]	p<0.001	p<0.001
		30-39	145	3 [2]		
		40-49	145	9 [6]		
		50-59	276	28 [10]		
		60-69	276	39 [14]		
		70-79	222	25 [16]		
		>80	172	41 [24]		
SEX	1890	Male	404	21 [5]	p<0.001	NS
		Female	1486	138 [13]		
INJURY CODE	1485	1	1165	144 [12]	p<0.01	NS
		2	86	7 [8]		
		3	148	2 [1]		
		4	15	2 [13]		
		5	25	1 [4]		
		6	46	3 [6]		
SHOPPING	1486	Yes	1356	132 [10]	p<0.001	NS
		No	130	27 [21]		
COMMINUTION	1468	None	974	39 [4]	p<0.001	p<0.001
		Dorsal	426	99 [23]		
		Volar	19	5 [26]		
		Both	49	13 [27]		
AO Type	1474	A	774	89 [11]	p<0.001	NS
		B	245	7 [3]		
		C	455	62 [14]		
AO Group		1	435	13 [3]	p<0.001	p<0.05
		2	703	65 [9]		
		3	336	80 [24]		
AO Subgroup		.1	984	77 [8]	p<0.001	NS
		.2	459	77 [17]		
		.3	31	4 [13]		
FRYKMAN CODE	1471	1	368	30 [8]	p<0.001	NS
		2	147	21 [14]		
		3	360	21 [6]		
		4	89	8 [9]		
		5	140	12 [9]		
		6	98	24 [25]		
		7	134	16 [11]		
		8	135	24 [18]		
ORIGINAL DORSAL ANGLE	1486	<-7	369	22 [6]	p<0.001	p<0.01
		-7-0	373	9 [3]		
		0-4	305	36 [12]		
		5-10	439	92 [21]		
ORIGINAL SHIFT	1486	<0	279	22 [8]	p<0.01	NS
		0	303	27 [9]		
		1	308	29 [9]		
		2	245	28 [11]		
		>2	351	53 [15]		
ORIGINAL ULNAR VARIANCE	1493	<-1	190	15 [8]	p<0.001	p<0.01
		-1	267	19 [7]		
		0	506	45 [9]		
		1-3	523	80 [15]		

**Figure 3.1.4b: Prognostic factors for early instability in fractures displaced at presentation**

	LEVEL	NUMBER	NUMBER DISPLACED AT ONE WEEK [%]	SIGNIFICANCE	
				UNIVARIATE	MLR
AGE	<30	122	28 [23]	p<0.001	p<0.001
	1595 30-39	109	26 [24]		
	40-49	118	29 [25]		
	50-59	256	84 [33]		
	60-69	385	168 [44]		
	70-79	364	198 [54]		
SEX	>80	241	149 [62]	p<0.001	NS
	1685 Male	249	69 [28]		
INJURY CODE	Female	1436	613 [45]	p<0.01	NS
	1	1356	604 [44]		
	1592 2	101	39 [39]		
	3	92	25 [27]		
	4	7	3 [43]		
	5	18	5 [28]		
SHOPPING	6	18	4 [22]	p<0.001	p<0.05
	1595 Yes	1388	550 [40]		
COMMINUTION	No	207	132 [64]	p<0.01	p<0.01
	None	109	34 [31]		
	1571 Dorsal	1289	568 [44]		
	Volar	11	6 [54]		
AO Type	Both	162	59 [37]	p<0.05	p<0.05
	A	775	319 [41]		
	1586 B	15	11 [73]		
AO Group	C	796	348 [44]	NS	
	1	35	17 [49]		
	2	633	272 [43]		
AO Subgroup	3	918	389 [42]	NS	
	.1	613	257 [42]		
	.2	943	406 [43]		
FRYKMAN CODE	.3	30	15 [50]	NS	
	1571 1	96	40 [42]		
	2	136	55 [40]		
	3	52	18 [35]		
	4	82	32 [39]		
	5	164	73 [44]		
	6	298	125 [42]		
	7	228	103 [45]		
8	515	221 [43]			
ORIGINAL DORSAL ANGLE	<-7	54	34 [63]	p<0.05	NS
	1595 -7-0	528	197 [37]		
	1-4	549	227 [41]		
ORIGINAL SHIFT	>4	464	224 [48]	NS	
	<0	192	78 [41]		
	1595 0-2	370	159 [43]		
	3-4	460	210 [46]		
ORIGINAL ULNAR VARIANCE	>4	573	235 [41]	p<0.001	p<0.001
	<0	159	59 [37]		
	1595 0-2	503	175 [35]		
	3-4	424	187 [44]		
	>4	509	261 [53]		

**Figure 3.1.4c: Prognostic factors for late instability in fractures minimally displaced at presentation**

	LEVEL	NUMBER	NUMBER DISPLACED AT SIX WEEKS [%]	SIGNIFICANCE		
				UNIVARIATE	MLR	
AGE		<30	188	17 [9]	p<0.001	p<0.001
	1125	30-39	118	9 [8]		
		40-49	112	12 [11]		
		50-59	224	51 [23]		
		60-69	204	48 [24]		
		70-79	165	61 [37]		
		>80	114	46 [40]		
SEX		Male	312	41 [13]	p<0.001	NS
	1125	Female	813	203 [25]		
INJURY CODE		1	881	216 [24]	p<0.01	NS
	1124	2	64	6 [9]		
		3	118	11 [9]		
		4	12	6 [50]		
		5	18	2 [11]		
		6	31	3 [10]		
SHOPPING		Yes	1035	207 [20]	p<0.001	NS
	1125	No	90	37 [41]		
COMMINUTION		None	769	105 [14]	p<0.001	p<0.01
	1112	Dorsal	296	113 [38]		
		Volar	14	7 [50]		
		Both	33	16 [49]		
AO Type		A	592	137 [23]	p<0.001	p<0.05
	1119	B	180	14 [8]		
		C	347	90 [26]		
AO Group		1	339	29 [9]	p<0.001	NS
		2	549	123 [22]		
		3	231	89 [39]		
AO Subgroup		.1	756	146 [19]	p<0.05	NS
		.2	341	88 [26]		
		.3	22	7 [32]		
FRYKMAN CODE		1	291	48 [17]	p<0.001	NS
	1116	2	115	25 [22]		
		3	262	30 [12]		
		4	72	17 [24]		
		5	105	28 [27]		
		6	65	25 [39]		
		7	109	29 [27]		
		8	97	40 [41]		
ORIGINAL DORSAL ANGLE		<-7	273	33 [12]	p<0.001	NS
	1125	-7-0	304	44 [14]		
		1-4	236	49 [21]		
		5-10	312	18 [38]		
ORIGINAL SHIFT		<0	211	39 [19]	p<0.01	NS
	1125	0	234	43 [18]		
		1	247	51 [21]		
		2	193	45 [23]		
		>2	240	66 [27]		
ORIGINAL ULNAR VARIANCE		<-1	144	30 [21]	p<0.001	NS
	1125	-1	207	39 [19]		
		0	400	58 [14]		
		1-3	374	120 [31]		
WEEK ONE DORSAL ANGLE		<-7	303	35 [12]	P<0.001	P<0.001
	1125	-7-0	300	40 [13]		
		0-4	245	38 [16]		
		5-10	277	131 [47]		
WEEK ONE SHIFT		<0	197	35 [18]	P<0.001	NS
	1125	0	214	34 [16]		
		1	233	53 [23]		
		2	208	51 [25]		
		>2	273	71 [26]		
WEEK ONE ULNAR VARIANCE		<-1	117	22 [19]	P<0.001	P<0.001
	1125	-1	218	31 [14]		
		0	392	69 [18]		
		1-3	398	122 [31]		

**Figure 3.1.4d: Prognostic factors for late instability in fractures displaced at presentation**

	LEVEL	NUMBER	NUMBER DISPLACED AT SIX WEEKS [%]	SIGNIFICANCE	
				UNIVARIATE	MLR
AGE	<30	90	24 [27]	p<0.001	p<0.001
	829 30-39	73	26 [36]		
	40-49	79	33 [42]		
	50-59	157	67 [43]		
	60-69	198	105 [53]		
	70-79	153	88 [57]		
	>80	79	48 [61]		
SEX	Male	166	73 [44]	NS	NS
	829 Female	663	318 [48]		
INJURY CODE	1	679	333 [49]	NS	NS
	828 2	56	26 [46]		
	3	64	21 [33]		
	4	4	2 [50]		
	5	12	4 [33]		
	6	13	5 [39]		
SHOPPING	Yes	769	352 [46]	p<0.01	NS
	829 No	60	39 [65]		
COMMINUTION	None	68	24 [35]	NS	NS
	820 Dorsal	652	319 [49]		
	Volar	4	2 [50]		
	Both	96	42 [44]		
AO Type	A	410	203 [50]	NS	NS
	828 B	4	1 [25]		
	C	414	186 [45]		
AO Group	1	15	8 [53]	NS	NS
	2	335	158 [44]		
	3	478	234 [49]		
AO Subgroup	.1	331	150 [45]	NS	NS
	.2	483	236 [49]		
	.3	14	4 [29]		
FRYKMAN CODE	1	52	29 [56]	NS	NS
	820 2	78	38 [49]		
	3	34	12 [35]		
	4	47	21 [45]		
	5	80	42 [53]		
	6	153	69 [45]		
	7	110	57 [52]		
	8	266	118 [44]		
ORIGINAL DORSAL ANGLE	<10	19	9 [47]	NS	NS
	829 10-19	296	38 [47]		
	20-29	293	44 [49]		
	>29	221	100 [45]		
ORIGINAL SHIFT	<0	106	45 [43]	NS	NS
	829 0-2	194	91 [47]		
	3-4	224	114 [51]		
	>4	305	141 [46]		
ORIGINAL ULNAR VARIANCE	<0	88	36 [41]	p<0.01	NS
	829 0-2	298	128 [43]		
	3-4	212	105 [50]		
	>4	231	122 [53]		
WEEK ONE DORSAL ANGLE	0-9	783	358 [46]	P<0.001	P<0.001
	829 >9	46	33 [72]		
WEEK ONE SHIFT	<0	65	27 [42]	NS	NS
	829 0-2	219	102 [47]		
	3-4	260	120 [46]		
	>4	285	142 [50]		
WEEK ONE ULNAR VARIANCE	<0	225	110 [35]	P<0.001	P<0.001
	686 0-2	239	100 [45]		
	2-3	222	138 [62]		



**Figure 3.1.4e: Prognostic factors for malunion in fractures minimally displaced at presentation**

	LEVEL	NUMBER	NUMBER DISPLACED AT SIX WEEKS [%]	SIGNIFICANCE	
				UNIVARIATE	MLR
AGE	<30	216	19 [8]	p<0.001	p<0.001
	1333 30-39	130	12 [9]		
	40-49	124	18 [14]		
	50-59	256	65 [24]		
	60-69	254	80 [31]		
	70-79	198	81 [40]		
	>80	155	79 [51]		
SEX	Male	359	54 [15]	p<0.001	NS
	1333 Female	974	300 [31]		
INJURY CODE	1	1056	315 [30]	p<0.001	NS
	1332 2	76	13 [17]		
	3	132	11 [8]		
	4	12	6 [50]		
	5	21	4 [19]		
	6	35	5 [14]		
SHOPPING	Yes	1208	292 [24]	p<0.001	p<0.05
	1333 No	125	62 [50]		
COMMINUTION	None	862	128 [15]	p<0.001	p<0.01
	1313 Dorsal	391	188 [48]		
	Volar	19	9 [47]		
AO Type	Both	41	23 [56]	p<0.001	NS
	A	715	202 [28]		
	1325 B	208	16 [8]		
AO Group	C	402	132 [33]	p<0.001	p<0.01
	1	377	38 [10]		
	2	641	186 [26]		
AO Subgroup	3	307	146 [48]	p<0.001	p<0.05
	.1	881	197 [22]		
	.2	418	144 [34]		
FRYKMAN CODE	.3	26	9 [35]	p<0.001	p<0.05
	1	338	65 [19]		
	1316 2	139	41 [29]		
	3	302	40 [13]		
	4	82	23 [28]		
	5	124	31 [39]		
	6	87	44 [51]		
	7	124	38 [31]		
8	120	58 [48]			
ORIGINAL DORSAL ANGLE	<-7	320	40 [12]	p<0.001	p<0.001
	1333 -7-0	334	52 [16]		
	1-4	280	74 [26]		
	5-10	399	188 [47]		
ORIGINAL SHIFT	<0	245	55 [22]	p<0.01	p<0.01
	1333 0	278	65 [23]		
	1	295	75 [25]		
	2	223	61 [27]		
	>2	292	98 [34]		
ORIGINAL ULNAR VARIANCE	<-1	163	38 [23]	p<0.001	p<0.001
	1333 -1	239	53 [22]		
	0	466	91 [19]		
	1-3	465	172 [37]		

**Figure 3.1.4f: Prognostic factors for malunion in fractures displaced at presentation**

	LEVEL	NUMBER	NUMBER DISPLACED AT SIX WEEKS [%]	SIGNIFICANCE		
				UNIVARIATE	MLR	
AGE		<30	99	30 [30]	p<0.001	p<0.001
	1236	30-39	76	28 [37]		
		40-49	95	45 [47]		
		50-59	198	99 [50]		
		60-69	293	185 [63]		
		70-79	272	191 [70]		
		>80	203	166 [82]		
SEX		Male	203	105 [52]	p<0.01	NS
	1236	Female	1033	639 [62]		
INJURY CODE		1	1053	658 [62]	p<0.01	NS
	1233	2	75	41 [55]		
		3	69	26 [38]		
		4	6	4 [67]		
		5	14	5 [36]		
		6	16	8 [50]		
			Yes	1063		
1236	No	173	147 [85]			
COMMINUTION		None	94	44 [47]	p<0.05	p<0.01
	1215	Dorsal	979	607 [62]		
		Volar	6	2 [33]		
		Both	136	76 [56]		
AO Type		A	605	371 [61]	NS	
	1234	B	12	6 [50]		
		C	617	365 [59]		
AO Group		1	27	17 [63]	NS	
		2	499	291 [58]		
		3	708	434 [61]		
AO Subgroup		.1	487	286 [59]	NS	
		.2	725	447 [62]		
		.3	22	9 [41]		
		1	76	49 [64]		
FRYKMAN CODE	1236	2	155	70 [61]		
		3	49	22 [45]		
		4	65	38 [58]		
		5	124	81 [65]		
		6	224	133 [59]		
		7	169	108 [64]		
		8	393	227 [58]		
ORIGINAL DORSAL ANGLE		<10	44	27 [61]	NS	
	1236	10-19	424	250 [59]		
		20-29	430	264 [61]		
		>29	338	203 [60]		
ORIGINAL SHIFT		<0	144	78 [54]	NS	
	1236	0-2	292	167 [57]		
		3-4	357	233 [65]		
		>4	443	266 [60]		
ORIGINAL ULNAR VARIANCE		<0	127	69 [54]	p<0.001	p<0.001
	1236	0-2	403	216 [54]		
		3-4	314	198 [63]		
		>4	392	261 [66]		

sub-group was reflected in increasing rates of early instability in group 3 and sub-groups 2 and 3. Early instability was greater in Frykman types 2, 4, 6, and 8, and particularly high in type 6. A dorsal angulation greater than neutral, and an ulnar variance greater than 1 millimetre were both associated with large increases in the rate of early instability.

Multiple logistic regression revealed the close relationship between several factors. Thus only patient age and fracture comminution retained their high levels of significance ( $p$  values  $<0.001$ ). Patients over 80 years of age had more than ten times the risk of early instability than patients less than 30 years old. The presence of any form of comminution (dorsal, volar or both), increased the risk of instability by a factor of six. The prognostic value of dorsal angulation and ulnar variance at presentation was reduced, but was still highly significant ( $p$  values  $<0.01$ ).

#### **3.1.4.2 Prediction of early instability in fractures displaced at presentation**

Instability occurred in 682/1595 patients, or 43 percent. Thus early instability was greatly affected by the presence of fracture displacement. All demographic factors were of significance following univariate analysis, as were fracture comminution, AO/ASIF type, dorsal angulation, and ulnar variance. Again, increasing patient age, female sex, and a low pre-morbid level of function were associated with increasing rates of early instability. At 62 percent, the risk of instability in the patient over 80 years was nearly three times that of a patient less than 30 years of age. It was also two-and-a-half times greater than the risk of early instability in a patient of a similar age, with a minimally displaced fracture at presentation. As in minimally displaced fractures, a simple fall and having a road traffic accident as a pedestrian led to a greater risk of early instability. Metaphyseal comminution increased the rate of early

instability, which interestingly was greatest in fractures with volar comminution. Also of interest was the far higher rate of early instability in AO/ASIF type B fractures. Perhaps counter-intuitively, the rate of early instability was highest in fractures with negative dorsal angulation, but did increase as expected with increasing ulnar variance. Over half the fractures with an ulnar variance of 4mm or more were displaced at one week.

Following multiple logistic regression, the only factors to retain high levels of prognostic significance were patient age ( $p<0.001$ ), fracture comminution ( $p<0.01$ ), and ulnar variance at presentation ( $p<0.001$ ).

#### **3.1.4.3 Prediction of late instability in fractures minimally displaced at presentation**

In this group no early instability was demonstrated, i.e. the fracture was minimally displaced at presentation and at one week. Late instability occurred in 244/1125 patients, or 22 percent. This is a lower rate of late instability than that quoted by Jenkins (1989). The pattern of prognostic significance following univariate analysis and multiple logistic regression was similar to that found in the prediction of early instability in minimally displaced fractures. Thus all factors were of high prognostic significance with univariate analysis. There was one noticeable difference however. Following multiple logistic regression, patient age ( $p<0.001$ ), fracture comminution ( $p<0.01$ ) and dorsal angulation and ulnar variance measured at 7-10 days ( $p$  values  $<0.001$ ) were the only factors to retain high levels of prognostic significance. A fourfold increase in late instability occurred between the age of 30 and 80 years. The presence of comminution increased the chance of instability by a factor of three approximately.

#### 3.1.4.4 Prediction of late instability in fractures displaced at presentation

This group represents those patients whose fractures malunited, despite maintaining a good position for a week following manipulation. Late instability occurred in 391/829 patients, or 47 percent. Again fewer factors were of prognostic significance for late instability in displaced fractures when compared to minimally displaced fractures. Following univariate analysis, patient age, premorbid level of function, ulnar variance at presentation, and dorsal angulation and ulnar variance at one week were significant. Regression analysis identified only patient age and dorsal angulation and ulnar variance at one week as being of independent prognostic significance (p values <0.001).

#### 3.1.4.5 Prediction of malunion in fractures minimally displaced at presentation

Untreated, malunion would have occurred in 354/1333 patients, or 27 percent. As in previous analyses of minimally displaced fractures, all factors were of prognostic significance following univariate analysis. The same factors were of independent prognostic value, namely patient age (p<0.001), fracture comminution (p<0.01), and dorsal angulation and ulnar variance measured at presentation (p values <0.001).

However, several other factors retained significance after regression: premorbid level of function (p<0.05), AO/ASIF group and subgroup (p values <0.01 and 0.05 respectively), the Frykman classification (p<0.05), and radial shift at presentation (p<0.01). Only patient sex, mode of injury, and the AO/ASIF type were not significant.

Fracture instability in a patient of 80 years was greater than that found in a patient of 30 years by a factor of six. An original dorsal angle of between 4 and 10 degrees was

three times as unstable as a fracture presenting with neutral or volar angulation. The risk of instability increases with an ulnar variance greater than zero.

The presence of comminution (whether dorsal, volar, or dorsal + volar) increased the likelihood of instability by a factor of three, to approximately 50 percent. This result reflected the findings for the prediction of early instability in minimally displaced fractures.

The AO group and subgroup, the Frykman classification, and the patient's level of function retained a degree of significance. In fractures with no involvement of the distal radio-ulnar joint (Frykman groups 1 to 4), involvement of the ulnar styloid (groups 2 and 4) indicated greater instability.

#### **3.1.4.6 Prediction of malunion in fractures displaced at presentation**

The risk of malunion in initially displaced fractures is very high. Untreated (except by manipulation in Accident & Emergency), malunion would have occurred in 744/1236 patients, or 60 percent. In displaced fractures, the factors predictive of malunion were similar to those predictive of early instability. Following multiple logistic regression, patient age ( $p<0.001$ ), fracture comminution ( $p<0.01$ ), and ulnar variance at presentation ( $p<0.001$ ) were all of independent predictive value. Age was strikingly significant here, with patients over 80 years having an 82 percent chance of an unstable fracture, compared with a 30 percent risk under 30 years of age. An ulnar variance of over 2 millimetres increased the risk of instability by 10 percent. The major difference was that the premorbid level of function (as measured by the patient's ability to do their own shopping) remained of high independent prognostic significance ( $p<0.001$ ).

### 3.1.5 Prediction of carpal malalignment

As stated in section 3.1.3, the whole database was used for the identification of factors predictive of carpal malalignment. Carpal malalignment was present in 1121/3559 patients (31.5 percent). All factors were of high prognostic significance following univariate analysis ( $p < 0.001$ ). Age, level of function, the degree of comminution, the AO subgroup, and the original dorsal angulation all remained highly significant following multiple logistic regression analysis with p values  $< 0.001$  (figure 3.1.5a). The AO type was also of prognostic significance with partial articular fractures (group B), being less likely to produce malalignment ( $p < 0.01$ ). The dorsal angulation was the only radiological measurement of significance in the prediction of carpal malalignment.

### 3.1.6 Predictive Formulae

The multiple logistic regression analysis provided weighted significance for each predictive factor. Using this information, predictive formulae were calculated. Below are the predictive formulae for early and late instability and the risk of malunion in minimally displaced and displaced fractures, and the risk of carpal malalignment in all fractures.

Early instability, minimally displaced at presentation

$$Y = (0.03 \times \text{age}) + 1.39 \text{ (if comminution present)} + (0.05 \times \text{original dorsal angle}) + (0.21 \times \text{original ulnar variance}) - 4.82$$

**Figure 3.1.5a: Prognostic factors for carpal malalignment**

	LEVEL	NUMBER	NUMBER WITH CARPAL MALALIGNMENT [%]	SIGNIFICANCE				
				UNIVARIATE	MLR			
AGE	<30	446	48 [11]	p<0.001	p<0.001			
	3559 30-39	287	40 [14]					
	40-49	294	62 [21]					
	50-59	595	148 [25]					
	60-69	758	261 [34]					
	70-79	695	308 [44]					
	>79	484	254 [52]					
SEX	Male	770	133 [17]	p<0.001	NS			
	3559 Female	2789	988 [35]					
INJURY CODE	1	2895	999 [34]	p<0.001	NS			
	3554 2	220	48 [22]					
	3	262	36 [14]					
	4	26	9 [34]					
	5	76	10 [13]					
	6	75	16 [21]					
	SHIPPING	Yes	3144			896 [28]	p<0.001	p<0.001
3529 No	415	225 [54]						
COMMINUTION	None	1209	159 [13]	p<0.001	p<0.001			
	3476 Dorsal	1905	825 [43]					
	Volar	87	25 [29]					
	Both	275	86 [31]					
AO Type	A	1749	570 [33]	p<0.001	p<0.01			
	3543 B	333	29 [9]					
	C	1461	517 [35]					
AO Group	1	520	56 [11]	p<0.001	NS			
	2	1546	450 [29]					
	3	1477	610 [41]					
AO Subgroup	.1	1817	468 [26]	p<0.001	p<0.001			
	.2	1598	622 [39]					
	.3	128	26 [20]					
	1	519	123 [24]					
FRYKMAN CODE	3478 2	306	116 [38]	p<0.001	p<0.05			
	3	471	65 [14]					
	4	189	60 [32]					
	5	333	141 [34]					
	6	448	180 [40]					
	7	451	167 [37]					
	8	761	272 [36]					
	ORIGINAL DORSAL ANGLE	<0	862			96 [11]	p<0.001	p<0.001
	3559 0-9	695	192 [28]					
10-19	619	271 [44]						
ORIGINAL SHIFT	>19	1383	562 [41]	p<0.001	NS			
<0	485	135 [28]						
3559 0-2	1013	283 [27]						
3-4	856	284 [33]						
ORIGINAL ULNAR VARIANCE	>4	1205	419 [35]	p<0.001	NS			
<0	622	141 [23]						
3559 0	787	190 [24]						
1-3	959	330 [34]						
>3	1191	460 [39]						



Early instability, displaced at presentation

$$Y = (0.03 \times \text{age}) + 0.38 \text{ (if comminution present)} + (0.21 \times \text{original ulnar variance}) - 3.12$$

Late instability, minimally displaced at presentation

$$Y = (0.03 \times \text{age}) + 0.93 \text{ (if comminution present)} + 1.45 \text{ (if dorsal angle at one week} > 4 \text{ degrees)} + 0.33 \text{ (if ulnar variance at one week} > 1 \text{mm)} - 3.92$$

Late instability, displaced at presentation

$$Y = (0.02 \times \text{age}) + (0.07 \times \text{dorsal angle at one week}) + (0.22 \times \text{ulnar variance at one week}) - 1.53$$

Malunion, minimally displaced at presentation

$$Y = (0.03 \times \text{age}) + 1.04 \text{ (if comminution present)} + (0.06 \times \text{original dorsal angle}) + (0.2 \times \text{original ulnar variance}) - 3.41$$

Malunion, displaced at presentation

$$Y = (0.04 \times \text{age}) - 0.8 \text{ (if able to do own shopping)} + 0.53 \text{ (if comminution = "dorsal")} + (0.09 \times \text{original ulnar variance}) - 1.65$$

Carpal malalignment, all fractures

$$Y = (0.03 \times \text{age}) - 0.56 \text{ (if able to do own shopping)} - 0.97 \text{ (if comminution = "none")} - 0.46 \text{ (if comminution = "dorsal + volar")} + 0.34 \text{ (if AO subgroup = 2)} + (0.0017 \times \text{original dorsal angle}) - 2.14$$

The probability of early or late instability and the risk of malunion or carpal malalignment can be expressed as a percentage, and is calculated by using the following conversion equation:

$$\text{Probability (\%)} = 100[e^y / (1 + e^y)]$$



## **3.2 Study section 2**

The results of various studies undertaken to validate the predictive formulae in section 3.1.6 are reported. These included an assessment of the sensitivity and specificity of the predictive formulae, and of the ability of the formulae to improve the predictive power of the clinician with respect to fracture instability.

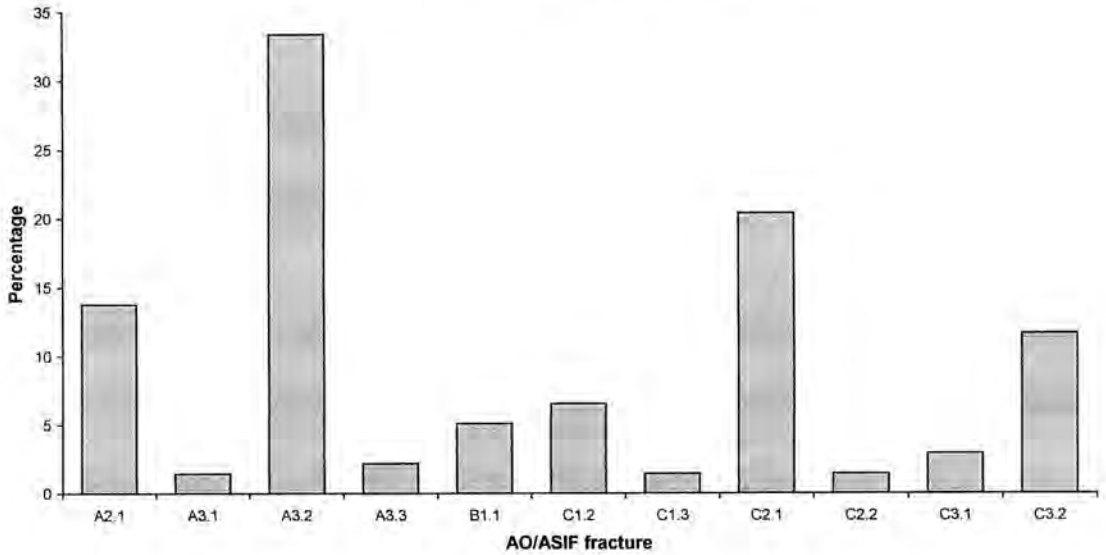
### **3.2.1 Prospective validation of the prediction of fracture instability and carpal malalignment**

Between September and December of the year 2000, 146 patients were recruited into the study. Seven patients were lost to follow-up (failure to attend clinic), leaving 139 patients for statistical analysis. One hundred and fifteen or 82.7 percent of the patients were female. The mean age of all patients was 59.7 years, of females was 61.5 years, and of males was 51.2 years. A good level of premorbid function was noted in 95.7 percent of patients, with only 6 patients unable to do their own shopping. The majority of fractures were caused by a fall from standing height (73.4 percent), with 15.1 percent caused by a fall from a height, and 10.1 percent caused by sporting endeavours. The distribution of fractures according to the AO/ASIF classification is seen in figure 3.2.1a.

#### **3.2.1.1 Minimally displaced fractures**

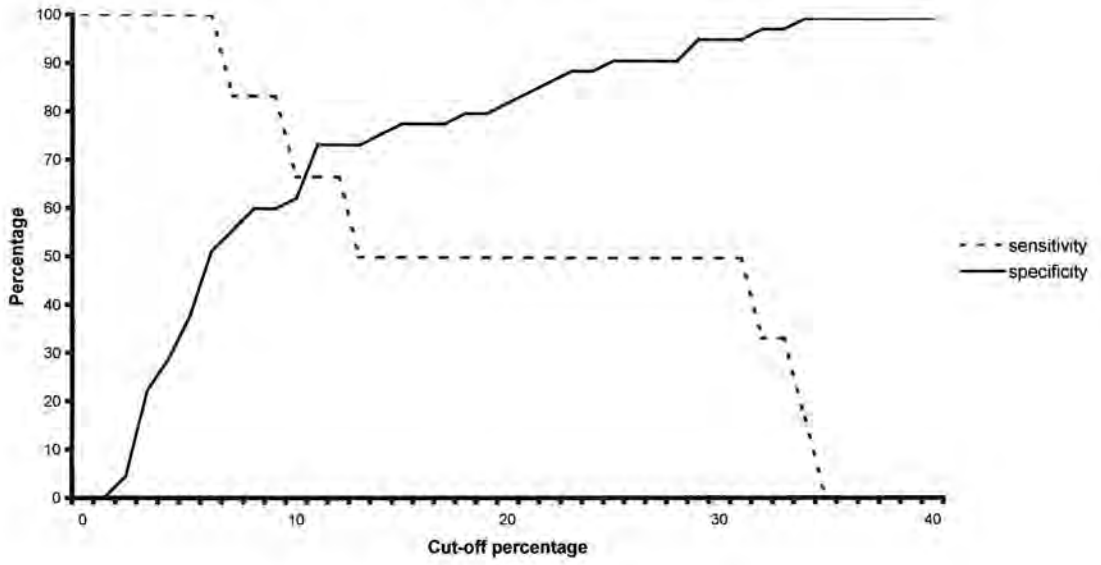
Fifty-eight patients (41.7 percent) presented with minimally displaced fractures. The mean age was 54.6 years. There was no metaphyseal comminution in 62.1 percent of

**Figure 3.2.1a: Percentage of fractures according to the AO/ASIF classification**

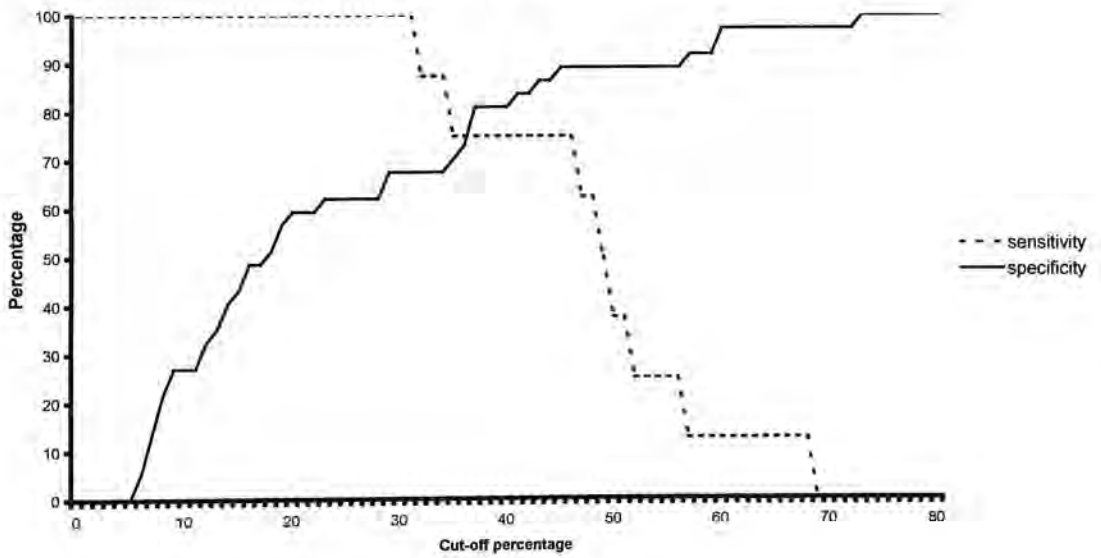


these minimally displaced fractures: if comminution were present, then it was almost exclusively dorsally located (32.8 percent). Early instability was seen in 6/52 or 11.5 percent of these fractures (six patients did not have radiological measurements made at one week). Of these six patients with fracture displacement at one week, one had surgery in the form of non-bridging external fixation. If no surgical intervention were undertaken, then malunion would have occurred in 14/58 (24.1 percent) of patients with minimally displaced fractures. The sensitivity and specificity of the predictive formulae for minimally displaced fractures can be seen in figures 3.2.1.1a, b, and c. The intersection of the curves on each graph gives the cut-off percentage for maximal sensitivity and specificity of each predictive formula. Therefore for the prediction of early instability in minimally displaced fractures (figure 3.2.1.1a), the cut-off is at 11 percent, At this point, the sensitivity of the formula is 66.7 percent, and the specificity 73.3 percent. For late instability, the cut-off is at 37 percent (figure 3.2.1.1b). The corresponding maximal sensitivity and specificity are 75

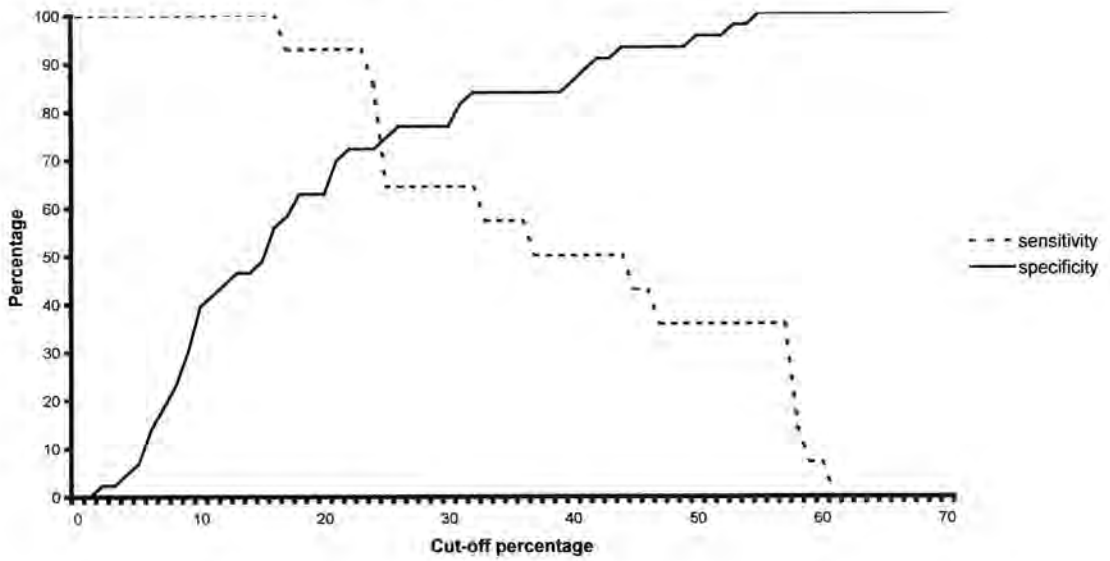
**Figure 3.2.1.1a: Minimally displaced fractures:  
sensitivity and specificity of prediction of early instability**



**Figure 3.2.1.1b: Minimally displaced fractures:  
sensitivity and specificity of prediction of late instability**



**Figure 3.2.1.1c: Minimally displaced fractures:  
sensitivity and specificity of prediction of malunion**



percent and 81.1 percent. For the intersection cut-off of 24 percent in figure 3.2.1.1c, the maximal sensitivity and specificity in the prediction of malunion are 85.7 percent and 72.1 percent.

There were 34 true negative predictions and 12 false positive predictions of early instability in minimally displaced fractures. The patients with a false positive prediction were older by 20.3 years with a mean age of 69.9 years (significant difference: Mann-Whitney  $p = 0.003$ ). There was also a significant difference in fracture comminution: 79.4 percent of the true negatives and 8.3 percent of the false positives had no metaphyseal comminution (chi-squared  $p < 0.001$ ). There were no significant differences in the dorsal angulation or ulnar variance between the two groups.

There were 7 false positive and 41 true negative predictions of late instability, and 12 false positive and 32 true negative predictions of malunion. In both predictions, there were significant differences in the patient age, and the proportion of fractures without

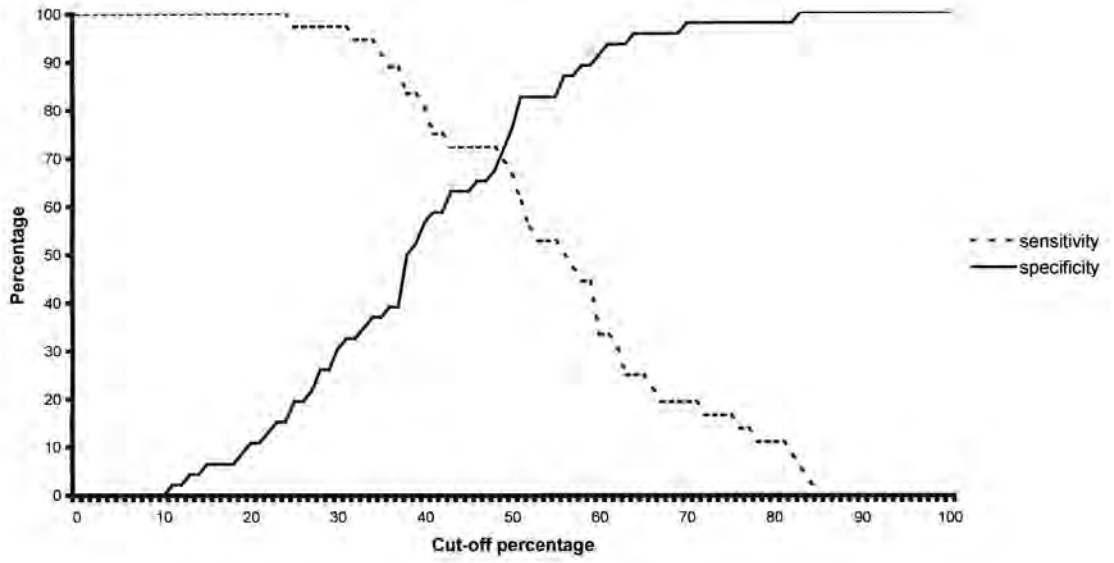
metaphyseal comminution. There were no significant differences found between those patients with false negative and true positive predictions of outcome of minimally displaced fractures. This may be due to the small numbers of patients with a false negative/true positive prediction of instability.

### 3.2.1.2 Displaced fractures

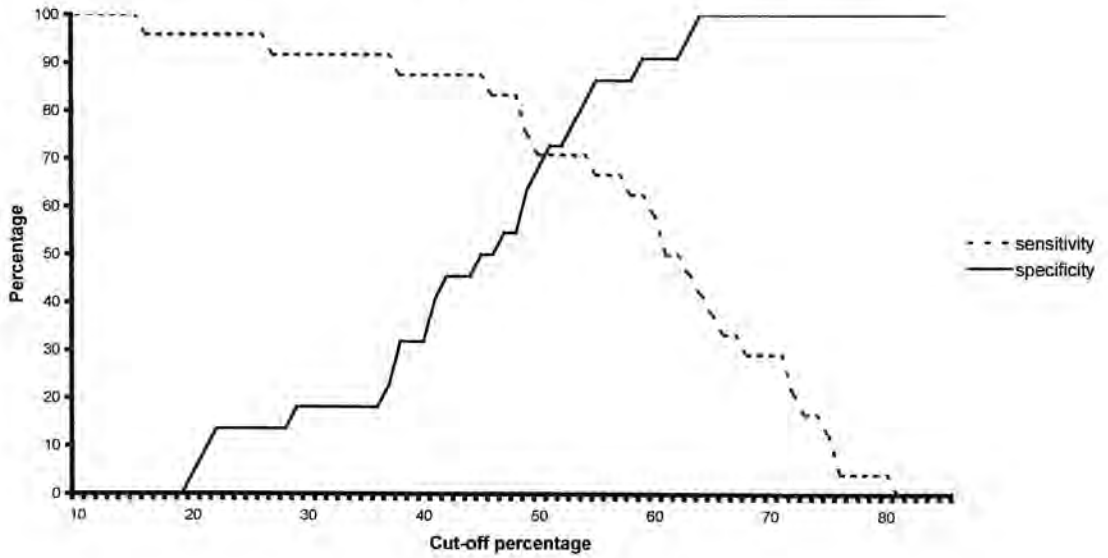
Eighty-one patients (58.3 percent) presented with displaced fractures. These patients were significantly older than those with minimally displaced fractures (Mann-Whitney  $p = 0.035$ ), with a mean age of with a mean age of 63.4 years. Only 13.6 percent of patients had a fracture with no metaphyseal comminution: approximately two-thirds of fractures were comminuted dorsally. All displaced fractures underwent closed reduction under regional anaesthesia in the Accident & Emergency Department. Early instability (i.e. redisplacement at one week) was seen in 36/81 patients (44.4 percent). Of these 36 patients, twenty underwent surgical intervention: 19 had non-bridging external fixation, and one had bridging external fixation. If no surgical intervention were undertaken, then malunion would have occurred in 60/81 patients (74 percent). The sensitivity and specificity of the predictive formulae for displaced fractures can be seen in figures 3.2.1.2a, b, and c. For the prediction of early instability in displaced fractures (figure 3.2.1.2a), the cut-off is at 49 percent. At this point the sensitivity of the formula is 69.4 percent, and the specificity 71.7 percent. For late instability, the cut-off is at 53 percent (figure 3.2.1.2b). The corresponding maximal sensitivity and specificity are 70.8 percent and 77.3 percent. For the intersection cut-off of 69 percent in figure 3.2.1.1c, the maximal sensitivity and specificity in the prediction of malunion are 69.3 percent and 77.3 percent.



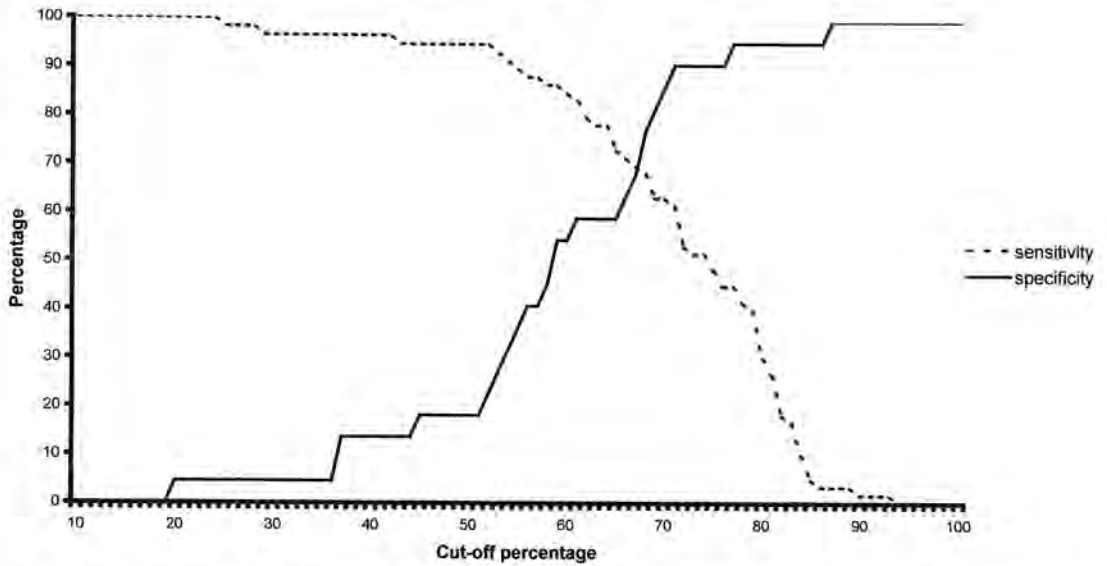
**Figure 3.2.1.2a: Displaced fractures:  
sensitivity and specificity of prediction of early instability**



**Figure 3.2.1.2b: Displaced fractures:  
sensitivity and specificity of prediction of late instability**



**Figure 3.2.1.2c: Displaced fractures:  
sensitivity and specificity of prediction of malunion**



There were 33 true negative and 12 false positive predictions of early instability in displaced fractures. The patients with a false positive prediction were significantly older by 14.9 years with a mean age of 70.2 years (Mann-Whitney  $p = 0.002$ ). These patients also had a significantly higher mean ulnar variance: 5.2 millimetres in false positives, 1.8 millimetres in true negatives (Mann-Whitney  $p < 0.001$ ). However, there were no significant differences found between true negatives and false positives in the prediction of late instability and the prediction of malunion.

There were 25 true positive and 11 false negative predictions of late instability in displaced fractures. Significant differences were noted between these groups with respect to patient age (Mann-Whitney  $p = 0.035$ ), and fracture ulnar variance at presentation (Mann-Whitney  $p < 0.001$ ). Patients with a true positive prediction were older on average by 8.7 years, with a mean age of 71.2 years. The ulnar variance in these patients was greater on average by 4.3 millimetres, with a mean of 5.8 millimetres. There were 41 true positive and 19 false negative predictions of late instability in displaced fractures. Significant differences were noted between these groups with respect to patient age (Mann-Whitney  $p < 0.001$ ), and fracture dorsal

angulation at one week (Mann-Whitney  $p < 0.04$ ). There were 41 true positive and 19 false negative predictions of malunion in displaced fractures. Significant differences were noted between these groups with respect to patient age (Mann-Whitney  $p < 0.001$ ), and fracture comminution (Mann-Whitney  $p < 0.001$ ).

### 3.2.1.3 Carpal malalignment

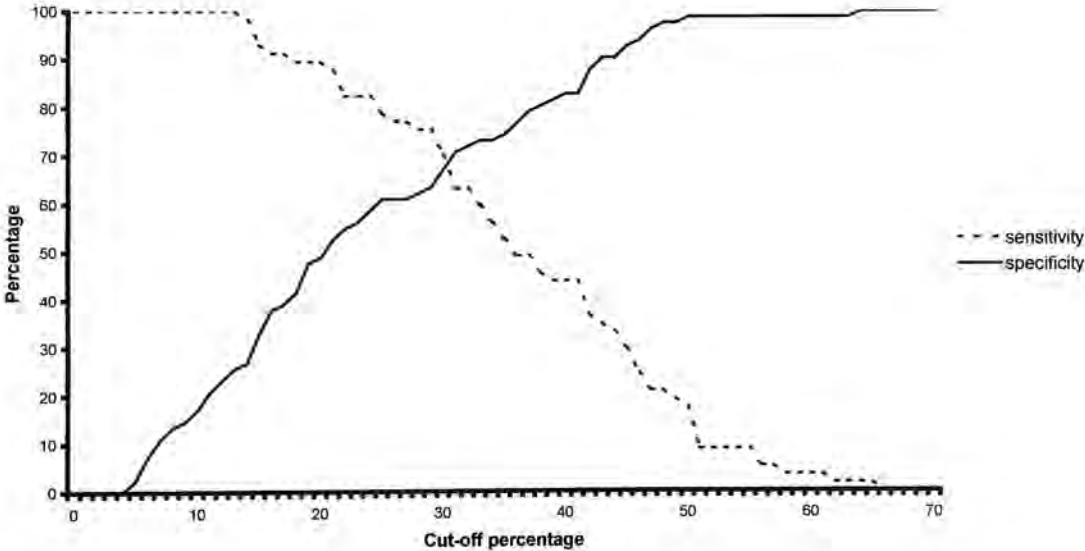
Carpal malalignment was noted in 57/139 or 41 percent of cases. Of these, twenty patients had carpal malalignment noted in conjunction with fracture displacement on radiographs taken at one week, and went on to surgical fixation of the fracture).

Forty-nine of these patients had fracture dorsal angulation of greater than 10 degrees: mean dorsal angulation 19.1 degrees, mean ulnar variance 3.8 millimetres. Of the remaining patients with less than 10 degrees of dorsal angulation, 5 had dorsal malalignment of the carpus, (mean dorsal angulation 6.6 degrees, mean ulnar variance 3 millimetres) and 3 patients had volar malalignment of the carpus (mean volar angulation 15.3 degrees, ulnar variance 5 millimetres).

Patients with carpal malalignment were significantly older, with a mean age of 64.5 years as opposed to 56.4 years in those without carpal malalignment (Mann-Whitney  $p = 0.03$ ). A highly significant difference was also seen in fracture comminution (chi-squared  $p < 0.001$ ), with dorsal comminution present in twice as many patients with carpal malalignment. The mean dorsal angulation at presentation was significantly greater in patients with carpal collapse at 23.1 degrees (Mann-Whitney  $p < 0.001$ ), compared to 10.1 degrees in patients without carpal malalignment.

The sensitivity and specificity of prediction of carpal malalignment are shown in figure 3.2.1.3a. Maximal sensitivity and specificity (70.2 percent and 67.1 percent respectively) are obtained with a cut-off of 30 percent. Using this cut-off, there were 40 true positive and 17 false negative predictions. No significant differences were noted between these groups with respect to the dorsal angulation of the fracture at presentation, the AO/ASIF subgroup, and the premorbid level of function. Significant differences were found between the true positives and false negatives with respect to age (Mann-Whitney  $p < 0.001$ ) and degree of comminution (chi-squared  $p = 0.01$ ). The mean age of the true positives was 70.7 years, as opposed to 49.8 years in the false positives. There were 35/40 fractures with dorsal comminution amongst the true positives, but only 7/17 amongst the false negatives.

**Figure 3.2.1.3a: Sensitivity and specificity of prediction of carpal malalignment.**



Fifty-five true negative and 27 false positive predictions are made with the same cut-off of 30 percent. Significant differences were noted between the true negatives and

false positives in all categories, except AO/ASIF subgroup. Therefore, false positives were more likely to have a poor premorbid level of function (chi-squared  $p=0.012$ ), and were more likely to have a fracture with dorsal comminution (chi-squared  $p<0.001$ ). False positive patients were significantly older (Mann-Whitney  $p<0.001$ ) with a mean age of 72.9 years, compared to 48.3 years for the true negatives. The mean dorsal angulation was also significantly greater in the false positives (Mann-Whitney  $p=0.003$ ) at 17.5 degrees, compared to 6.5 degrees in the true negatives. In false negative predictions of malunion, a prediction of carpal malalignment was present in only 5/19 cases. In false positive predictions of malunion, a prediction of the absence of carpal malalignment was present in 2/5 cases. Therefore in incorrect prediction of malunion, prediction of carpal malalignment was potentially helpful in 7/24 cases. In 41 true positive predictions of malunion, the prediction of carpal malalignment was negative in one case. However in the 17 true negative predictions, the prediction of carpal malalignment was positive in 11/16 cases. The prediction of carpal malalignment when the prediction of malunion was correct was potentially unhelpful in 12/57 cases.

### **3.2.2 Prediction of instability: comparison of predictive formulae and clinical experience**

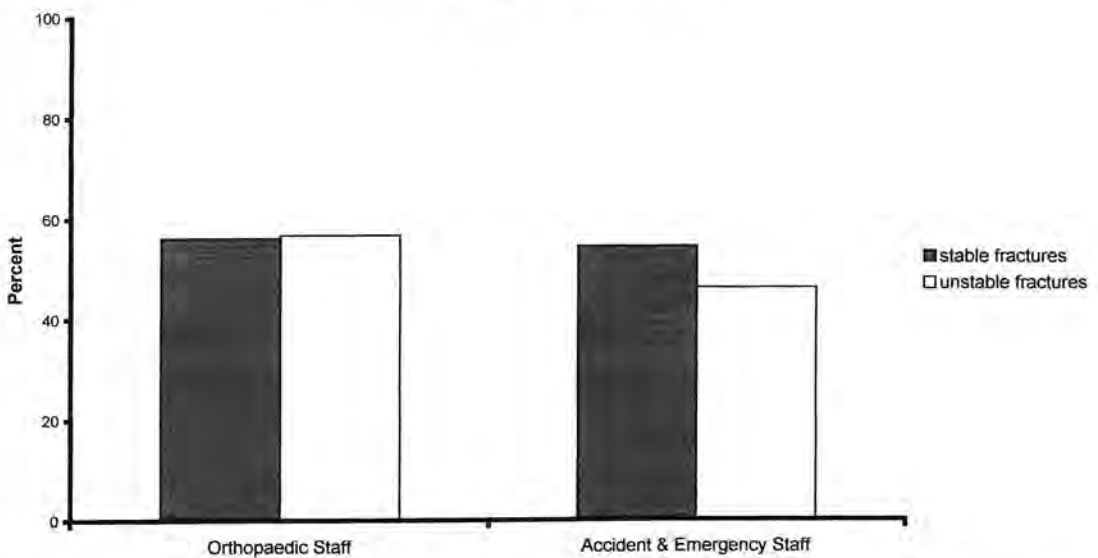
As described in section 2.2.2, this part of the study comprised four parts. The 14 participating clinicians were asked to predict the anatomical outcome of forty displaced fractures, using their experience. They were then asked to record the most important items of information required in making their predictions. The exercise was then repeated, only on the second occasion, the clinicians used the predictive formula in making their prediction. Finally the sensitivity and specificity of

prediction was calculated for each clinician with and without the use of the predictive formula.

### 3.2.2.1 Prediction of malunion using clinical experience

The results of this prediction can be seen in figure 3.2.2.1a. There was no significant difference in the predictive ability of the Orthopaedic and Accident & Emergency Staff for stable fractures. The range for the prediction of stable fractures was 1/6 – 6/6 correct for Orthopaedic Staff, and 1/8 – 7/8 for Accident & Emergency Staff. The Orthopaedic Staff only agreed on the outcome of stable fractures on 5/16 occasions, and were only correct on three of those occasions. The Accident & Emergency Physicians agreed on the outcome of stable fracture on 8/16 occasions, but were only correct twice.

**Figure 3.2.2.1a: Correct prediction of fracture outcome using clinical experience**



The difference between the two sets of staff in the prediction of unstable fracture outcome was not significant (chi-squared  $p=0.17$ ), however the Orthopaedic Staff

were to be slightly more accurate in their prediction (56.9 percent correct versus 46.4 percent correct). The range of correct prediction for unstable fractures was none to all correct for both sets of staff. Agreement upon outcome for unstable fractures occurred on 5 occasions for the Orthopaedic Staff, and on 8 occasions for the Accident & Emergency Physicians. The agreed predictions were correct on 3 occasions for the Orthopaedic Staff, and on 2 occasions for the Accident & Emergency Physicians.

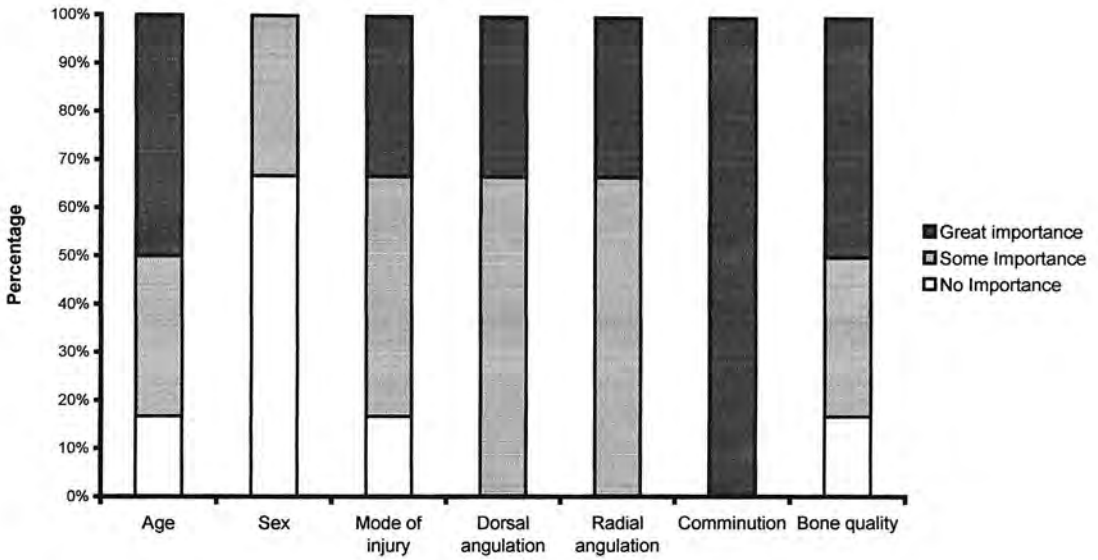
### **3.2.2.2 Importance of predictive factors**

The participants were asked to comment upon the relative importance of the following factors:

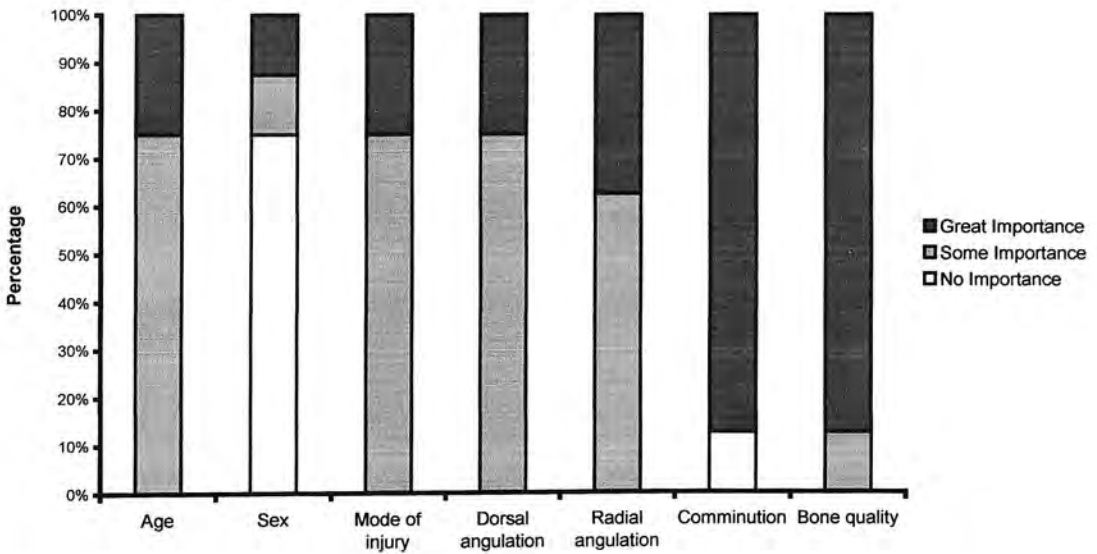
- patient age
- patient sex
- mode of injury
- dorsal angulation
- radial angulation
- fracture comminution
- bone quality

The results are seen in figure 3.2.2.2a and b. Fracture comminution was considered to be the most important factor in determining fracture stability by the Orthopaedic Staff. Patient age, mode of injury, dorsal and radial angulation, are all considered of equal importance. Interestingly, Accident & Emergency Staff consider an assessment

**Figure 3.2.2.2a: Relative importance of information used in the prediction of fracture outcome: Orthopaedic staff**



**Figure 3.2.2.2b: Relative importance of information used in the prediction of fracture outcome: Accident & Emergency staff**





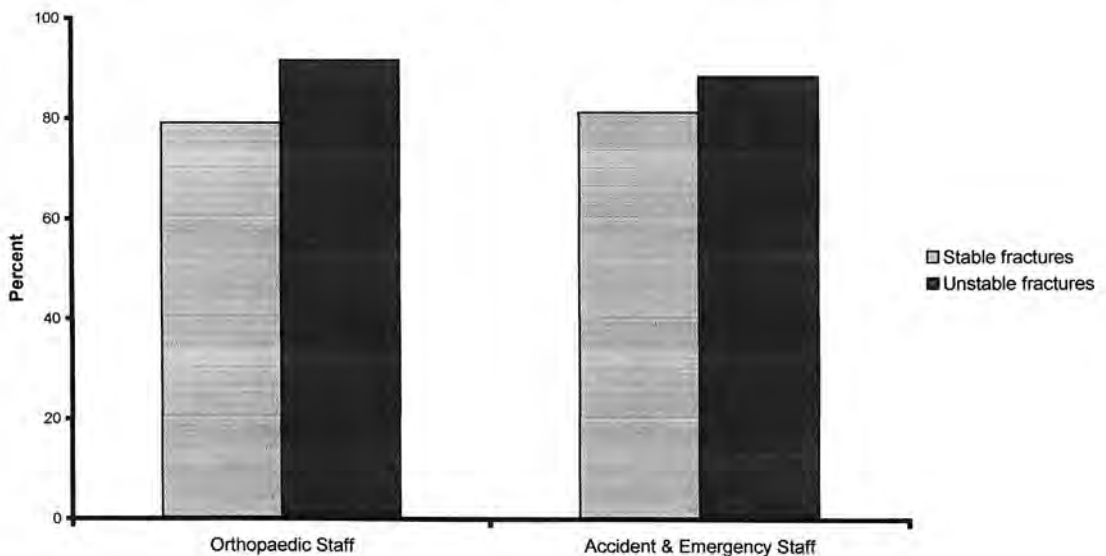
of bone quality on the x-ray to be the most important factor in predicting fracture stability. A number of other factors were noted as important. These included:

- fracture of the ulna/ulna styloid (mentioned by two participants)
- volar comminution
- intra-articular fracture
- quality of the manipulative reduction
- muscular status
- past medical history and medications (eg. steroids).

### 3.2.2.3 Prediction of malunion using the formula

The results of prediction using the formula can be seen in figure 3.2.2.3a. Using a cut-off percentage of 70 percent, The Orthopaedic Staff correctly predicted the outcome in 79.2 percent of stable fractures, and in 91.7 percent of unstable fractures.

**Figure 3.2.2.3a: Correct prediction of outcome using predictive formula**

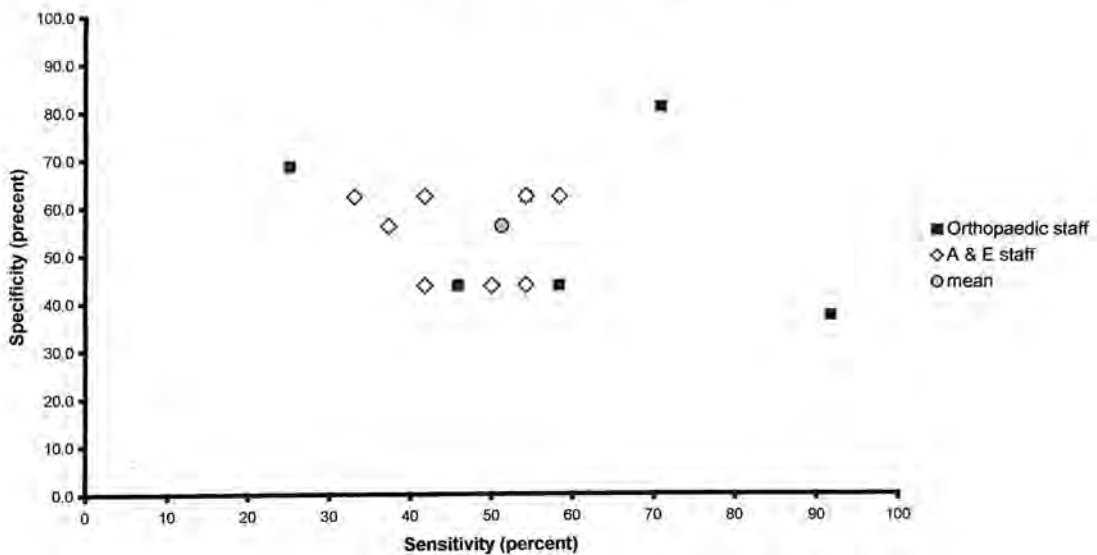


The corresponding figures for the Accident & Emergency Staff are 81.3 and 88.5 percent. The ranges for each prediction in both sets of Staff were none to all correct. However, complete agreement between the Orthopaedic Staff occurred on 13 occasions (11 correct) for stable fractures, and on 22 occasions (21 correct) for unstable fractures. For Accident & Emergency Physicians agreement was recorded in 11 stable fractures (10 correct), and 18 unstable fractures (17 correct).

### 3.2.2.4 Sensitivity and specificity of prediction

The sensitivity of prediction is the ability to correctly predict malunion. Conversely, the specificity is the ability to correctly predict the absence of malunion, or the ability to identify the stable fracture. The sensitivity and specificity of prediction of each participant using clinical experience alone is shown in figure 3.2.2.4a.

**Figure 3.2.2.4a: Prediction of outcome using clinical experience**

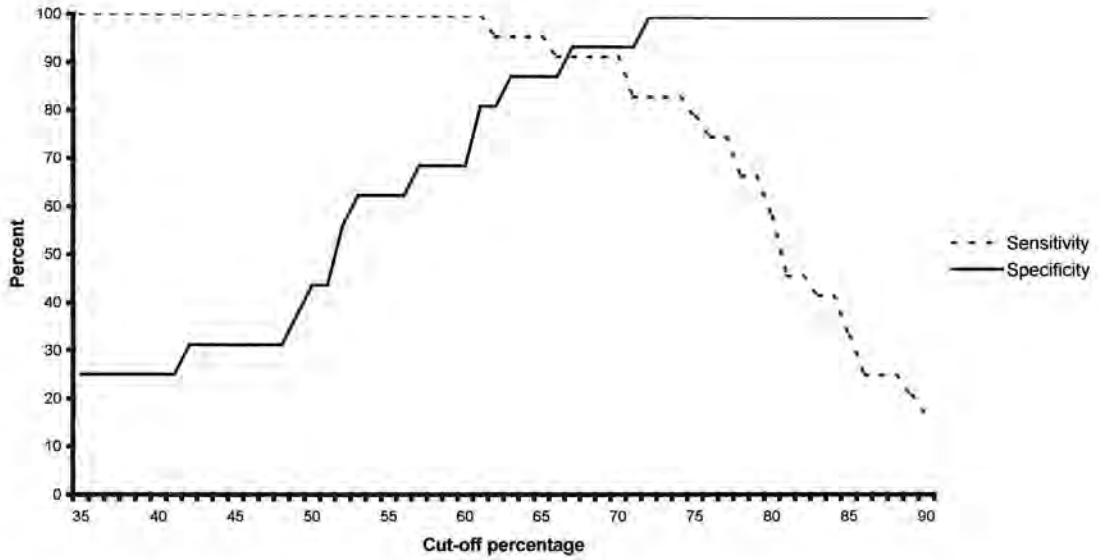


The mean sensitivity and specificity of prediction using clinical experience alone are 51.2 and 55.4 percent respectively. The group was therefore slightly more successful

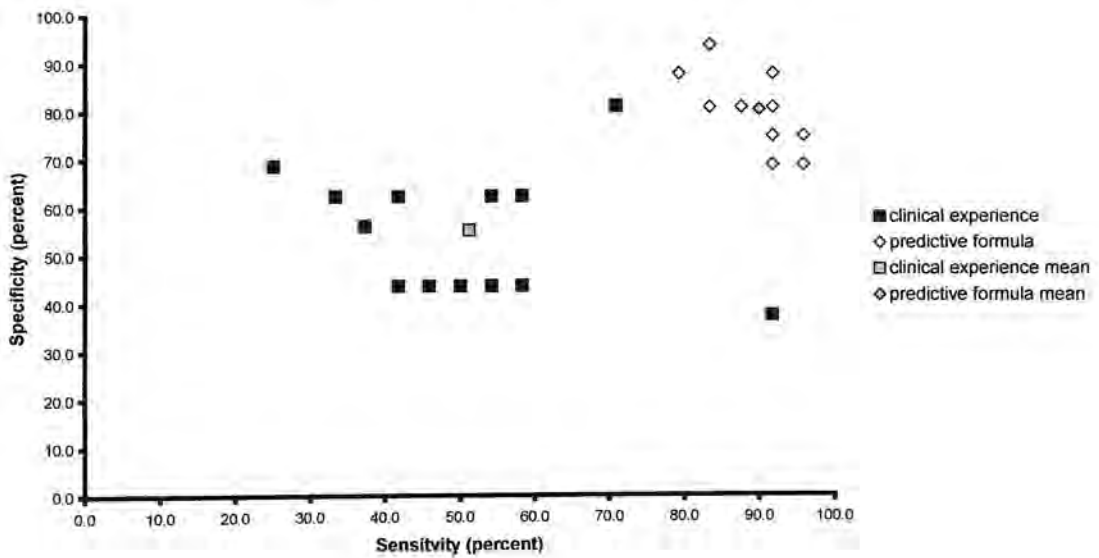
in identifying the stable fractures. Prediction of outcome was correct in 23/40 cases. There were two notable exceptions. With a sensitivity of 91.7 percent and a specificity of 25 percent, one was an Orthopaedic Consultant (with a specialist interest in distal radius fracture) who had an extremely low threshold for deciding that a fracture was unstable. The other was an Orthopaedic trainee who had recently attended a lecture on distal radius fracture instability, and achieved sensitivity and specificity of 70.8 and 81.25 percent respectively. Although there was no significant difference (Mann-Whitney  $p=0.135$ ), Accident and Emergency staff tended to consider more fractures as stable (and were thus more specific), and Orthopaedic staff tended to consider more fractures as unstable (and were thus more sensitive). The use of the cut-off percentage allows the conversion of a quantitative variable (percentage probability of fracture instability) into a qualitative variable (fracture stable or unstable). The formula is most sensitive and specific at the point where the sensitivity and specificity curves intersect. As the sensitivity and specificity do not change between cut-off values of 67 percent and 70 percent, a cut-off value of 70 percent was chosen for ease of use (figure 3.2.2.4b). At this cut-off, the formula correctly predicted fracture outcome in 37 of 40 fractures; i.e. it was 91.7 percent sensitive, and 93.75 percent specific.

The sensitivity and specificity of each participant using the predictive formula is shown in figure 3.2.2.4c. The mean sensitivity and specificity with the formula were 89.9 and 80.5 percent respectively. Prediction was correct in 35/40 cases. Apart from the improvement inability to predict outcome, the level of agreement between

**Figure 3.2.2.4b: Sensitivity and specificity of the predictive formula according to cut-off percentage**



**Figure 3.2.2.4c: Prediction of malunion with and without predictive formula**

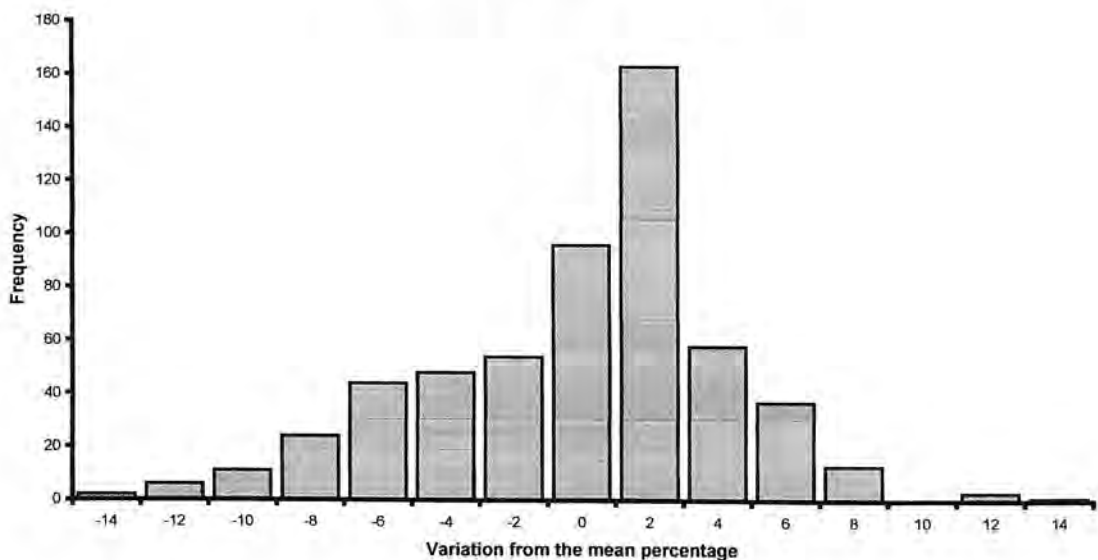


assessors is also increased. This is apparent in the closer grouping of the points on the scatter-gram when comparing with and without formula. This difference in the variation from mean sensitivity and specificity was highly significant (Mann-Whitney  $p=0.005$  for variation in sensitivity, and  $p=0.035$  for variation in specificity). This can be expressed in terms of correct prediction:

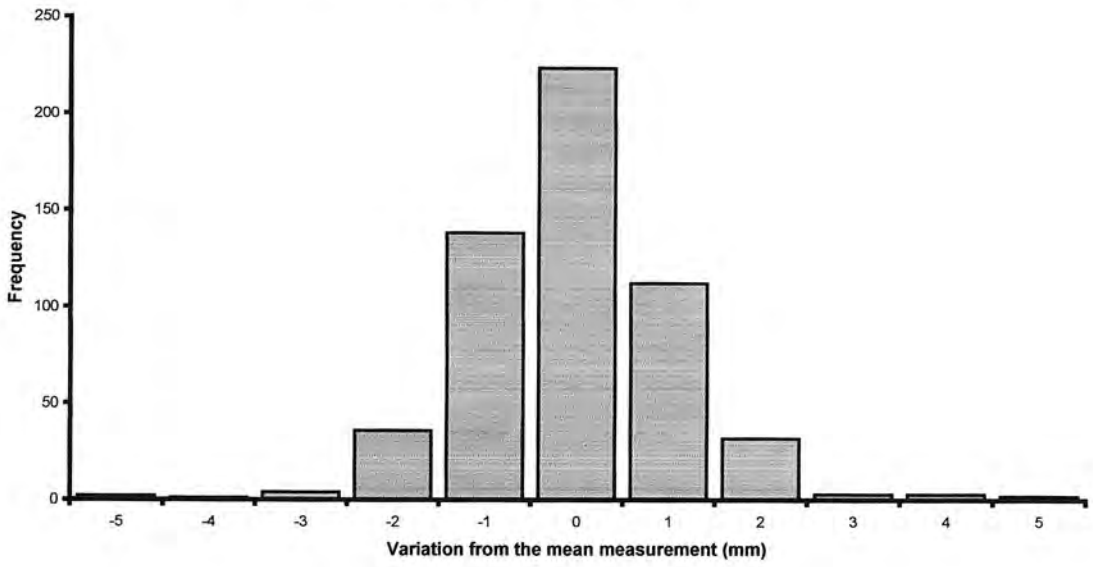
- when using clinical experience alone, on average 73 percent of the participants were in agreement as to outcome, but the majority opinion was correct only 50 percent of the time
- when using the predictive formula, 95 percent of the participants agreed as to outcome, and were correct 88 percent of the time

The variation in probability of prediction about the mean for all 560 predictions using the formula is shown in figure 3.2.2.4d. The variation was not a normal distribution. The calculation of the probability of instability requires the measurement of ulnar variance, and the categorisation of metaphyseal comminution.

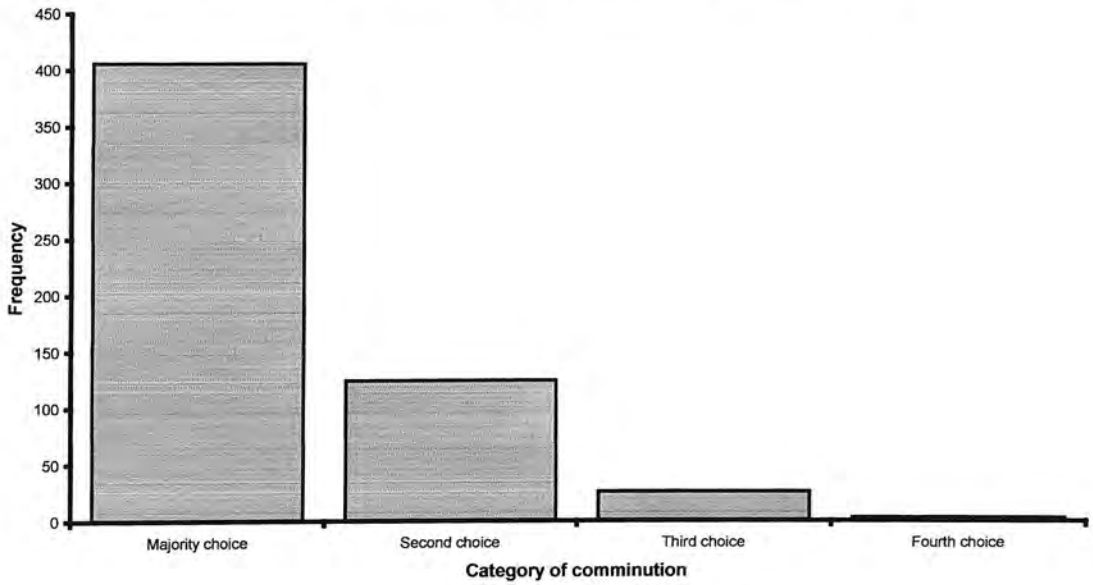
**Figure 3.2.2.4d: Variation about the mean of predicted probabilities of malunion**



**Figure 3.2.2.4e: Variation from the mean measurement of ulnar variance**



**Figure 3.2.2.4f: Agreement in the assessment of comminution**



The variation from the mean in the 560 measurements of ulnar variance is shown in figure 3.2.2.4e. The distribution was normal and 95 percent confidence limits are +/-2.3 millimetres. The non-Gaussian distribution of probability was due the decision as to whether dorsal comminution is present or not. This altered the probability of malunion by approximately 6 percent. On average 72.5 percent of the assessments agreed as to the category of comminution. (figure 3.2.2.4f). Therefore in 27.5 percent of predictions, the probability of malunion would be changed by approximately 6 percent, with reference to the effect of comminution category alone.

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## **4. DISCUSSION**



<b>4.1</b>	<b><u>Study Section 1</u></b>	<b><u>183</u></b>
	4.1.1 Validation of the database	183
	4.1.2 Epidemiology of fractures of the distal radius in the Lothian Region	184
	4.1.2.1 Age and sex distribution	184
	4.1.2.2 Seasonal variation	185
	4.1.2.3 Premorbid level of function	186
	4.1.2.4 Mode of injury	187
	4.1.2.5 Additional injuries	187
	4.1.2.6 Fracture displacement	188
	4.1.2.7 AO/ASIF classification	188
	4.1.2.8 Fracture comminution	190
	4.1.2.9 Fracture reduction	190
	4.1.2.10 Fracture trends with time	191
	4.1.3 Radiological outcome	192
	4.1.3.1 Age and sex	194
	4.1.3.2 Mode of injury	194
	4.1.3.3 Premorbid level of function	195
	4.1.3.4 AO/ASIF classification	195
	4.1.3.5 Fracture displacement	196
	4.1.3.6 Fracture comminution	196
	4.1.3.7 Fracture reduction	196
	4.1.4 Prediction of fracture instability	197
	4.1.4.1 Prediction of early instability in fractures minimally displaced at presentation	198
	4.1.4.2 Prediction of early instability in fractures displaced at presentation	199
	4.1.4.3 Prediction of late instability in fractures minimally displaced at presentation	200
	4.1.4.4 Prediction of late instability in fractures displaced at presentation	200
	4.1.4.5 Prediction of malunion in fractures minimally displaced at presentation	201
	4.1.4.6 Prediction of malunion in fractures displaced at presentation	201
	4.1.5 Prediction of carpal malalignment	201
<b>4.2</b>	<b><u>Study Section 2</u></b>	<b><u>203</u></b>
	4.2.1 Prospective validation of prediction of fracture instability and carpal collapse	203
	4.2.1.1 Minimally displaced fractures	204
	4.2.1.2 Displaced fractures	204
	4.2.1.3 Carpal malalignment	205
	4.2.2 Prediction of fracture instability: comparison of predictive formula and clinical experience	205
	4.2.2.1 Prediction of malunion using clinical experience	206
	4.2.2.2 Importance of predictive factors	207
	4.2.2.3 Prediction of malunion using the formula	207
<b>4.3</b>	<b><u>References</u></b>	<b><u>209</u></b>



## **4.1 Study Section 1**

The results will be discussed in the same sections as the results for ease of reference.

### **4.1.1 Validation of the database**

An assessment of accuracy of data was required. Data such as date of birth, age, and side of injury were deemed either correct or incorrect, as neither judgement nor measurement was required. However the decision as to whether a radiological measurement was correct or not was more difficult. "Correct" must be defined. Correct measurement of a radiological parameter may not be possible using the films available: measurement is affected by factors such as forearm rotation. In addition, the validation measurement was open to as much observer error as the original measurement: neither may be correct. For these reasons, differences between the original and validation measurements were allowed. These differences were set to reflect inter-observer variation of such measurements in other studies (Johnson 1993, Kreder et al 1996). If measurements of one parameter differed wildly then an error of data recording had occurred. If the measurement difference were only slightly greater than the set margin, then an error in method of measurement had occurred. Thus correct was defined in two ways.

With respect to this validation database, recording error of indisputable data such as age was low. Mean and median variation of measured data was less than 4 percent. However, variation of ulnar variance at six weeks was greater than 12 percent. The significance of this variation in measured data is open to question. Certainly, fracture incidences and outcomes will be affected by this error. However, the generation of the predictive formulae should not have been adversely affected by such variation. The multiple logistic regression analysis is based upon measured data,

a proportion of which must be “incorrect”. Therefore the analysis has taken measurement variation into account.

#### **4.1.2 Epidemiology of fractures of the distal radius in the Lothian Region**

Fracture of the distal radius is extremely common: with an incidence of 145 per 100,000 per year, this fracture constitutes 14 percent of new out-patient referrals to the Orthopaedic Trauma Unit in Edinburgh. There are marked differences in distribution in relation to all fracture and patient factors, as discussed below.

##### **4.1.2.1 Age and sex distribution**

This fracture occurred predominately in the older female. This study concurred with others in finding a female to male ratio of approximately 3:1. The incidence curves approximated the classical distributions described by Buhr and Cooke in 1959. The curve for females was essentially ‘J’ shaped. There were slight departures from the classical post-wage-earning fracture distribution. There was a very small peak in the young female (age group 20-24 years), and in the 1992 – 1993 data, the incidence of fractures in women declined in the eldest age group (over 85 years). The incidence curve for 1999-2000 data did conform to the classical distribution, with the eldest age group having the highest fracture incidence. These different fracture distributions are noted in the literature. Schmalholz (1988) and Robertsson et al (1990) described a plateau in incidence over the age of 60-65 years, and Solgaard and Petersen (1985) a decrease in incidence over the age of 80 years. The classical ‘J’ shaped incidence curve was described by Mallmin and Ljunghall (1992), Doczi and Renner (1994), and Bengner and Johnell (1985). This difference in distribution was ascribed to the differences in definition of a distal radius fracture: the fracture defined as being

within 2.5 centimetres to 4 centimetres from the distal joint surface, depending upon the study. Bengner and Johnell (1985) found little difference in the distribution curves for females 25 years apart, other than a real increase in incidence over the age of 45 years. We have found the distribution to be different in our two data sets, with a fall in incidence over the age of 80 years in 1992-1993, and no fall in incidence in 1999. In both studies, the definition of the fracture was not altered between the periods of data collection. Therefore differences in distribution may well be due to chance: in the eldest age groups the number of fractures (less than 100) and the population (11,000 to 12,000) are both comparatively small.

The curve for males was bimodal, with peak incidences in the third and ninth decades. The peak incidence in males at the age of 80-84 years was less than a fifth of the peak incidence in females. Although the lesser incidence peak is in the 20-24 years age group, it is however significantly greater than the corresponding peak in females. Previous studies have found greater variation in the age related incidence distribution in males. Bengner and Johnell (1985) noted a 'J' shaped curve.

Robertsson et al (1990) reported a bimodal distribution with a peak in the sixth and seventh decades, a marked trough in the eighth decade and a second greater peak over the age of 80 years. These variations in distribution could again be attributable to chance, as the numbers of fractures in males is relatively small.

#### **4.1.2.2 Seasonal variation**

There was a striking increase in the incidence of distal radius fracture during the winter months, with nearly two-fifths of the fractures occurring in one quarter of the year. The significant differences in the demography of winter and non-winter fractures relate to mode of injury and level of function. Not surprisingly the



proportion of fractures due to a simple fall increase during the winter months, as conditions became more treacherous. It would seem counter-intuitive that the premorbid level of function in the fracture population is better during the winter months. However, poor outdoor conditions are likely to prevent less mobile individuals from venturing outside, and will therefore reduce their risk of fracture during the winter months. Other northern European epidemiological studies have demonstrated similar peaks in fracture numbers during the winter months. In Sweden, Mallmin and Ljunghall (1992) reported that 13 percent of fractures in their study occurred in just 4 days of January. Solgaard and Petersen (1985) were the only study to note a difference in the seasonal fracture distribution with respect to sex. Females were far more likely to have sustained their fracture during the winter months, whereas the seasonal distribution in males was far more even. In this study we did not find a sex related difference in seasonal distribution.

#### **4.1.2.3 Premorbid level of function**

Despite the fact that this was a fracture of the elderly, the patients in the study group had an extremely good level of function. Between the ages of 65 and 85 years, 79.1 percent of patients did their own shopping. Similar comments were made by Robertsson et al (1990). The demography of his study population was similar to ours. He reported that nearly 60 percent of patients were in employment, and two-thirds of fractures occurred outdoors. He commented that although it was predominately a fracture of the elderly, the people who sustained the fracture were not inactive. This is extremely important. In much of the literature, increased age is a relative contra-indication to surgical intervention. Thus surgical intervention is considered

inappropriate in an active section of the fracture population, whose independence may be adversely affected by a poor functional result.

#### **4.1.2.4 Mode of injury**

This study has shown that over four-fifths of these fractures are as a result of a fall from standing height. The fracture from these falls occurred even more frequently in females. The age of the patients with these fractures was significantly higher. Thus the typical distal radius fracture patient was not just older and female, but also sustained their fracture through a low energy injury. These findings are reported consistently in the literature. Mallmin and Ljunghall (1992), Robertsson et al (1990), Bengner and Johnell (1985), and Doczi and Renner (1994) also recorded the cause of the fracture. They too reported that the majority of fractures occur as a result of lower energy injuries, and that the proportion of fractures so caused increased with the age of the patient.

#### **4.1.2.5 Additional Injuries**

Additional injuries tended to follow the demographic patterns described above. Males with more than one injury were slightly younger than their single injury counterparts, and their injury was higher energy in 83 percent of cases. Females with more than one injury were of a higher mean age, and 85 percent sustained their injuries through a simple fall. In addition, 13.2 percent of the additional fractures in females were fractures characteristically indicative of osteoporosis.

#### 4.1.2.6 Fracture displacement

Fracture displacement was rather a reflection of the nature of the patient than the nature of the injury. Thus it was an elderly female who was more likely to sustain a displaced fracture from a low energy injury, than a younger male from a higher energy injury. From an epidemiological point of view, comments on fracture displacement in the literature are less than satisfactory. A fracture was considered displaced if reduction were performed. As seen in section 3.1.1.9, fracture reduction was not necessarily performed in all displaced fractures, and reduction may have been undertaken in minimally displaced fractures. Despite failings in the definition of fracture displacement, various trends have been noted. Robertsson et al (1990) and Schmalholz (1988) both record greater numbers of displaced fractures in females, and with increasing age. Solgaard and Petersen (1985) noted the relationship between patient sex and displacement, and Bengner and Johnell (1985) the relationship between age and displacement.

#### 4.1.2.7 AO/ASIF classification

Nearly 90 percent of fractures were due to just 6 AO/ASIF fractures. The six fractures could be broadly grouped into three, depending upon the nature of the fracture, and the type of patient sustaining the fracture. By far the commonest group was the A3.2, C2.1, and C3.2 fractures. These fractures constituted 56.9 percent of the study group. With reference to the measurement of outcome used in this thesis the C2.1 and C3.2 fractures were essentially A3.2 fractures, but with varying degrees of articular comminution. These fractures occurred typically in the elderly female patient through a low energy injury. The only significant difference in the

demography of these three fractures was that the proportion of C3.2 fractures caused by a fall from >3ft was greater (10 percent compared to 4 percent in A3.2 fractures). The A2.1 and C1.2 fractures again were equivalent: the C1.2 fracture was an A2.1 fracture with a sagittal split in the articular surface. These patients were younger than those in the above group with a peak incidence occurring in the 55-59 year age group. The decreased age was reflected in the significantly reduced proportion of fractures that were displaced at presentation. These fractures were less common, constituting 23.6 percent of the study group.

Finally, the B1.1 fractures represented another demographic group. These fractures occurred typically in the young male. The likelihood of a higher energy injury causing the B1.1 fracture was significantly higher than in the two groups above. The B1.1 fracture was problematic with reference to the outcome measures in this study. Radiological measurements did not recognise displacement in the articular surface: this perhaps explains the extremely low percentage of B1.1 fractures that were defined as displaced.

All findings in relation to the AO/ASIF classification must be viewed circumspectly. All inter-observer variation was eliminated in this thesis as the Project Supervisor classified all fractures. However intra-observer variation must be recognised.

Illarramendi et al (1998) showed only moderate intra-observer reproducibility of the AO/ASIF classification in their study. Andersen et al (1996) felt that they could not recommend the AO/ASIF classification as a means of management decision-making, because of the poor levels of inter- and intra-observer agreement. The classification system has only been used in this study as a means of describing fracture epidemiology, and of drawing comparisons between data sets in different sets of the study.

#### **4.1.2.8 Fracture comminution**

Unsurprisingly, the patients whose fractures had metaphyseal comminution display similar characteristics as patients in the most common AO/ASIF grouping above. Therefore nearly 90 percent were female, the mean age was early in the seventh decade, nearly 90 percent were caused through a simple fall, and four fifths of the fractures were displaced at presentation. The non-comminuted fractures bore comparison with the A2.1/C1.2 fractures. The mean age of the patients and the proportion of low energy injuries were lower with respect to comminuted fractures. The proportion of fractures displaced at presentation was also lower. Classifying the fractures according to fracture comminution is a far simpler task than using the AO/ASIF system, and would appear to identify similar broad fracture groups. It has the advantage of being more inclusive: all fractures fall into the four comminution groups, whereas only 90 percent fall into one of the commonest six AO/ASIF fracture groups. As will be seen later, this simple classification also had far greater prognostic value with respect to anatomical outcome. The level of inter-observer agreement as to fracture comminution was good (section 3.2.2.4).

#### **4.1.2.9 Fracture reduction**

The decision to reduce the fracture in the Accident and Emergency Department seemed to be quite closely linked to our definition of fracture displacement. Thus few patients with minimally displaced fractures had manipulations, and few with displaced fractures did not. Other factors clearly had influence – thus patients who did not have reduction of a displaced fracture were older and had poorer levels of function prior to the fracture. The decision as to whom to manipulate was not terribly discerning. Only 46.1 percent of manipulations were successful. Thus less than half

of the fractures manipulated were sufficiently stable to retain the reduced position until the post manipulation X-ray was taken. The decision to manipulate should not therefore be based upon the traditional criterion of fracture displacement.

Manipulation should be undertaken for displaced fractures that have characteristics indicative of stability once reduced.

#### **4.1.2.10 Fracture trends with time**

This part of the study was of limited significance. As data were collected retrospectively for fractures in 1999 – 2000, the breadth of data was limited to demographics. Also the completeness of the data set could not be assumed to be comparable to that obtained during the dedicated study period. However certain significant trends were identified. The number of fractures in the over 85 years age group was increasing both in real terms and in terms of incidence: there were more elderly people sustaining this fracture, and they were doing it more frequently. This may indicate that this age group was more active than before: implying a better physical and mental condition. In addition there was a significant increase in the number of A3.2 fractures. The burden of treatment provision is therefore more and more toward the characteristic older female patient. The difference in the incidence of fracture was not as marked as that recorded by Bengner and Johnell (1985). They noted that the incidence of fracture in females over 80 years more than doubled between 1953 and 1981. The time between data sets in this study was only 6 years, and no significant difference was found in overall fracture incidence. The change in population demographics between 1953-1981 was likely to have been substantially greater than the changes between 1992/3-1999: this may explain the differences in results between the two studies.

### 4.1.3 Radiological outcome

The significant relationship between each recorded factor and radiological outcome has been outlined in section 3.1.3. This has highlighted the difficulty for the clinician in reliably predicting outcome. All factors can be taken into account when deciding upon the treatment plan for the individual fracture, but it is difficult to weight the relative importance of each factor.

The literature regarding anatomical outcome of distal radius fracture alone is rather limited: defining the natural history of the fracture is rarely the primary study aim. Prognostic factors for anatomical outcome are usually identified in the context of functional outcome, or the evaluation of a method of fracture treatment. In 1951 Gartland and Werley published a study on the evaluation of healed Colles fracture. The paper was primarily an assessment of functional outcome, but a number of factors were identified as having an effect upon anatomical outcome. Dorsal tilt, radial deviation and radial shortening were all found to have an effect upon anatomical outcome: the greater the displacement, the worse the position at union. Interestingly the authors attributed this relationship to the increasing inadequacy of fracture reduction with increasing displacement. Frykman's treatise (1967) on this fracture was again directed towards the assessment of functional outcome. His classification system reflects the findings of his study. Thus anatomical outcome was linked to the presence or absence of distal ulnar fracture. Despite making radiological measurements, he did not analyse the relationship between the fracture position at presentation and at union. Fracture displacement does not therefore figure in the Frykman classification. Van der Linden and Ericson (1981) looked at the measurement of displacement and the treatment of the fracture. They found that the quality of the reduction had the greatest influence upon anatomical outcome, but that

the position of the fracture prior to reduction influenced the quality of the reduction. Although not made by the authors the conclusion can be drawn that the anatomical outcome is influenced by the fracture displacement at presentation. Dias et al (1987) also showed a relationship between initial displacement and anatomical outcome. Interestingly, metaphyseal comminution was shown to affect the anatomical outcome only in undisplaced fractures: it did not affect the outcome in fractures that had been reduced. Stewart et al (1985) reiterated the effect of quality of reduction upon outcome, but also noted the effect of patient age and sex. Age and sex were however only weakly linked to outcome. Axial shortening was found to be the most important component of displacement by Schmalholz (1989). Dorsal angulation could be improved by reduction, however significant axial shortening could not. Jenkins (1989) demonstrated the relationship between displacement and outcome, and identified the lack of metaphyseal comminution as a factor indicative of fracture stability. Lafontaine et al (1989) showed that dorsal angulation, dorsal comminution, concomitant ulnar fracture, patient age and intra-articular involvement were all significant predictors of outcome. Hove et al (1994) and Abbaszadegan et al (1989) both employed multiple regression analysis to look at factors prognostic of anatomical outcome. The former demonstrated that initial dorsal angulation, age and Older classification were predictive of dorsal angulation at union, and that initial shortening, dorsal angulation and age were predictive of shortening at union. The latter found that radial shortening, Lidstrom class, and patient age were the most significant predictors of outcome.

Thus the literature does not consistently agree upon factors prognostic of anatomical outcome. Initial displacement seems to be of importance, but there is no agreement as to the most important radiological parameter. Various authors identify fracture



comminution and patient age as influencing outcome, but in no study are these factors seen to be the most important predictors of outcome.

This section of the study has described the natural history of distal radius fracture in terms of patient and fracture characteristics. This had not been addressed previously.

This section also identifies the gap between natural history and treatment. If management decisions are to be influenced by knowledge of the natural history, then the effect of individual predictors of outcome must be accurately quantified.

#### **4.1.3.1 Patient age and sex**

The study has identified the significant differences in outcome between different age groups and the sexes. The proportion of fractures which malunited quadrupled between the third and ninth decades and the malunion rate rose by 15 percent if the patient were female. However, the intimate relationship between patient age and sex was seen in section 3.1.1.1. Therefore one factor must be of overriding importance. Epidemiological studies have identified the relationship between the need for reduction and the age and sex of the patient (section 4.1.1.1). The relationship between displacement and outcome is also reported widely (section 4.1.2). It is interesting that the literature has failed to identify consistently a relationship between age, sex and anatomical outcome.

#### **4.1.3.2 Mode of injury**

The mode of injury affected outcome in an unexpected fashion. A low energy injury had a greater risk of producing an unstable fracture. The demographics of the mode of injury supplied the explanation for this relationship with outcome. The simple fall from standing height is the commonest cause of the fracture in the elderly female

patient. This type of patient is also the one most at risk of developing a malunion. Thus the effect of mode of injury is mediated by the age of the patient.

#### **4.1.3.3 Premorbid level of function**

The physical and mental status of the patient significantly affected the chance of fracture instability. The chance of malunion in patients who were able to do their own shopping was approximately a third less than in patients who were not able to do their own shopping. These independent patients are in better condition physiologically. This manifests itself in not only better bone quality but also in reduced risk of falling. This echoes similar findings in the literature looking at the risk of sustaining hip fracture (Porter et al 1990).

#### **4.1.3.4 AO/ASIF classification**

The function of a fracture classification system was defined by one of the founders of the AO/ASIF group (section 1.3.1). With respect to the outcome measures used in this study, the AO/ASIF classification failed to predict outcome. Thus the risk of malunion in an A3.2 fracture was far greater than that of a B1.1 or a C1.2 fracture. However within each fracture type, the groups and sub-groups did indicate different prognosis: an A3.2 fracture having a worse chance of poor outcome than an A2.1 fracture. This failure to predict outcome may have been a reflection of the outcome measures used in the project: AO/ASIF fracture types distinguish between degrees of intra-articular involvement. Unfortunately the literature has demonstrated that the inter- and intra-observer variation in classifying fractures according to the AO/ASIF system is only acceptable if the classification is based upon the fracture type alone

(Kreder et al 1996). The complexity of the classification system would therefore seem to hamper its value as a prognostic tool on two fronts.

#### **4.1.3.5 Fracture displacement**

The risk of malunion rose by a factor of three if the fracture were displaced at presentation. However there were strong relationships between fracture displacement and age and sex noted in section 3.1.1.6. Our results confirm the findings of many of the studies mentioned in section 4.1.2. Again the interdependence of these factors in predicting outcome was likely to be high. Fracture displacement alone is limited as a prognostic tool: the effects of each component of fracture displacement need to be quantified in any system for predicting fracture outcome.

#### **4.1.3.6 Fracture comminution**

Classifying the fracture according to the degree of metaphyseal comminution seems to have had significant prognostic value. Thus the rate of malunion rose by a factor of three when comminution was present. However the demographics of the fracture according to comminution pointed to further interdependence of prognostic factors. Thus patients with comminuted fractures were more likely to be elderly females with low energy injuries. The literature fails to provide consistent evidence for the importance of comminution. However other researchers have not use the classification of fracture comminution used in this study.

#### **4.1.3.7 Fracture reduction**

Fracture reduction was an indirect measurement of the ability of the clinicians to predict fracture outcome. Unfortunately less than half of the manipulated fractures

were reduced. Thus over half of the fractures reduced were highly unstable. The fact that a manipulative reduction was performed had very little effect upon the malunion rate. However if a successful reduction were performed, this did reduce the malunion rate. Successful reduction is likely to be a reflection upon the stability of the reduced fracture rather than an independently significant predictor of outcome.

#### **4.1.4 Prediction of fracture instability**

The radiological outcome of the fracture has been shown in Study Section 1 to have significant associations with all patient and fracture related factors. In section 3.1.4 the independent significance of each factor was ascertained in relation to early and late instability, and the risk of malunion. Late instability had been described by various authors, but was first characterised as a separate entity by Jenkins (1989). This study has confirmed that late instability occurred. It also confirmed that it was a separate entity, as the factors predictive of late instability were different from those predictive of early instability. The literature has identified factors significant association with anatomical outcome (section 1.4 and 4.1.2). However, these studies have never quantified the relative significance of these factors. Only one study has attempted to predict fracture outcome using data available at presentation, and the method of prediction required a computer (Adolphson et al, 1993). A literature search has failed to identify a study validating this predictive method.

This section of the thesis differed from the previous studies in another important way. The fractures were subdivided into two major groups according to fracture displacement. The literature supports the rationale for this division. Most of the literature looking at factors prognostic of outcome concentrates upon the effect of initial displacement: the more displaced, the more unstable. However, direct

evidence is available for the different behaviour of displaced and 'undisplaced' fractures. Abbaszadegan et al (1989) showed that undisplaced fractures maintained a good position until union even without immobilisation in a cast. Dias et al (1987) reported that a factor predictive of outcome was significant in undisplaced fractures, but not in fractures that had been reduced. The subdivision of fractures into displaced and minimally displaced will have increased the predictive accuracy of the formulae. The different behaviour (and therefore nature) of the two groups is confirmed by the difference in the predictive formulae for the two groups.

#### 4.1.4.1 Prediction of early instability in fractures minimally displaced at presentation

The results of univariate analysis of the prognostic factors echo the results of section 3.1.3. All factors are found to be of statistically significant prognostic value.

Following multiple logistic regression analysis (MLRA), only four factors retain their prognostic significance. As the older patient tends to be female and sustains their fracture through a simple fall or pedestrian road traffic accident, it is only the age of the patient that retains significance after MLRA. As the important component of the AO/ASIF classification (with reference to the outcome measures in this study) is the degree of comminution, then after MLRA only fracture comminution retains a high level of significance. The Frykman classification is significant as the fractures with concomitant ulnar styloid fracture are more unstable. Once fracture displacement is taken into account (dorsal angulation and ulnar variance), then the Frykman classification loses its significance. This may reflect a relationship between fracture displacement and disruption of the linkage between distal radius and ulna. Radial shift has no prognostic value following MLRA. This may be due to the intimate relationship between radiological measurements (section 1.3.2.1). However,

as ulnar variance and dorsal angulation are the measurements used to define displacement, radial shift is less likely to be of significance.

#### 4.1.4.2 Prediction of early instability in fractures displaced at presentation

Fracture displacement is important in the prediction of early instability: displaced fractures had a 43 percent risk, as opposed to 11 percent risk in minimally displaced fractures. As in section 3.1.3.1, most factors are of significance following univariate analysis. Again the sex of the patient and the mode of injury lose significance when patient age is taken into account. The Frykman classification is not of prognostic significance in either univariate or regression analysis. This may be because the fractures are all displaced at presentation, and the Frykman classification includes no reference to either metaphyseal comminution or displacement. Interestingly, dorsal angulation is of no significance following MLRA. The reason for this can be seen in the instability rates according to the dorsal angulation. The most unstable fractures are those with the least dorsal angulation. This again is due to the definition of displacement: fractures with less than 10 degrees of dorsal angulation by definition must have greater than 3mm of ulnar variance. Ulnar variance is far more difficult to correct than dorsal angulation (Schmalholz 1989). These fractures were also less likely to be considered as displaced in Accident & Emergency: only 31 percent of fractures with a dorsal angulation  $<0$  were manipulated. In addition, two fifths of the patients with dorsal angulation  $<-7$  degrees had excessive volar angulation at 7-10 days, and were therefore unstable volarly. The AO/ASIF type maintained a degree of significance following MLRA: type B fractures had significantly higher levels of early instability. This retained significance may be spurious, as there were only 15 fractures in this group. The patients' ability to do their own shopping also retained

independent prognostic significance. As discussed above (section 4.1.3.3) this is probably an indirect measure of physiological age, and thus has an effect on the risk of instability.

#### **4.1.4.3 Prediction of late instability in fractures minimally displaced at presentation**

As in the prediction of early instability in minimally displaced fractures, the risk of instability is low (22 percent), and all factors are of prognostic significance after univariate analysis. High levels of significance are retained by patient age and fracture comminution following MLRA. However, radiological measurements at presentation lose their significance following MLRA. This is because of the inclusion of radiological measurements at one week in this analysis: dorsal angulation and ulnar variance at one week are highly significant. The measurements at presentation are predictive of fracture displacement at 7-10 days (early instability), and therefore indirectly predict late instability.

#### **4.1.4.4 Prediction of late instability in fractures displaced at presentation**

Following MLRA, only patient age and fracture measurements at one week (dorsal angulation and ulnar variance) retain any prognostic significance. This is perhaps surprising because of the significance retained by fracture comminution in all other instability predictions. The rate of late instability in displaced fractures was over twice the rate of late instability recorded in minimally displaced fractures. The fact that the fractures were displaced at presentation may explain the loss of significance of fracture comminution.

#### **4.1.4.5 Prediction of malunion in fractures minimally displaced at presentation**

Most of the prognostic factors retained significance following MLRA. The malunion rate was 27 percent. These included the fracture classifications and radial shift. The retained significance of the AO/ASIF grouping was surprising, as the grouping is based upon the degree of metaphyseal comminution. The retained significance of the Frykman classification was due to the greater instability present with ulnar styloid fracture. This may be simply a reflection of the amount of energy involved in the injury.

#### **4.1.4.6 Prediction of malunion in fractures displaced at presentation**

Here the independently significant prognostic factors were patient age, premorbid level of function, fracture comminution, and the ulnar variance measured at presentation. The malunion rate in displaced fractures (60 percent) was more than twice that in minimally displaced fractures, reiterating the significance of fracture displacement as a prognostic factor. The dorsal angulation again is of no prognostic significance independently.

#### **4.1.5 Prediction of carpal malalignment**

The prediction of carpal malalignment or collapse resembled the prediction of fracture instability in that age was a highly significant independent predictor. Other predictors of fracture displacement also had significance here, namely fracture comminution and patient premorbid level of function. The degree of carpal malalignment was dependent upon the degree of dorsal angulation. Thus factors that played a role in dorsal angulation retain significance. These include the dorsal angulation at presentation, the AO/ASIF type, and the Frykman classification. The



AO/ASIF type B fractures were protective against carpal malalignment. In the common type B fractures (B1.1), the lunate facet is not involved in the fracture therefore the angular relationship of radial axis, lunate, and capitate is undisturbed. The Frykman classification retained prognostic significance as the presence of the ulnar styloid fracture reduced stability of the radial fracture, presumably as a reflection of the energy involved in the injury. Here ulnar variance does not predict carpal malalignment: pure ulnar shortening does not produce malalignment, and the metaphyseal damage implied by severe radial shortening is better described by fracture metaphyseal comminution.

### **4.2.1 Prospective validation of the prediction of fracture instability and carpal collapse**

According to the epidemiological data approximately 240 patients should have been recruited into this part of the study. Recruitment was dependent upon patients being local and willing to participate in this part of the study, which required careful follow-up in the Edinburgh Trauma Unit. In addition fractures that required immediate surgical intervention were excluded. The numbers in this section of the study were therefore limited by inclusion criteria, patient willingness to participate, and time constraints. As the aim of this section was to assess the predictive accuracy of the formulae in the individual fracture and not to compare two methods of prediction, a power calculation of minimum sample size was not deemed necessary. The demographics of the sample were comparable to the epidemiological study sample. The age and sex distribution was different only in that the male population was significantly older (mean age of 51.2 years versus 42.5 years). The population had a higher premorbid level of function, probably as a result of the inclusion criterion relating to consent. The proportion of fractures caused by a simple fall was reduced by 8 percent. This may have been due to the time of year, and the better levels of premorbid function. The distribution of fractures according to the AO/ASIF classification was broadly similar to the epidemiological study distribution. The same six AO/ASIF fractures constituted nine tenths of the fractures. However, the C3.2 fractures replaced the C1.2 fractures as the fourth commonest. Again, as the study was looking at the predictive accuracy of the formulae in the individual fracture, it

was not essential that the study population was representative of the fracture population as a whole.

#### **4.2.1.1 Minimally displaced fractures**

The instability and malunion rates in the minimally displaced fractures were comparable to those in section 3.1.3. Fortunately, the most clinically significant prediction was also the most accurate. The formula was able to correctly predict malunion in 12/14 cases (sensitivity 85.7 percent), and to correctly predict the absence of malunion in 32/44 cases (specificity 72 percent). There was no significant difference to be found between the true positive and the false negative predictions, however this was almost certainly due to the small numbers involved. It is therefore not possible to say why the formula failed in the prediction of malunion. However, there were sufficient numbers to identify the failure in specificity of the formula. The false positive predictions (12/44) were in patients who were older, and in fractures in which comminution was more often present. In these patients, the weighting of these factors in the predictive formula was inappropriate.

#### **4.2.1.2 Displaced fractures**

The rate of early instability was comparable to that found in section 3.1.3, however the rate of malunion was greater at 74 percent versus 60 percent. Similar predictive accuracy was found for the formulae for displaced fractures. The formula for prediction of malunion was less sensitive but more specific than the formula for minimally displaced fractures. The specificity of prediction of early instability was reduced because of the increased ulnar variance and patient age in stable fractures. Unfortunately the numbers of fractures that did not malunion were so small as to

preclude identification of significant differences in the true negatives and false positives. The prediction of malunion failed in 19/60 patients. These patients were significantly younger and less frequently had fracture comminution. On this occasion it is the sensitivity of prediction of malunion that is affected by the formula weighting of these two factors.

#### **4.2.1.3 Carpal malalignment**

A similar predictive accuracy is found in the prediction of carpal malalignment: sensitivity 70.2 percent, specificity 67.1 percent. The failings of the sensitivity of the formula were due to patient age and fracture comminution. However age, dorsal angulation, pre-morbid level of function, and the presence of dorsal comminution were all significantly different between true negatives and false positives. The value of predicting carpal malalignment is questionable, despite the findings of McQueen et al (1996) suggesting that carpal malalignment is most closely linked to functional outcome. Overall, the disagreement between the predictions of carpal malalignment and malunion was not useful. The disagreement would have correctly influenced the treatment decision less often when the prediction of malunion was incorrect, than it would have incorrectly influenced the treatment decision when the prediction of malunion was correct.

#### **4.2.2 Prediction of fracture instability: a comparison of the predictive formulae and clinical experience**

This section of the study could be criticised as the fractures used had been part of the original database used in the calculation of the predictive formulae. However, this section was not to test the predictive accuracy of the formula, but to test the ease and

reproducibility of its use. The ease of use was tested by the difference between the outcome prediction using the data from the original database, and the outcome generated by the clinicians. The reproducibility was tested by the difference in sensitivity and specificity of each clinician from the mean.

#### 4.2.2.1 Prediction of malunion using clinical experience

The clinicians' predictive accuracy was little better than chance. It was interesting that the most sensitive predictor was an Orthopaedic Consultant with a specialist interest in distal radial fracture. However, the most sensitive predictor was also the least specific predictor: the greater the experience of the clinician, the more likely the fracture was deemed unstable. This trend was seen in the other clinicians (although the difference was not significant): Accident & Emergency Staff tended to be more specific, and Orthopaedic Staff more sensitive.

The agreement between the clinicians was seen to be poor. The Orthopaedic Staff only agreed on the outcome in 10 fractures, and were only correct on 5 occasions.

The Accident & Emergency Staff agreed more often (16 fractures), but were correct in only 4 cases. This difference in opinion was reiterated in spread of the sensitivity and specificity seen in scattergram 3.2.2.1a.

These findings suggested that clinical experience was a poor tool in predicting outcome. Not only was the accuracy of prediction poor, but also there was very little agreement between staff as to outcome. The most experienced clinician in the study has compensated for the lack of a good predictive tool by reducing specificity of prediction. This must be due to a conviction that the complications of over-treatment were preferable to the complications of under-treatment.

#### 4.2.2.2 Importance of predictive factors

From the results of this survey, it would appear that the appearance of the fracture on the X-ray was the overriding focus of attention in the assessment of instability. With fracture comminution considered the most important predictor, the age of the patient is considered of equal importance to the mode of injury. Most interestingly, the Accident & Emergency Staff felt that bone quality was their most important factor in predicting outcome. This may well be the case, but unfortunately, there is no reliable cheap and rapid method of assessing bone quality in the Accident & Emergency setting. The assessment of premorbid function (the ability/inability to do the shopping) may be the best measure of this factor, as it is a rough indicator of physiological age.

#### 4.2.2.3 Prediction of malunion using the formula

The patients and fractures in this section of the study had been used in the initial calculation of the predictive formulae (section 3.1.3). Therefore the sensitivity and specificity of prediction were high at 91.7 and 93.75 percent respectively. Using the formula, the sensitivity of the clinicians increased to 89.9 percent, and the specificity to 80.5 percent. On this occasion, the Orthopaedic Staff were more specific, and the Accident & Emergency Staff were more sensitive in prediction. As important as the increase in predictive accuracy was the decrease in inter-observer variability. The value of the predictive formula would have been significantly reduced if despite improving predictive accuracy, there had been no improvement in agreement in fracture outcome. In that situation, prediction would be dependent upon the clinician making the prediction. The inter-observer variability had a non-normal distribution. This was because of the yes/no decision with regards to the presence of dorsal

comminution, which altered the percentage risk of malunion by approximately 6 percent. Other variation in the percentage risk was due to the normal distribution of measurement of ulnar variance. Unfortunately there will always be disagreement in the measurement of any entity, be it qualitative or quantitative.

If it were possible to express the risk of malunion purely as a percentage, then the inter-observer variation would probably be acceptable. However, in the clinical setting, this percentage must be converted into a yes/no decision as to the development of malunion: the choice of treatment being dependent upon this decision. The value of expressing the risk of malunion as a percentage is that it can be tailored to the philosophy of the clinician. The optimum cut-off percentages have been calculated from the intersection of sensitivity and specificity curves, i.e. where both sensitivity and specificity are maximal. A reduction in the cut-off percentage will make the prediction more sensitive, reducing false negative numbers, and thus the numbers of patients with missed malunion. It will however increase the numbers of false positives, and thus the number of complications generated by operative treatment. An increase in the cut-off percentage will have the opposite effect: reducing the rate of complications from over-treatment, but increasing the risk of missed malunion.

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## **5. CONCLUSION**



The treatment of fractures has evolved considerably since data collection began for the first section of the project. A reliable method for the treatment of unstable fractures was reported in 1998 (McQueen), and was found to be effective in the elderly patient. The complications of this treatment were related to the use of an external fixator. Internal stabilisation of the fracture could reduce the risk of these complications. Internal stabilisation could be achieved in two ways. Firstly the stabilisation of the fracture could be promoted thereby reducing the duration of external fixation, and by extension, the risk of complications. Both structural grafts and osseo-inductive agents (such as bone morphogenic proteins) may provide the answer. Secondly, the fracture could be stabilized with an internal fixation device. Previous internal fixation devices had high levels of complications and were recommended for the fixation of comminuted high energy injuries in the young patient. With the advent of locking internal fixation devices, a volarly applied device may avoid the complications of the other devices, and has been shown to provide the appropriate level of stability even in the elderly patient (Orbay and Fernandez, 2004). However, the purpose of this project was not the treatment of the fracture, rather the decision making in the approach to treatment. The extent and character of the problem posed by distal radius fracture has been defined in the Lothian Region. The study has shown that the burden of treatment lies with the elderly, mostly female patient, who sustains a low energy injury. It does not lie with the young male sustaining a higher energy injury. The typical patient has a displaced fracture, and has a high level of function prior to the fall: the fracture therefore should be treated in some way to maximise functional outcome. Unfortunately this typical patient is likely to have an unstable fracture. Under-treatment should be unacceptable as we

have shown most of these patients have a high functional demand. It should also be unacceptable because of the cost to the community if the patient subsequently requires support due to functional loss. Over-treatment is unacceptable, because of the number of patients suffering complications, and because of the cost of operative treatment of this extremely large group of patients. The results in Section 3.2.1 can give us an indication of the balance of under-diagnosis and over-treatment. If used at presentation to aid treatment planning, the predictive formula would have affected the treatment of the 81 patients with displaced fractures in the following ways:

- ineffective closed reduction avoided in 41 patients
- 7-10 day delay in diagnosis of early instability avoided in 27 patients
- malunion through late instability avoided in 14 patients
- primary fixation of fractures with false positive predictions of malunion in 10 patients.

By altering the cut-off percentage, the sensitivity and specificity of prediction can also be altered to increase detection of instability, or reduce the risk of fixing stable fractures.

The study has shown that currently our ability to treat these patients is poor. Firstly, the treatment protocol is fundamentally flawed. The patients treated in Accident and Emergency with manipulative reduction typically have unstable fractures. These are precisely the patients in whom manipulative reduction is destined to fail. The protocol also ignores late instability, as the last chance for definitive fracture stabilisation is at 7-10 days. This study has shown that the rate of late instability exceeds the rate of early instability, further undermining the logic of decision-making at 7-10 days. Even if it were decided to institute definitive treatment at presentation based upon an assessment of fracture instability, our ability to predict

anatomical outcome has been shown to be little better than chance. Having a reliable definitive method of treatment is of little value if it cannot be decided in whom it is required.

The study has generated formulae predictive of early and late instability and the risk of malunion in displaced and minimally displaced fractures. It has also generated a formula for predicting carpal malalignment. In practice the important prediction is the risk of malunion in displaced fractures. This is for several reasons:

1. The outcome of interest clinically is malunion, rather than whether the fracture has early or late instability
2. If a patient has a displaced fracture (and functional requirements demand it), then some form of treatment is necessary. The formula will help in making the correct choice
3. It will be difficult to persuade a patient to undergo immediate surgical stabilisation of their fracture based upon the results of a mathematical calculation, if the fracture is minimally displaced at presentation. It will also be difficult to persuade the Orthopaedic community to adopt such an approach.
4. The prediction of carpal malalignment as a separate entity is of questionable value. Firstly, carpal collapse is unlikely to occur if an anatomical reduction has been achieved and maintained until union. Secondly, section 3.2.1 demonstrated that the prediction of carpal malalignment in addition to the prediction of malunion is counterproductive.

The tabulated format for the prediction of malunion in displaced fractures is seen in figure 5a. The formula has a similar accuracy of prediction to the computer-based prediction researched by Adolphson et al (1994). However the hardware required is

**Figure 5a: Risk of malunion (%)**

**Criteria:** Displaced fracture: dorsal angulation > 10 degrees  
Patient able to do shopping without assistance

**no dorsal comminution present**

**dorsal comminution present**

ulnar variance (mm)

ulnar variance (mm)

	-2	-1	0	1	2	3	4	5	6	7	8	9	10	-2	-1	0	1	2	3	4	5	6	7	8	9	10
<b>45</b>	30	32	34	36	38	41	43	45	47	50	52	54	56	43	47	47	47	47	47	47	47	47	47	47	47	
<b>46</b>	31	33	35	37	39	42	44	46	48	50	53	55	57	44	48	48	48	48	48	48	48	48	48	48	48	
<b>47</b>	32	34	36	38	40	43	45	47	49	51	54	56	58	45	49	49	49	49	49	49	49	49	49	49	49	
<b>48</b>	33	35	37	39	41	44	46	48	50	52	55	57	59	46	50	50	50	50	50	50	50	50	50	50	50	
<b>49</b>	34	36	38	40	42	45	47	49	51	53	56	58	60	47	51	51	51	51	51	51	51	51	51	51	51	
<b>50</b>	35	37	39	41	43	46	48	50	52	54	57	59	61	48	52	52	52	52	52	52	52	52	52	52	52	
<b>51</b>	36	38	40	42	44	47	49	51	53	55	58	60	62	49	53	53	53	53	53	53	53	53	53	53	53	
<b>52</b>	37	39	41	43	45	48	50	52	54	56	59	61	63	50	54	54	54	54	54	54	54	54	54	54	54	
<b>53</b>	38	40	42	44	46	49	51	53	55	57	60	62	64	50	55	55	55	55	55	55	55	55	55	55	55	
<b>54</b>	38	41	43	45	47	50	52	54	56	58	61	63	65	51	56	56	56	56	56	56	56	56	56	56	56	
<b>55</b>	39	42	44	46	48	50	53	55	57	59	62	64	66	52	57	57	57	57	57	57	57	57	57	57	57	
<b>56</b>	40	43	45	47	49	51	54	56	58	60	62	65	67	53	58	58	58	58	58	58	58	58	58	58	58	
<b>57</b>	41	44	46	48	50	52	55	57	59	61	63	65	67	54	59	59	59	59	59	59	59	59	59	59	59	
<b>58</b>	42	45	47	49	51	53	56	58	60	62	64	66	68	55	60	60	60	60	60	60	60	60	60	60	60	
<b>59</b>	43	46	48	50	52	54	57	59	61	63	65	67	69	56	61	61	61	61	61	61	61	61	61	61	61	
<b>60</b>	44	47	49	51	53	55	58	60	62	64	66	68	70	57	62	62	62	62	62	62	62	62	62	62	62	
<b>61</b>	45	48	50	52	54	56	59	61	63	65	67	69	71	58	63	63	63	63	63	63	63	63	63	63	63	
<b>62</b>	46	49	51	53	55	57	60	62	64	66	68	70	72	59	64	64	64	64	64	64	64	64	64	64	64	
<b>63</b>	47	50	52	54	56	58	61	63	65	67	69	71	73	60	65	65	65	65	65	65	65	65	65	65	65	
<b>a</b>	<b>64</b>	48	50	53	55	57	59	62	64	66	68	70	72	73	61	65	65	66	66	66	66	66	66	66	66	
<b>g</b>	<b>65</b>	49	51	54	56	58	60	62	65	67	69	70	72	74	62	66	66	66	66	66	66	67	67	67	67	
<b>e</b>	<b>66</b>	50	52	55	57	59	61	63	65	67	69	71	73	75	63	67	67	67	67	67	67	67	68	68	68	
<b>67</b>	51	53	56	58	60	62	64	66	68	70	72	74	76	64	68	68	68	68	68	68	68	68	68	68	69	
<b>68</b>	52	54	57	59	61	63	65	67	69	71	73	75	76	65	69	69	69	69	69	69	69	69	69	69	69	
<b>69</b>	53	55	58	60	62	64	66	68	70	72	74	75	77	66	70	70	70	70	70	70	70	70	70	70	70	
<b>70</b>	54	56	59	61	63	65	67	69	71	73	74	76	78	67	71	71	71	71	71	71	71	71	71	71	71	
<b>71</b>	55	57	60	62	64	66	68	70	72	73	75	77	78	68	71	72	72	72	72	72	72	72	72	72	72	
<b>72</b>	56	58	61	63	65	67	69	71	73	74	76	78	79	69	72	72	72	72	72	72	72	73	73	73	73	
<b>73</b>	57	59	62	64	66	68	70	72	73	75	77	78	80	69	73	73	73	73	73	73	73	73	73	73	73	
<b>74</b>	58	60	62	65	67	69	70	72	74	76	77	79	80	70	74	74	74	74	74	74	74	74	74	74	74	
<b>75</b>	59	61	63	65	67	69	71	73	75	76	78	80	81	71	75	75	75	75	75	75	75	75	75	75	75	
<b>76</b>	60	62	64	66	68	70	72	74	76	77	79	80	82	72	75	75	75	75	75	75	76	76	76	76	76	
<b>77</b>	61	63	65	67	69	71	73	75	76	78	79	81	82	73	76	76	76	76	76	76	76	76	76	76	76	
<b>78</b>	62	64	66	68	70	72	74	75	77	79	80	81	83	73	77	77	77	77	77	77	77	77	77	77	77	
<b>79</b>	63	65	67	69	71	73	74	76	78	79	81	82	83	74	78	78	78	78	78	78	78	78	78	78	78	
<b>80</b>	64	66	68	70	72	73	75	77	78	80	81	83	84	75	78	78	78	78	78	78	78	78	78	79	79	
<b>81</b>	65	67	69	71	73	74	76	78	79	81	82	83	84	76	79	79	79	79	79	79	79	79	79	79	79	
<b>82</b>	66	68	70	72	73	75	77	78	80	81	82	84	85	76	80	80	80	80	80	80	80	80	80	80	80	
<b>83</b>	67	69	70	72	74	76	77	79	80	82	83	84	85	77	80	80	80	80	80	80	80	80	80	80	80	
<b>84</b>	67	69	71	73	75	76	78	80	81	82	84	85	86	78	81	81	81	81	81	81	81	81	81	81	81	
<b>85</b>	68	70	72	74	76	77	79	80	82	83	84	85	86	79	81	81	81	82	82	82	82	82	82	82	82	
<b>86</b>	69	71	73	75	76	78	79	81	82	83	85	86	87	79	82	82	82	82	82	82	82	82	82	82	82	
<b>87</b>	70	72	74	75	77	79	80	81	83	84	85	86	87	80	83	83	83	83	83	83	83	83	83	83	83	
<b>88</b>	71	73	74	76	78	79	81	82	83	85	86	87	88	81	83	83	83	83	83	83	83	83	83	83	83	
<b>89</b>	72	73	75	77	78	80	81	83	84	85	86	87	88	81	84	84	84	84	84	84	84	84	84	84	84	
<b>90</b>	73	74	76	78	79	81	82	83	84	86	87	88	89	82	84	84	84	84	84	84	84	84	84	84	85	
<b>91</b>	73	75	77	78	80	81	82	84	85	86	87	88	89	82	85	85	85	85	85	85	85	85	85	85	85	
<b>92</b>	74	76	77	79	80	82	83	84	85	87	88	88	89	83	85	85	85	85	85	85	85	85	85	86	86	
<b>93</b>	75	76	78	80	81	82	84	85	86	87	88	89	90	83	86	86	86	86	86	86	86	86	86	86	86	
<b>94</b>	76	77	79	80	82	83	84	85	86	87	88	89	90	84	86	86	86	86	86	86	86	86	86	86	86	
<b>95</b>	76	78	79	81	82	83	85	86	87	88	89	90	90	85	87	87	87	87	87	87	87	87	87	87	87	

considerably less expensive: no computer is required. The use of the formula requires asking the patient's age and whether they are able to do their own shopping, the measurement of ulnar variance and the categorisation of metaphyseal comminution. The radiological parameters are thus open to observer error. However observer error was present when the measurements were made for the original database, and when the validation studies were performed. This error is therefore included in the calculation of the formula, and in the formula validation.

Study Section 2 has demonstrated that the predictive formula for malunion in displaced fractures is correct in approximately 7/10 fractures. The study has also shown that the prediction is easy to make, and that clinicians using the predictive formula agree upon fracture outcome. With these results it would seem reasonable therefore to base a fracture treatment protocol around the fracture outcome prediction. Differences in fracture behaviour were identified according to fracture displacement. Thus the formulae predictive of outcome for displaced and minimally displaced fractures were different. Further stratification of the dataset may have improved predictive accuracy. For example, the factor consistently producing incorrect prediction (section 3.2.1) was patient age. Thus predictive formulae for patients with displaced fractures above and below the age of 50 years could be generated. Attempts to improve predictive accuracy must be weighed against making the prediction tables too large and complex. A method of fracture instability prediction in the busy Accident & Emergency setting must be quick and easy, otherwise it will not be used.

Finally, this study has demonstrated the value of the method. The literature has previously identified all the factors of importance in predicting anatomical outcome



in distal radius fracture. However the risk of malunion with respect to these factors has not been quantified. Multiple logistic regression analysis has:

- identified independently significant predictors of outcome
- produced a mathematical method to quantify the risk of an adverse outcome

The accuracy of the formula is not perfect, however this study has shown it to improve upon current practice with respect to inter-observer variation and observer accuracy. Therefore, this method of statistical analysis may prove to be a useful tool in answering similar clinical questions: beneficial interventions can be employed in a timely fashion when the outcome of the condition can be predicted.

## **References**

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