Outcome and Management of Acute Dorsally Displaced Fractures of the Distal Radius

By

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Table of contents

List of tables

List of figures

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Declarations

This thesis is submitted to the University of Warwick in support of my application for the degree of Doctor of Philosophy. It has been composed by myself, with the exception of the randomisation sequence generated by Nicholas Parsons (statistician) in chapter 4, the acquisition of the patient reported outcome measures supplied by the DRAFFT team in chapters 5 and 6 and the collection of physical outcome measure data by Miss Hayley Rice and Miss Kate Denninson. This work has not been submitted in the application for any other degree.

The following research paper has been published as a result of the work contained in this thesis:
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Abbreviations

CI	Confidence Interval
CONSORT	Consolidated Standards of Reporting Trials
CP	Caroline Plant
CRF	Clinical Reporting Forms
CRPS	Complex Regional Pain Syndrome
DASH	Disability of the Arm, Shoulder and Hand
DRAFFT	Distal Radius Fracture Fixation Trial
EPL	Extensor Pollicis Longus
EMBASE	The Excerpta Medica database
FG	Frances Griffiths
FRCS	Fellowship Royal College of Surgeons
GCP	Good Clinical Practice
HJ	Hannah James
HR	Hayley Rice
HTA	Health Technology Assessment
ICC	Interclass Correlation Coefficient
ISRCTN	International Standard Randomised Controlled Trial Number
KD	Kate Denninson
MEDLINE	Database on biomedicine as they relate to health care
MHQ	Michigan Hand Questionnaire
MVC	Maximum Voluntary Contraction
NICE	National Institute of Clinical Excellence
OST	Orthopaedic Specialist Trainee
PH1	Physiotherapist 1
PH2	Physiotherapist 2
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses
PROM	Patient Reported Outcome Measure
PRWE	Patient Rated Wrist Evaluation
RCT	Randomised Controlled Trial
SD	Standard Deviation
SF36	Short form 36
SMD	Standardised Mean Difference
SRM	Standardised Response Mean
TFCC	Triangular Fibrocartilage Complex
UHCW	University Hospital Coventry and Warwickshire
UK	United Kingdom
US/ USA	United States of America
VAS	Visual Analogue Scale

Abstract

Background

Fractures of the distal radius are a common injury, affecting younger patients typically through sporting and road traffic accidents, and older osteoporotic patients often due to falls from a standing height. The potential consequences of these fractures are rare but can be catastrophic, with risk of lasting impairment to the patient.

Objectives

This thesis aimed to examine (1) how surgeons decide which patients with a dorsally displaced distal radius fracture need an operation, (2) what is the evidence basis for the two most commonly performed operations for patients with this fracture in the UK, (3) Are electronic and manual goniometers and dynamometers able to reliably assess wrist function in patients and healthy volunteers, (4) Does the patients' functional outcome correspond with their radiological outcome, and (5) what is the long-term outcome of these patients.

Methods

A number of research methods were employed to achieve these objectives.
A mixed methods approach was deployed, involving observations of nineteen patient/ surgeon consultations followed by mini interviews with the consulting surgeons, to gain an insight into which patients with a dorsally displaced distal radius fracture receive an operation in practice. In-depth interviews were undertaken with 14 Orthopaedic surgeons to explore the patient/surgeon/context related factors that contribute to their decision-making.

A systematic search of the literature was performed to identify and critically appraise randomised controlled trials comparing the functional outcome of patients treated with either volar locking plate or Kirschner wire fixation.

A reliability study was then conducted to assess the intra-observer and inter-observer reliability with twenty five healthy volunteers, and the inter-instrument reliability for twenty five patients with a dorsally displaced distal radius fracture, for both electronic and manual dynometry and goniometry of the wrist and forearm.

A correlation study was then performed to investigate the association between functional outcome data (grip strength, pinch strength, ROM, DASH, PRWE and EQ5D scores) at 3, 6 and 12 months post-fixation, with the radiological outcome at 6 weeks and 12 months post-fixation.

Lastly, a qualitative interview study with the integration of quantitative findings was undertaken to determine the long-term consequences of these fractures. In-depth interviews were conducted with 14 patients at 1-3 years following fixation of a dorsally displaced fracture of the distal radius, to determine their perspectives of their recovery. Data from the patient reported and physical outcome measures at 12 months post-fixation for these patients was then analysed alongside the interview findings to determine the long-term functional outcome and the processes involved in the patients recovery.

Results

The main findings from this thesis are as follows:

Orthopaedic surgeons' decision-making

The decision-making of orthopaedic surgeons was shown to vary with respect to factors relating to the patient, the surgeon and to a lesser extent the context within which the decisions were made. Despite this disparity, the surgeons' decision-making shared a number of common processes including: the detection and recognition of the fracture configuration, the acquisition of patient factors, the assessment of the anaesthetic risk, the stability of the fracture and the density of the affected bone. Differences in surgeons' thresholds at each stage of formulating their decision may account for variations in their decisions to operate.

Systematic review of operative fixation

The search strategy generated 812 citations of these only six studies including 747 patients met the eligibility criteria. The functional outcome of patients was assessed with the DASH, PRWE, EQ5D scores and physical measures of function. At 12 months, there was a small treatment effect in favour of the volar locking plate fixation, but it is unlikely to be clinical important.

Reliability of electronic and manual goniometry and dynamometry

The electronic and manual dynamometers demonstrated excellent reliability for the assessment of the pinch and grip strength. In contrast, the reliability ranged from poor to acceptable for both the electronic and manual goniometers.

Correlation of functional and radiological outcomes

Weak correlations were detected between the physical and patient reported functional outcome measures, and the radiological outcomes during the 12 months post-operative fixation.

Patients' perspectives of their long-term outcome

Patients continued to have DASH and PRWE scores above their baseline scores at 12 months after their operation. These problems persisted for up to 3 years for some patients. During their recoveries, a number of patients adopted adaptive and avoidance strategies to enable them to return to their previous level of function.

Conclusions

The findings of this thesis suggest that surgeons' decision-making is a complex process influenced by a number of factors that may or may not be directly relevant to the patient. Once the surgeon has decided upon operative management, the patients' fracture can be fixed with either Kirschner wires or a volar locking plate. The assessment of their outcome can then be measured with patient reported and physical measures of function, with most patients demonstrating a significant improvement in function by 12 months after their operation. The patients' baseline function may take longer to return, and for some patients they may continue to have a deficit.

Research Training

I undertook the following research training in order to gain the necessary skills required to complete the work presented in this thesis:

University of Warwick

- Research student skills programme:
  - Academic writing
  - Comprehensive literature searching
- Transferable skills in Science
  - Decision making and leadership
  - Team development and networking
- Integrated Clinical Academic Training Programme
- Good Clinical Practice
- Comparative and qualitative research methods in healthcare

University of Liverpool

- Statistical Issues in design and analysis of research projects

1. Introduction

Declarations

None

Preface

In this thesis I provide an insight into the journey of patients who have undergone an operation for a dorsally displaced distal radius fracture, with each chapter investigating an element of that journey. I begin by considering how surgeons decide who should receive operative management, and then proceed by appraising the evidence available to them for the two predominate operations undertaken in the UK. In the middle chapters, I consider how patients can be monitored in the post-operative period, and the relationship between the radiological and functional outcomes, which in turn is an important consideration for surgeons' choice of operation. In the final chapter, I address patients' perspectives of their recovery, providing an insight into both the longevity of their symptoms and the processes by which they recover.

Although, non-operative management options such as closed reduction casting and splinting are important and commonly used for the management of these patients, as an orthopaedic surgical trainee I am primarily interested in the journey of patients upon whom I will operate. Therefore, I have focused throughout this thesis upon those undergoing operative fixation, mainly with either Kirschner wire or plate fixation.

In order, to achieve the aims of this thesis, I have adopted a number of research methodologies. This has allowed me to gain numerous research skills in new disciplines, as well as exploring this subject in a way that has not been considered previously.

Introduction

In this introductory section, I will provide a narrative of the main concepts that will arise within this thesis. Broadly these will include:

- The anatomy and kinematics of the wrist
- The epidemiology and aetiology of distal radius fractures
- The processes involved in fracture healing
- The management and complications associated with a distal radius fracture
- Clinical decision making
- Measures used to assess wrist function
- A discussion of the research methods used within this thesis
- Thesis aims and objectives

By arming the reader with this knowledge, it is hoped they will be able to circumnavigate through the varied studies I have undertaken as part of this thesis, and gain a perspective of the patient's journey following a fracture of the distal radius.

Anatomy and biomechanics of the wrist

The wrist joint is a synovial joint comprising of an articulation between the distal radius and the proximal row of carpal bones, surrounded by a synovial membrane(1).

Articular Surface

The proximal articular surface of the radio-carpal joint is comprised of the elliptical concave surface of the distal radius, and the triangular fibrocartilage complex(2). The biconcave distal radius surface is lined by the hyaline cartilage, with an average radial inclination of 21 degrees and palmar tilt of 11 degrees(3).

The triangular fibrocartilage complex (TFCC) consists of the meniscal homologue, the ulnocarpal ligament, the extensor carpi ulnaris tendon and the articular disc. It expands from the base of the ulnar styloid process to the inferomedial border of the radial sigmoid notch to extend the ulnar side of the proximal articular surface (3, 4). The outer fibres blend with the volar and dorsal radio-ulnar ligaments on the ulna aspect of the wrist(4). The TFCC acts as the main stabiliser of the radioulnar joint and a cushion for the proximal carpus allowing the axial loading to be transmitted across both the radius and the ulna(5). In the absence of the TFCC the radial load increases(5).

The distal articular surface is comprised of the proximal row of the carpal bones; the scaphoid, lunate and triquetral bones held together by the intercarpal and interosseous ligaments to form a convex surface, allowing the proximal row to function as an intercalated segment(6).

The radio-carpal and radio-ulnar joints are surrounded by a fibrous capsule lined by synovial membrane (6). The synovial membrane attaches at the margins of the articular surfaces, with numerous synovial folds(6).

Ligaments of the wrist

The osseous congruity of the radio-carpal joint provides little stability, hence the joint is instead stabilised by ligaments responsible for guiding and constraining the complex movements of the carpal bones in relation to the radius and ulna(7). These ligaments can be classified as either extrinsic or intrinsic(8, 9).

The extrinsic ligaments arise from the distal radius and ulna crossing the carpal bones, and include the dorsal radio-carpal, the palmar radio-carpal and the palmar radio-ulnar ligaments. There are no ligaments between the ulna and the carpal bones on the dorsal side of the wrist. The dorsal radio-carpal ligament runs in a distal and ulna direction from Lister's tubercle to the triquetrum and lunate, to resist the carpus sliding along the distal radius in a volar and ulnar direction(9, 10). This ligaments allows the hand to follow in the same direction of the wrist in pronation(6) (11).

The palmar extrinsic ligaments are a stronger group of ligaments, attaching onto both rows of carpal bones in the form of two v-shaped ligamentous complexes(12). The palmar radio-carpal ligaments run from the lateral portion of the distal radius, articulating with the scaphoid, capitate and lunate, to give the radioscaphoid, the radioscaphoid-capitate, and the long and short radiolunate ligaments(7, 9). The palmar ulnocarpal ligaments include the superficial ulnar capitate ligaments which runs obliquely from the base of the ulnar styloid to the capitate, forming part of the distal 'V' complex with the radioscaphoid-capitate ligament(9). The ulnar triquetrum and ulnar lunate ligaments arise from the triangular fibrocartilage complex running vertically to insert into the lunate and triquetrum(12). The proximal 'V' complex is formed from the combined ulnocarpal and radiolunate ligaments(12). The main function of the palmar ligaments is the control of the movement of the carpus in the extremes of wrist motion whilst enabling the hand to follow in supination(6, 7, 11).

The intrinsic ligaments originate and insert into the carpal bones(11). These include the scapholunate, lunate triquetrum and distal carpal row interosseous ligaments and the midcarpal ligaments, which connect the carpal bones within each row, the distal row held rigid whilst the proximal row held looser allowing some intercarpal movement (7, 11, 12).

Blood Supply

The wrist joint is supplied by the dorsal and palmar carpal branches of the radial and ulnar arteries that anastomose to provide collateral circulation to the wrist(2).

The palmar carpal branch of the ulnar artery runs across the wrist, deep to the tendon of flexor digitorum profundus to join with the corresponding palmar carpal branch of the radial artery arising from the distal border of pronator quadratus(2).

The ulnar and radial contributories to the dorsal carpal branch arise from the pisiform medially and at the level of radiocarpal joint laterally, penetrating the radiocarpal ligament to anastamose deep to the extensor tendons(13).

Innervation

Branches of the median, radial and ulna nerves innervate the wrist.

Median nerve

The median nerves supplies the majority of the anterior compartment, except for the flexor carpi ulnaris and medial half of flexor digitorum profundus(14). It descends from the cubital fossa between the two heads of pronator teres to give off its largest branch; the anterior interosseous nerve. The median nerve then continues in a linear course distally giving off a palmar branch and then enters the palm through the carpal tunnel(6). After leaving the pronator teres the anterior interosseous nerve then passes along the anterior surface of the interosseous membrane to innerve the deep layer of the anterior compartment; flexor pollicis longus, the lateral half of flexor digitorum profundus and pronator quadratus(15). It terminates as articular branches to the distal radiocarpal, radioulnar and carpal joints(6, 16).

Radial nerve

The radial nerve is responsible for the innervation of the posterior compartment of the forearm(6). It enters the forearm via the cubital fossa and innervates the extensor carpi radialis longus and brachioradialis muscles before dividing into the deep and superficial branches. The deep branch innervates the extensor carpi radialis brevis and then passes through the two heads of the supinator muscle to becomes the posterior interosseous nerve(6, 14). It then emerges to lie between the deep and superficial layers to supply the remaining muscles of the posterior compartment and terminates as an articular branch to the wrist(6, 16).

Ulnar nerve

The ulnar nerve passes down the medial border of the forearm lying between flexor carpi ulnaris and flexor digitorum profundus giving rise to the muscular and cutaneous branches in Guyon's canal(6). The muscular branch innervates both the flexor carpi ulnaris and the medial half of flexor digitorum profundus, as well as adductor pollicis, the deep head of flexor pollicis brevis, the interossei 3^{rd} and 4^{th} lumbricals and the hypothenar muscles in the hand(14, 15). The cutaneous branches supplying sensation to the dorsomedial aspect of the wrist and hand, palm and dorsal aspect of the medial one and a half fingers(14, 17).

Wrist kinematics

The wrist joint is comprised of the radiocarpal and midcarpal joints, offering a unique combination of movements; flexion/extension, radial/ulnar deviation and circumduction, the latter being a combination of flexion/extension and radial.ulna deviation(18). Various models have been proposed to describe the kinematics of these joints during wrist motion from in vivo and in vitro studies(18, 19). The earliest and most prominent are the fixed-row and column models(20).

The 'fixed-row' model considers there to be a proximal (lunate and triquetrum) and a distal row of carpus (trapezium, trapezoid, capitate, and hamate), with the scaphoid acting as a connector between the two rows(20, 21). Flexion and extension occurs between the two rows, with ulnar and radial deviation at the articulation of the scaphoid and radius(18, 20). The column theory provides an alternative description of the carpus as three columns; the radial column (scaphoid, trapezium and trapezoid), the central column (capitate, hamate and lunate), and the ulnar column (triquetrum). Flexion and extension occur through the articulations of the central column, and radial/ ulnar deviation via the rotation of the scaphoid and triquetrum around the central column(20). Later studies came to the conclusion that individuals may have either a column type or row type wrist, dependent upon the morphology of the carpal bones or the laxity of the joint capsule and ligaments(22, 23). For example, Garcia-Elias *et al.* found greater ligamentous laxity promoted a greater amount of scaphoid extension in ulnar deviation, hence exhibited a column-type wrist(23). These theories were predominately based upon 2D planar studies, which infer the 3D motion of the carpus based upon their changes in length. Any subtle changes in posture or the position of the wrist could alter the findings(20). The contribution of the individual carpal motions was largely ignored by these models(18, 20).

The advent of 3D and 4D computer topography and magnetic resonance imaging has led to improvements in the measurement of carpal kinematics(20). Through these techniques it has been shown the individual carpal bones in the proximal row rotate to different amounts, and hence do not move as a single unit even in the same orthogonal plane of motion(19, 20, 24). During wrist flexion from neutral to 60° the scaphoid and lunate flex to 73% and 46% of the amount the capitate flexes in relation to the radius(24). This indicates that during wrist flexion from 0° to 60°, approximately 50% of the motion occurs at the midcarpal joint and the remaining 50% at the radiocarpal joint(24). Conversely in wrist extension from neutral to 60°, the motion occurs at the radiocarpal joint to a greater extent as the scaphoid extends in synchrony with the capitate(24). In radial and ulnar deviation, the majority of this movement is believed to involve the scaphoid, lunate and capitate. During radial deviation, the scaphoid and lunate flex in relation to the radiocarpal joint, whilst the capitate extends in the midcarpal joint(25, 26). The reverse has been shown to occur in ulnar deviation with extension of the scaphoid and lunate, and flexion of the capitate(25, 26).

The majority of functional activities, however, do not rely upon movement in a single orthogonal plane, instead a combination of motions are required(27). The functional plane of motion for the wrist involves the combined arc of motion from wrist extension with radial deviation to wrist flexion with ulnar deviation(20). This arc of motion was first discovered for activities such as throwing a dart or conducting an orchestra(27). Palmar *et al.* went on to show that many occupational and sporting activities are reliant upon this functional plane of motion, which was eventually popularised as the 'dart thrower's arc'(28). Interestingly, during the dart thrower's arc there is little variation in the movement of scaphoid and lunate in the proximal row, with the majority of motion instead occurring at the midcarpal joint(29, 30). This was hypothesised to provide stability for the wrist when carrying out precision tasks(31, 32). Recent studies have since shown that the mechanical axis of the wrist is orientated obliquely to the anatomical axis along the dart thrower's arc(33).

Musculature

The muscles of the wrist can be considered in terms of the movement they promote; extension, flexion, radial and ulnar deviation.

Extension

Extension of the wrist is primarily enabled by the combined actions of extensor carpi radialis longus, extensor carpi radialis brevis and extensor carpi ulnaris, which all lie in the superficial layer of the posterior compartment(6).

- The deep branch of the radial nerve innervates the extensor carpi radialis longus. It originates from the supra-epicondylar ridge and lateral epicondyle of the humerus and inserts onto the dorsal surface of the base of the 2nd metacarpus(6).
- The extensor carpi radialis brevis is similarly innervated by the deep branch of the radial nerve and originates from the lateral epicondyle of the humerus. However, it inserts onto both the base of the 2nd and 3rd metacarpal bones and lies deep to extensor carpi radialis longus for most of its course(6).
- The extensor carpi ulnaris again originates at the lateral epicondyle of the humerus, but inserts onto the base of the 5th metacarpus and is innervated by the posterior interosseous nerve(6).

Extensor digitorum can also act as accessory extensor of the wrist as its tendons cross the wrist joint, however, it is predominately an extensor of the fingers(6).

Flexion

There are two main flexors of the wrist; flexor carpi ulnaris and flexor carpi radialis, with a further three accessory flexors.

- Flexor Carpi ulnaris is a powerful flexor and adductor of the wrist, supplied by the ulnar nerve. It has two heads of origin; the medical epicondyle of the humerus and the olecranon and posterior border of the ulna(6). The main body of the muscle lies within the medial aspect of the superficial layer of the flexors, inserting onto the pisiform bone(6). The force of the muscle contraction is transferred to the hamate bone and the base of the 5th metacarpus via the pisohamate and pisometacarpal ligaments(6).
- Flexor Carpi Radialis is innervated by the median nerve and lies lateral to palmaris longus in the superficial layer of flexors(6). It originates from the medial epicondyle of the humerus and inserts onto the base of the 2nd and 3rd metacarpals. It is also an

important landmark for determining the pulse of the radial artery lying immediately lateral to it.

The accessory flexors of the wrist include palmaris longus, flexor digitorum superficialis and profundus. The primary function of these muscles is to enable flexion of the digits, however as their tendons cross the wrist joint they are able to contribute to wrist flexion(6). They are all supplied by the median nerve, apart from the medial half of flexor digitorum profundus, which is supplied by the muscular branch of the ulnar nerve.

Radial Deviation

Radial deviation is achieved by the combined action of flexor carpi radialis, extensor carpi radialis longus and extensor carpi radialis brevis(6). The normal range of radial deviation is from 0-15 degrees(4). The range is limited by the radial styloid process, which extends further distally than the ulnar styloid process, causing a considerable difference in the range of radial and ulnar deviation(4, 6).

Ulnar Deviation

The normal range of ulnar deviation is from 0-45 degrees. Similar to radial deviation it is achieved by the combined actions of flexor carpi ulnaris and extensor carpi ulnaris(4, 6).

Epidemiology

Fractures of the distal radius in adults have a bimodal distribution affecting young adults and the elderly(34, 35). In the UK, a survey conducted in six centres found the annual incidence in patients over 35 years and older to be 36.8/10000 in women and 9.0/10000 in men(36). A further study of the Dorset population found that the annual incidence increased from a pre-menopausal baseline of 10/10000 person-years in women to a peak of 120/10000 person-years in women over 85 years. In the male population, a similar trend was shown with an incidence of 10/10000 person-years in those under 65 years and a peak of 33/10000 in those over 85 years. The lifetime risk of sustaining a distal radial fracture by 95 years has been estimated as 9% for women and 1.4% for men in the western world(37).

Aetiology of distal radius fractures

Fractures of the distal radius result from a hyperextension load applied to the distal radius, leading to a cascade of damage to surrounding structures. In dorsally displaced distal radius fractures, initially the flexor tendons and palmar ligaments tense, exerting pressure over the carpus that impinges dorsally onto the radial articular surface(35, 38). The distal radius then fractures as the metaphysis reaches its yield point(35, 38). Depending upon the strength and force exerted on the palmar ligaments they may also rupture during this process (35, 38).

The aetiology of this type of fracture can be considered as two groups according to the force applied to the distal radius during hyperextension. Low-energy fractures occur more often and are prevalent in older patients who are prone to repeated falls and have a higher incidence of osteoporosis(2, 36). The typical mechanism is fall from standing height or lower onto a weakened osteoporotic wrist. High-energy fractures, however, are more prominent in younger adults and involve a significant injury often resulting from road traffic or sporting accidents(2).

Fracture Healing

Fracture healing is a complex regenerative process initiated in response to injury, resulting in skeletal repair(39). The fracture site undergoes three stages during the repair process; (a) inflammation, (b) repair; with soft and hard callus formation and (c) remodelling(11, 40).

Inflammation

Haematoma develops from the disruption of blood vessels and resultant bleeding at the fracture site(11, 40). Growth factors, signalling molecules and cytokines are released prompting the migration of inflammatory cells and the replacement of the haematoma with fibrin fibres to form a fibrin clot(40).

Callus formation

Soft bridging callus is formed within the first month of the fracture, which is replaced by hard (i.e. bony) callus by 4 months(11). During soft callus formation, fibroblasts invade the haematoma producing collagen fibres resulting in granulation tissue. The cells in this tissue then differentiate to form fibrocartilage, replacing the haematoma at the fracture ends(11, 41). This soft callus is then calcified and converted to woven bone to form a hard callus through endochondral ossification(11, 41). In order for callus to form, the fracture fixation must permit interfragmentary strain at the fracture site, whilst holding the fracture ends in alignment e.g. immobilisation in cast(11).

Remodelling

Remodelling of the hard callus is the final stage of fracture healing, during which osteoclasts form cutting cones at the fracture site removing dead bone(39). Osteoblasts follow in the path left by the osteocasts, laying down lamellar bone in the form of osteons invaded by new vessels(11).

Complications

Distal radial fractures, whether managed operatively or non-operatively are susceptible to a number of complications. These complications include malunion, arthrosis of the radiocarpal or radioulnar joints, complex regional pain syndrome, tendon ruptures, compression neuropathy, compartment syndrome and infection(42, 43).

Malunion

Malunion is the most commonly reported complication of distal radius fractures managed with closed reduction(44, 45). The fracture heals in an inadequate anatomical position, with deformity often arising from a loss of radial length and metaphyseal angulation, which may or may not affect the radio-carpal and radio-ulnar joints(46, 47). A number of *in-vitro* cadaveric and *in-vivo* kinematic studies have examined the effects of malunion upon wrist mechanics(44, 47-49). Typical deformities such as radial shortening, reduced radial inclination and increased dorsal angulation, have been shown to alter the load bearing and congruence of the radiocarpal and radioulnar joints(44, 47, 48). As a result, the radioulnar ligaments lengthen, and the strains upon the triangular fibrocartilage complex are altered(44, 47, 48).
The resultant deformity, can be either symptomatic or asymptomatic however, hence treatment of such deformities are guided by the patients' functional limitations(46, 47). Patients affected by a symptomatic malunion may present with pain, reduced range of motion, carpal instability and eventually arthritis(48). Increased age (over 65years), has been shown to be associated with diminishing effects of malunion upon wrist function, with patients aged over 80years old in particular rarely affected by such malunions(50, 51).

Complex regional pain syndrome

Complex regional pain syndrome (CRPS) commonly occurs as a complication of injury or fracture, typically affecting only one limb(52, 53). The International association for the study of pain define CRPS as a collection of locally appearing painful conditions following a trauma, occurring distally and exceeding in the intensity and duration of the expected clinical course for that injury(52). Motor function is often restricted and it is characterised by a variable progression over time(52). Three subtypes of CRPS exist: type I; limited disease with predominately vasomotor signs; type II, limited disease with predominately neuropathic pain or sensory abnormalities and type III, a florid syndrome with motor/ trophic signs and disuse related osteopenia(54). Typically women of 40-50yrs are affected four times more often than men, and it commonly follows an upper extremity fracture(52). The estimated incidence irrespective of the preceding injury varies from 5 to 26.2 per 100 000, and in prospective studies of Colle's fractures, the incidence varies from 7-35%(52). A number of mechanisms have been proposed to explain the Pathophysiology of CRPS, these are: peripheral, afferent, efferent and central mechanisms(55, 56). A clear consensus however has not been reached.

Extensor Pollicis Longus Rupture

Rupture of the extensor pollicis longus (EPL) tendon is a recognised complication of angulated and volar plate fixated distal radius fractures, occurring in 0.07-0.88% typically between 1-3months post injury(43). There are two proposed accepted aetiologies; mechanical and vascular aetiologies.

Mechanical aetiology

Damage to the EPL tendon arises from either the protrusion of the dorsal bone edges into the EPL compartment, or due to screw and drill penetration of the tendon(43). The EPL tendon becomes entrapped in volar angulated fractures**(43)**

Vascular aetiology

The EPL tendon has a marginal blood supply, vascular injury to the tendon arises from reduced synovial perfusion of the 3rd compartment due to pressure from the fracture haematoma, and due to systemic factors such as corticosteroids(43)

Nerve compression

Compression of the median, ulnar and radial nerves can occur as a result of either the fracture or the management of the fracture.

Median Nerve compression

The median nerve is the most commonly affected nerve, perhaps due to its central location, proximity to the radius and confinement within the carpal tunnel(57). The incidence of acute median nerve compression following fracture of the distal radius is 4%(58). Nerve compression has been attributed to the following:

- Increase in carpal tunnel pressure due to haematoma, oedema and local anaesthetic(58)
- Direct compression by volar fragments(58)
- Multiple attempts at reduction(57)
- Fracture comminution(57).

Late median nerve compression can occur several months to years after the initial injury, affecting 0.5-22% of patients and is associated with malunion, residual volar displacement and prolonged limb immobilisation(58).

Ulnar Nerve Compression

Ulnar nerve compression occurs in 1% of distal radius fractures and is typically associated with high-energy fractures with marked dorsal comminution(58). Clinical features can present either early or late secondary to direct compression in Guyon's canal due to residual haematoma, malalignment or local soft tissue oedema(58, 59).

Radial Nerve Compression

Radial nerve compression is an extremely rare complication of distal radius fractures and typically results from an iatrogenic injury(59, 60). The superficial radial nerve can be compressed by either the application of a tight cast or irritated by k-wire fixation(58, 59).

Compartment syndrome

A rare complication which affects less than 1% of distal radial fractures, this is typically associated with high energy injuries with severe bone and soft-tissue involvement(60). The pressure in the osseofascial compartments of the hand and forearm rise, impairing the circulation to the muscles and nerves and unless they are decompressed will develop muscle death and neuropathy(59). The volar compartment tends to be more commonly affected than the dorsal compartment(60).

Infection

Infection is a potential complication of operatively managed distal radial fractures. In a meta-analysis comparing external and internal fixation, a higher incidence of 11% was associated with external fixated distal radius fractures, in comparison to 0.8% for internal fixation(60, 61). Haematoma block, used for closed manipulation can result in infection through haematogenous spread although it is highly unlikely and is accounted for by poor asepsis on administration of the block(60, 62).

Management of fractures of the distal radius

Dorsally displaced fractures of the distal radius can be managed either operatively or non-operatively dependent upon patient related factors such as comorbidities and functional demand, as well as fracture characteristics such as the stability of the fracture(63, 64). The ultimate aim of both operative and non-operative management is to provide the patient with a painless, functioning wrist with bony union(63). There is significant debate regarding whether the anatomy of the wrist needs to be fully restored to achieve these goals(65, 66).

Non-operative management

Abraham Colles first proposed closed reduction and casting for all patients with a distal radius fracture in 1814 on the premise that regardless of the resultant deformity of the wrist, the patient would regain sufficient function in their wrist for most tasks(67). Closed reduction and casting however, is now reserved for patients with a stable fracture, the elderly with low functional demands and those with significant co-morbidities deeming a general anaesthesia inappropriate.

Dependent upon the degree of deformity, the fracture is reduced under either anaesthesia or sedation by exaggerating the deformity with the application of longitudinal traction to allow the fragments to part(2). The fracture is then manipulated reversing the injury e.g. for a dorsally displaced fracture the distal fragment is manipulated in a volar ulnar direction with the forearm pronated, and held with a temporary cast due to soft tissue swelling, which is later replaced by either a full cast or external brace for 4-6 weeks post-injury(2). A recent Cochrane review concluded that there was inconclusive evidence to determine the most appropriate method and duration of immobilisation with either a plaster cast or brace(64). In addition it remains unknown whether the fracture should be manipulated at all prior to immobilization as it has been suggested that elderly patients may not need manipulation as no association has been shown between anatomical reduction and patient reported outcome measures in the elderly(68). In addition, Kelly *et al*. found no difference in the outcome of patients' whether they were manipulated or not(69). Of those that were manipulated two thirds redisplaced by 6 weeks post-injury(69).

Operative management

There are three main types of operative management: closed reduction and wire fixation, open reduction internal fixation and external fixation. All have been shown to result in an improvement in the functional outcome of the wrist, with numerous studies suggesting there is little difference in the functional outcome at 1 year post-injury (70-75). A robust meta-analysis comparing these different types of fixation has not been performed in the past decade to determine the optimum management of unstable dorsally displaced distal radius fractures.

Closed reduction and Kirschner wire fixation

Traditionally this technique has been reserved for extra-articular fractures without significant dorsal comminution(63). It provides a less invasive stabilisation of the wrist which is often less costly than fixation with open reduction and internal fixation(76). A number of complications however are specific to this type of fixation, including; pin track infections, late collapse, and nerve/ vessel damage on insertion of the wire(76).

The fracture is reduced closed as previously detailed and wires are inserted percutaneously to hold the fracture in place via two methods(77):

- *Extrafocal* – the wire is inserted from the distal fragment across the fracture site proximally crossing the opposite cortex(78). One popular method is to insert one wire at the radial styloid and the other through one of the extensor compartments(76).
- *Intrafocal* – first described by Kapandji in 1976, wires are inserted into the fracture site to allow the distal fragment to be levered into place, to provide control for distal fragment rotation(76, 79).

Henry (2008*)* suggests that the wires assist in maintaining the reduction of the fracture by bearing the forces transmitted across the fracture site by the digital flexor and extensor tendons(78). At present, there remains insufficient evidence to determine the precise method, and the number of wires required for percutaneous pinning(77). In comparison to conservative management, wire fixation has been shown to confer an improvement in the radiological outcome, and equivalent or improved functional outcomes(80, 81).

Open reduction and internal fixation

Open reduction and internal fixation of the wrist has become increasingly popular over the past decade, providing anatomical reduction with rigid stabilisation of the fracture allowing early mobilisation of the wrist(82). The fracture is reduced under direct observation by either a dorsal or volar approach, typically with the application of a locking or non-locking plate. It is indicated for unstable intra and extra-articular fractures and fractures that cannot be reduced using closed techniques. A dorsal approach offering the ability to use bone graft with a stable fixation was originally favoured, however, due to a high complication rate has become less popular in favour of a volar approach(82, 83).

- Dorsal plating - the plate is placed under the extensor tendons on the dorsal aspect of the wrist, acting as a buttress to maintain the fragments in position(63). A number of concerns have been raised about this technique, firstly regarding the close proximity of the plate to the extensor tendons risking irritation and rupture, and secondly in the osteoporotic bone the screws may not achieve sufficient osseous contact to buttress the articular fragments against axial loads leading to articular collapse(63, 82).
- Volar plating –the plate is applied to the volar aspect of the wrist, typically with distal locking to allow the transmittance of force from the dorsal metaphysis towards the volar cortex(63). Providing the plate is placed correctly it should be covered by the pronator quadratus to reduce the risk of tendon damage(78, 82).

Both have been shown to result in a functional improvement of the wrist in regards to radiological, and functional outcome with physical and patient reported measures e.g. DASH and PRWE scores(84-86). In the management of intra-articular fractures, volar plating has been shown to have an early improvement in functional and pain outcomes that persists above those for dorsal plating at 12 months(82).

External fixation

External fixation of the wrist was developed to provide a minimally invasive fixation of highly comminuted distal radius fractures with poor surrounding soft tissues. This type of fixation involves a closed reduction often in conjunction with the insertion of wires through the skin into the bone, which are then secured to an external frame. A number of techniques and devices can be employed with this technique(87). In the wrist there are three main variants:

- Bridging – the distal wires are inserted into one the metacarpal bones and the proximal ones into the shaft of the radius either on the volar or dorsal aspect, so that the external fixator spans the wrist joint. This type of fixation is therefore suitable for fractures with distal fragment comminution(78). The reduction of the fracture is therefore maintained by ligamentotaxis(78, 87). In the placement of this device, the surgeon needs to be mindful that excessive longitudinal forces aren't applied which can result in excessive pain and wrist stiffness(78).
- Non-bridging – the wires are placed in the radius proximal and distal to the fracture site to allow early mobilisation of the wrist joint. This is however dependent upon a sufficiently large distal fragment to allow the placement of wires(88).
- Dynamic hinged external fixator – the fixator spans the wrist similar to bridging fixators, however a hinge is placed at the level of the wrist joint to allow early mobilisation.

Although an improvement in the functional outcome of patients with a distal radius fracture has been detected with all variants, no difference has been detected between bridging, non-bridging and dynamic fixators(88-91). All variants can result in pin track infections, finger stiffness and irritation of the superficial radial nerve resulting in chronic regional pain syndrome(78).

In comparison to casting a recent Cochrane review concluded that although external fixation resulted in a better radiological outcome there was insufficient evidence to confirm an improvement in the functional outcome in comparison to conservative management(87).

Clinical decision making

A number of models have been proposed to depict the cognitive processes involved in clinicians' decision-making (92, 93). Although these models have traditionally been based upon the practice of nurses and physicians, they may also be applicable to surgical decision-making. Historically, these cognitive processes were assigned to two theoretical categories: the systematic-positivist and the intuitive-humanist stance. Thompson suggests the primary distinction between these approaches is the motivation for the decision(92). The systematic-positivist stance is driven by the task, whilst the intuitive-humanist stance is driven by the individual forming the decision(92).

Systematic-positivist Stance

The systematic-positivist stance was the predominant theoretical stance until the 1980s, and is based upon analytical reasoning(94, 95). Two prominent models feature in this stance; the information-processing model and Bayes theorem(92).

Information-processing model

The information-processing model is based upon the assumption that the human memory is separated into the short and long-term memories(94, 96). The short-term memory stores a limited amount of learnt information in the form of stimulus patterns(96). In contrast, the long-term memory stores large amounts of semantic and episodic information, that can only be released by stimuli from the short-term memory(94, 96). This model displays four distinct stages of reasoning based upon a hypothetico-deductive approach(92, 94, 96):

(1) Cue acquisition
(2) Hypothesis generation
(3) Cue interpretation
(4) Hypothesis evaluation

During a patient encounter, the clinician will acquire a variety of cues about the patient such as the patient's age, gender, presence and location of pain(92, 96). Typically 3-5 tentative hypotheses are generated early in the patient encounter, transferred from the long-term memory to the short-term memory to allow for rapid information processing(97-99). Elstein suggests the formation of these early hypotheses is to overcome the limited capacity of the short-term memory, by organising the information processed into manageable 'chunks'(97). Patient cues are then interpreted as either confirming, refuting or not contributing to these tentative hypotheses(92). In the final phase, the clinician will weigh up the advantages and disadvantages of each hypothesis to determine an overall diagnosis(92, 96, 97). This hypothetico-deductive approach has been shown to be prevalent in clinical decision-making(100). In a study of graduate nurses, a hypothetico-deductive approach was taken in 25 of 37 patient-nurse encounters(100). Flawed decisions may result from this decision-making model, either by failing to generate the correct hypothesis during the hypothesis generation stage, or by incorrectly evaluating the cues during the interpretative phase(93).

Bayes' Theorem

Models based upon Bayes' theorem, suggest that clinicians exert degrees of belief in relation to outcomes (condition/treatment) that alters in response to the presentation of new evidence(92). Similar to the cue interpretation phase of the information-processing model, new evidence will be categorised as either confirming, refuting or providing no evidence for the hypothesis(92). The belief in the hypothesis will alter in line with the new evidence(92, 93). Bayesian models have been criticised for being prescriptive as opposed to descriptive of actual decision-making(92). In a vignette-based study of physicians' encounters with diabetic patients, Lutfey *et al.* found cognitive and psychological traits were more frequently addressed when assessing the likelihood of complications, as opposed to physical symptoms and epidemiological base rates as might be expected with a Bayesian approach(101, 102). Elstein Schwarz suggest that only a minority of physicians trained in evidence-based medicine are likely to follow this model(103).

Intuitive-humanist Stance

The intuitive-humanist stance focuses upon the use of intuition and pattern recognition by expert clinicians(94). Unlike the systematic-positivist stance, it is based upon non-analytical reasoning. Pattern recognition is often considered to be associated with intuition(104). Buckingham and Arber, however, suggest intuition and pattern recognition are separate entities whereby intuition is an unconscious process, whilst pattern recognition occurs at a conscious level. In this review they will be considered separately:

Intuition

Various authors have attempted to define intuition. Benner and Tanner provide a succinct definition of 'understanding without a rationale'(104). Rew provides a more comprehensive description of intuition as 'a component of complex judgement, the act of deciding what to do in a perplexing, often ambiguous and uncertain situation(105). It is the act of synthesising empirical, ethical, aesthetic and personal knowledge. Intuitive judgement is the decision to act on a sudden awareness of knowledge, that is related to previous experience as a whole and difficult to articulate'(94). Several themes arise in all the definitions of intuition, firstly, the role of experience and, secondly, that this is an unconscious process. Benner and Tanner suggest that as clinicians gain knowledge with experience, their decision-making is enriched thus reducing their reliance upon analytic cognitive processes(94, 104). King and Macleod Clark, studied the expertise of surgical and intensive care nurses of various degrees of experience(106). Although all nurses displayed a degree of intuitive awareness, the ability to understand the basis of their intuitive concern, and the importance in relation to the patient's condition, improved with the degree of expertise(106).

Benner adapted a five-stage model originally proposed by Dreyfus and Dreyfus (1986), to explain the acquisition of knowledge and the role of intuition from novice to expert(104).

- Novice – they have no experience of the situation in which they are expected to perform and must depend on context–free rules to guide their actions.
- Advanced Beginner – they have amassed enough experience to recognize recurring meaning from their experience, but can not reliably prioritise in complex situations
- Competent – they have a sense of mastery and are able to prioritise within long term goals, but do not have the speed and flexibility of a proficient clinician
- Proficient – have a holistic perspective and are able to adjust rapidly to alterations in long term plans
- Expert – have an intuitive grasp of situations, no longer relying on guiding rules unless met with new or unexpected challenges, when hypothetico-deductive logic is used.

Pattern recognition

Pattern recognition is the formation of a decision based upon the recognition of patient cues(94, 107). In the patient-clinician encounter, cues arise from the patient's signs and symptoms, which are then matched to patterns recognised from memory(94). Offredy and Buckingham & Adams suggest a process of categorisation occurs, whereby the recognisable patterns constitute a series of categories(107, 108). The patient will be assigned the diagnosis of the best fitting category(107). There are two dominant models that explain this categorisation process:

Prototype model - Each category is represented by a single prototype, generated from the critical features of a number of exemplars experienced by the clinician(108, 109). For example, Buckingham & Adams suggest a prototype for a cardiac patient, would be 65years old with high blood pressure, crushing chest pain radiating down the left arm and shortness of breath(108). Each new patient would be matched with the prototype.

Exemplar model- Each category is characterised by the cue patterns of all exemplars known to the clinician(108, 109). In the example of a cardiac patient, cues of all patients with chest pain experienced by the clinician will be considered.

Alternative models of clinical decision-making

In a study of cardio-respiratory physiotherapists decision-making, both the hypothetico-deductive reasoning and pattern recognition were displayed(110). Smith *et al* suggests that these processes were embedded within a more complicated process(110). Several alternatives to the models within the systematic-positivist and intuitive-humanist stances have evolved around this premise suggested by Smith *et al*(110). The Dual-processing model and Classification Model are the key alternatives that will be considered:

Dual-processing Model

The Dual-processing model proposes that two systems of cognition are involved in clinical reasoning and decision-making: the intuitive and analytical systems(111-114). System 1 is the intuitive, a rapid system based upon the recognition of cues and the use of readily available information(114). System 2 is analytical, a slow, rational and deliberate system employed when tasks are new or challenging(114). If we consider a clinical encounter where the clinician recognises the features of the patient's condition, a diagnosis will be made using system 1. (112). If however, the features are not immediately recognised, system 2 will be engaged and the diagnosis deliberated e.g. for a patient presenting with a global headache there are a number of possible diagnoses(111, 112). Oscillations can occur between the two systems; for example, system 1 can override system 2, this would be indicative of irrational behaviour(112). System 2 can similarly override system 1, by acting as a surveillance mechanism(112).

It is also possible, with repeated exposure to a process using system 2, for it to be relegated to system 1(111, 112). This would coincide with Benner's model of knowledge acquisition(104).

Classification Model

Buckingham and Adams proposed that the hypothetico-deductive and pattern recognition approaches are essentially classification processes(93). They propose a general model of classification for decision-making occurring in a sequential process. Adams *et al* have refined the model to represent three linked tasks: the formulation of the diagnosis, the potential outcomes as a result of the diagnosis and the prescription of interventions based upon the diagnosis(93, 115).

- Cue recognition – (pattern vector) – this includes all features of the patient that may or may not be relevant to the diagnosis
- Cue selection – (feature vector) – cues that are considered relevant to the diagnosis are selected and irrelevant cues removed
- Psychological representation of the cues e.g. age 75 is represented as elderly
- Classification of cues into decision classes

Outcome measures used in Research

A number of outcome assessments exist in the literature for measuring the clinical outcome of patients with a fracture of the distal radius. No universal agreement has been reached regarding which measures should be used in clinical trials. Goldhann *et al* performed a search of outcome measures used in orthopaedic literature over the past 25 years and found that the majority of studies assessed impairment and radiographic findings, followed by combined scores and lastly patient reported outcome measures(116).

Measures of impairment

There are three measures of impairment commonly assessed for fractures of the distal radius:

- Grip strength – the maximal grip strength is typically measured with a hydraulic dynamometer and has been shown to be both reliable and responsive in monitoring the clinical outcome of patients with a fracture of the distal radius(117-119).
- Pinch strength –the most commonly measured types of pinch include; the lateral (key) pinch and tripod pinch, assessed with a pinch gauge and found to be reliable in patients with an upper limb injury(119, 120).
- Range of movement assessed with a goniometer in three planes of motion; flexion/extension, radial/ulnar deviation and pronation/supination. There is some evidence to suggest it is responsive to clinical changes in patients with a distal

radius fracture between 3 and 6 months post-injury, however the evidence is unclear regarding the reliability of this measure(117, 121, 122).

Radiographic features

Lateral and posteroanterior radiographs are commonly used to assess the configuration and 'stability' of the fracture at presentation, and subsequently to assess for signs of late instability and malunion(123, 124). The stability of the fracture is determined from the palmar tilt, radial height, radial inclination, ulnar variance, degree of dorsal comminution and carpal alignment (Figure 1). These are assessed as follows:

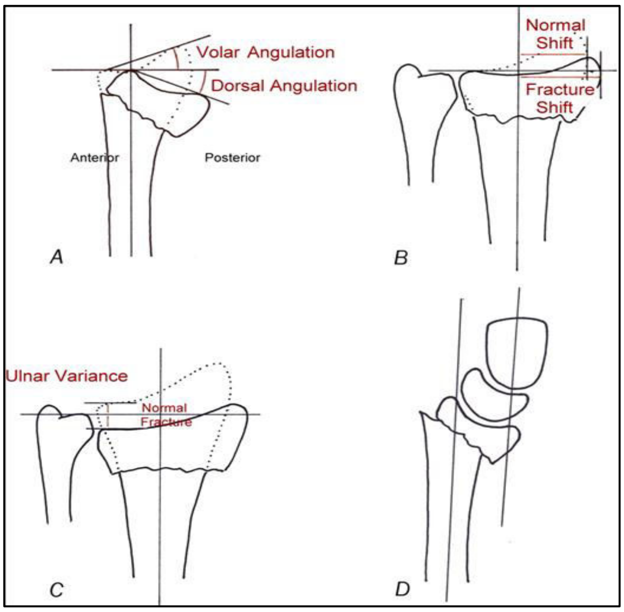
Assessed on the lateral radiograph

- Palmar tilt – the angle of the articular surface in relation to the longitudinal axis. Typically the radius has 11 degrees of volar tilt (2, 124, 125).
- Carpal malalignment – the long axes of the capitate and radius fail to intersect within the carpus(123).
- Dorsal comminution

Assessed on the posteroanterior radiograph

- Radial Height – the distance between the radial styloid and the articular surface of the distal ulnar. Typically the radial height is 11mm ranging from 8-18mm(2, 124).
- Radial inclination - the angle of the articular surface in relation to the longitudinal axis of the radius, typically 22 degrees but ranging from 13-30 degree
- Ulnar variance - the difference in the height between the articular surface of the lunate fossa and the distal articular surface of the ulnar(2, 124, 125).

Figure 1 - Radiographic features of a distal radius fracture: (A) Palmar tilt (B) Radial shift (C) Ulnar Variance (D) Carpal Malalignment. Taken from Mackenney et al(123)



Fracture instability

Mackenney *et al* define fracture displacement and instability as follows:

- *Minimal displacement* – dorsal angulation of ≤10˚ and an ulnar variance of <3mm(123)
- *Displaced* – dorsal angulation >10˚ and an ulnar variance >3mm(123)
- *Early instability* – a radiographically displaced or redisplaced fracture within two weeks of the injury(123)
- *Late instability* – a radiographically displaced fracture at the time of union (six weeks)(123)

Classification systems

A number of classification systems have been derived to describe and communicate the radiographic configuration of the fracture(126, 127). Pilcher proposed the first classification of distal radius fractures in 1917. This classification system, like many others derived up until the 1960s are no longer recognised. Six classification systems commonly cited in the literature include: the Frykman, Fernandez, Melone, Mayo, AO and Universal systems.

- *Frykman* – was published in 1967 and was based upon the involvement of the radiocarpal and radioulnar joints in the fracture and the presence of an ulnar styloid fracture. However, it does not consider displacement and fragmentation of the fracture(128, 129).
- *Fernandez* – was proposed in 1993 by Fernandez, and consists of 5 groups based upon the mechanism of injury. It was developed to guide the

management of the fracture by predicting the stability of the fracture and the identification of the presence of associated injuries(128, 130).

- *Melone* – was published in 1984 and classifies intra-articular distal radius fractures based upon the involvement of the radial shaft and radius styloid and the presence of dorsal and palmar fragments(129, 130).
- *AO classification* – based upon the location of the fracture and classified into groups and subgroups based upon articular involvement and the morphological characteristics of the fracture(128, 129).
- *Universal classification* – it was first described by Cooney in 1993, and provides a simple classification system where fractures are classified according to; (1) articular involvement (2) presence of displacement (3) stability of the fracture and potential for reduction(129, 130).

Despite the number of classification systems proposed, all have been shown to have poor interobserver and intraobserver reliability (128-130).

Physician rated scores

Traditionally patient outcome scores were based upon physical measures of function rated by the clinician, and the radiographic outcome of the fracture. These measures do not incorporate the patient's perspective of their recovery and pain in either the development of the score or as part of the score. In addition many of these scores remain unvalidated for monitoring the outcome of distal radius fractures despite their widespread use. These scores included; the Gartland and Werley and the Green and O'brien scores:

Gartland and Werley score

This score was developed in 1951 and as based upon a demerit system whereby patients were awarded demerits with an arbitrary loss of movement, or grip strength. Although this system is one of the most frequently used scores in the literature it has not been validated for distal radius fractures, and neither the responsiveness nor reliability have been assessed(124, 131).

Green and O'brien

This provides a combined score based upon the clinicians' assessment of the patient's range of movement, grip strength, pain, wrist demand and the radiographic appearance(124). The responsiveness and reliability of this score has not been assessed in patients with a fracture of the distal radius.

Patient Reported Outcome Measures

Patient reported outcome measures were developed to provide the patient's self-assessment of their pain, function and the burden of their injury, in line with the International Classification of Functioning, Disability and Health (ICF) guidelines. In a recent review of the most commonly cited outcome measures for the assessment of distal radius fractures, Goldhann *et al* found the DASH, quick DASH, PRWE, MHQ and SF36 were most commonly used(116). Other measures such as the Brigham and Women's Hospital carpal tunnel instrument, Arthritis Impact Measurement Scale and the EQ5D are also present in the literature but to a much lesser extent(132).

Patient-Rated Wrist Evaluation (PRWE)

The PRWE provides a reliable and valid score, developed specifically to assess the outcome of patients with a fracture of the distal radius(124, 133). It was first described by Macdermid in 1998 and comprises of two sections assessing pain and function, and has been shown to be responsive to clinical change in patients with a fracture of the distal radius(117, 124).

The PRWE was developed in a five-stage process: (1) A survey of current outcome measure use amongst physicians with an interest in wrist pathology to determine the structure and content of the score (2) Generation of items through information gleaned from patient and expert interviews, other outcome measures and biomechanical literature (3) Item reduction through expert review with pilot testing (4) Refinement of items and construction of the score (5) Pilot testing of the final score(133).

Disability of the Arm, Shoulder and Hand (DASH)

The DASH score is an upper extremity specific score shown to be reliable and valid in the assessment of single-joint and multi-joint disability(124). It was first developed by Hudak *et al* in conjunction with the upper limb extremity collaborative group, through a three stage process(134). In the first stage, 13 outcome measure scales were reviewed by a group of methodologists and clinical experts to generate a list of 821 items(131, 134). Next, the list was reduced to 78 items by removing those deemed generic, repetitive, or not reflective of upper extremity disability or the patient's symptoms and functional status(131, 134). Lastly the score was field tested with patients in the United States, Canada and Australia to further reduce the number of items and ensure scores were intelligible to patients(134).

Although it has been shown to be responsive in the assessment of patients with a distal radius fracture in addition to other upper extremity injuries, concomitant diseases affecting the ipsilateral or contralateral limb may influence the score(117, 124).

Quick-DASH

The quick-DASH is a validated 11 item tool developed from the full DASH score using a concept-retention approach (135). This approach selected items identified from key domains of the DASH score. Items were grouped into domains and then selected based upon field-testing data, which ranked the items in terms of importance, difficulty and correlation with the total score. The highest-ranking items were chosen from the 16 domains and then 5 items were removed due to poor acceptability and representation of the core concepts, and similarity to other domains in the score(135).

The quick-DASH has been shown to have comparable reliability and responsiveness to the full DASH score for a number of upper-extremity disorders and offers the potential to be more acceptable to patients(136).

Michigan Hand Questionnaire (MHQ)

The MHQ is a 37 item hand-specific outcome measure consisting of 6 domains of; pain, function, aesthetics, satisfaction, work performance and activities of daily living(137, 138).

Similar to the DASH and PRWE, it was developed from a review of existing outcome measures from which items were generated to be included in the questionnaire(139). These were combined with additional items generated by a panel of patients with hand disorders deemed to be important to their hand function and assigned to one of 6 domains by a panel of patients, hand therapists and hand surgeons(139). The number of items was then reduced to 37 distinct items within the 6 domains(139).

It has been shown to be both a valid and reliable tool, responsive to a clinical change with numerous hand conditions including recovery from distal radius fractures(137-140).

Short form health survey (SF36)

The SF36 is a generic measure of health consisting of 8 subscales, in regards to the wrist the physical summary and the bodily pain, physical function and physical role domains are particularly relevant(117). It was developed from a review of existing health surveys for the Medical Outcomes Study and unlike the MHQ and PRWE scores, patients were not involved in the generation of this tool(141). The physical domains and subscale summary have been shown to be valid and reliable, capable of detecting a clinical change in patients with a fracture of the distal radius although to a lesser extent than disease and upper extremity specific measures(117, 132).

Research Methodology

“Research is centrally important in the modern world” (Punch, p.11, 2014), infiltrating society, by altering our ways of thinking, solving our problems and developing our knowledge base(142). In consideration of the importance Punch places upon research to our everyday lives, it is essential to consider the processes involved in the undertaking of research to the same degree. In this section I will firstly consider what research is and the processes involved in general terms, and then set out the specific methods I have used within this thesis.

Griffiths describes research as the discovery of knowledge through the study of the natural, social or technical world in such a way, that others can follow the relevant stages laid out(143). Punch mirrors this emphasis upon a systematic approach, by describing research as organised common sense *"an organised, systematic and logical process of inquiry, using data to answer questions" (Punch, p.11, 2014)(142)*. From these descriptions we are introduced to the notion of research as a series of ordered processes that can be applied to the acquisition of different types of knowledge.

Before these processes can be executed, the researcher must firstly formulate their 'research question', and then decide upon the research design, of which there are three commonly used in healthcare research; quantitative, qualitative and mixed methods. Creswell suggests this decision should be informed by the researchers' philosophical worldviews (a set of beliefs that guide action), the research strategies related to those views and the specific methods used to collect the data(144). Frequently, only the research strategies and methods are apparent in the study design, with little consideration to the researchers' worldviews, despite their influence upon shaping the general research stance taken(144). Creswell proposes four prominent worldviews or paradigms formed by the researchers' discipline of study, prior experiences, and influences within their department(144). These include; post-positivism, constructivism, advocacy and pragmatism(144). Historically, these views were considered separate entities segregating qualitative and quantitative research often referred to as the 'paradigm wars'(144). This thinking has however changed and instead these views are considered to exist on a scale(144).

In this thesis, quantitative and mixed methods research designs have been employed for the main studies. In this section, a discussion of the research designs with respect to their underlying philosophical stance, as well as the strategies and methods are presented. Additionally, a narrative of the current recommendations for reporting each of these methods is also included.

Quantitative research studies

Quantitative research is rooted within the positivist paradigm, first developed by Auguste Comte(145). Positivists believe it is possible to understand both the natural and social worlds through the application of scientific methods(145). Bryman suggests this stance is bound by several principles(145). Firstly, only knowledge that can be confirmed by an individual's senses can be accepted (phenomenalism). Secondly, the acquisition of that knowledge must be objective (value-free), and both deductive (driven by theory) and inductive (the data acquired can alter the theory)(145). Positivism has since been superseded by the emergence of post-positivism, which challenges this perception of knowledge as absolute when studying the actions and beliefs of people(144). It instead concedes that it is not possible to know with complete certainty, as the social world is complicated and open to interpretation(145).

Post-positivism is primarily concerned with the investigation of variables to test theory, and can be defined as; "A means for testing objective theories by examining the relationship among variables. These variables, in turn, can be measured, typically on instruments, so that numbered data can be analysed using statistical procedures" (Creswell, p.4, 2009)(144). This definition highlights the deductive nature of quantitative research, whereby the researcher deduces a hypothesis to be tested from prior knowledge and theory(145).

Figure 2 - Functions of quantitative research (Punch 2014, p206)(142)

- To conceptualise reality in terms of variables
- To measures variables
- To study relationships between variables

Punch (2014) suggests this type of research performs three main functions (figure 2), enabling causes and effects to be isolated, phenomena to be measured and quantified, and laws to be formulated(142). The design and analysis of quantitative studies can be broadly separated into two strands of design; the first provides a comparison between groups, whilst the second assesses the relationships between variables(142). These strands are investigated using experimental (e.g. randomised controlled trials), quasi-experimental (non-randomised comparative studies) and observational strategies (e.g. cohort studies). These strategies differ with regards to the researchers' control over the independent variables being studied. In experimental studies, the researcher is able to study the outcome of manipulating one or more of the independent variables upon the dependent variable(142). The independent groups for the quasi-experimental and observational studies, are however, either naturally occurring preventing any manipulation or are indistinguishable(142).

Quantitative research is however not without its limitations and has been criticised for the specific methods it uses and its epistemological and ontological orientations(145). Through the application of natural world methods, individuals' perceptions and the meanings they place upon the world around them are omitted from the analysis(145). This reduces the depth of answer that can be gained, as well as limiting the types of questions that can be answered. For example, a quantitative assessment of relationships between variables would not consider how those relationships arise, nor how these findings fit in to everyday contexts. Lastly, the measurement process may also give a false sense of precision for measures such as questionnaires, as respondents may interpret the questions differently(145).

I will now proceed to provide a narrative of the observational strategies I have used for the reliability and correlation studies, and the systematic review of experimental studies.

Reliability study

We have seen that quantitative research is primarily focused upon the conceptualisation and measurement of variables. In order to ensure the differences between the study groups are genuine, the measurement tools and instruments used to assess these changes must be reliable. There are several facets of reliability that can be assessed:

- Stability – the consistency of the measure over time, also referred to as the test-retest or intra-rater reliability(145)
- Internal consistency – the coherence of the tool and whether the components of the tool are related(145)
- Inter-rater reliability – the consistency of the measure with multiple observers taken on the same occasion(145)
- Inter-instrument reliability – the consistency of measurements taken with several instruments at the same occasion(145)

For the assessment of the dynometers and goniometers in this study, only the measurement of intra-rater, inter-rater and inter-instrument reliability were deemed relevant. If an overall functional score had been derived from these measurements, then the internal consistency would also need to be assessed.

Reliability can be assessed using either an in vivo study (non-experimental) study design, whereby the measurements are taken on patients or healthy volunteers. Alternatively, biomechanical studies can be performed using cadavers, to measure the reliability of different goniometry techniques(122).

A substantial proportion of clinical literature consists of observational studies(146). The reporting of these studies however is often poor, hampering the ability of the reader to determine the quality of the study and the applicability of the results(146). In order to improve this reporting, the strengthening the reporting of observational studies in epidemiology (STROBE) statement was developed(146). The STROBE statement consists of 22 items including all aspects of the report, 18 of those are applicable to the three main types of study and 4 items specific to each type of study(146).

Correlation study

The assessment of causality between two variables is not always straightforward. Ideally, an experimental strategy would ideally be used to perform such an assessment. However, this is not always possible or ethical to undertake, instead a correlation study design should be employed. This type of strategy assesses both the strength and direction of the relationship between two variables. There are two key reasons for its use, firstly, it may not be possible to manipulate the independent variable or other variables that could effect the dependent variable, and secondly, it maybe unethical to manipulate the independent variable(147). These reasons are apparent when we use the example of engaging in a risky behaviour such as texting whilst driving or the effects of smoking upon the risk of developing lung cancer(148, 149). In both examples it would be unethical to manipulate the independent variable due to the increased risk of harm. It might also not be possible to control all of the variables that could affect the dependent variables, for example with the example of texting whilst driving, the driver’s texting behaviour maybe influenced by the number of times they drive, their beliefs regarding the dangers of texting whilst driving, the age of their passengers and their social group(150). In these examples, only the presence and strength of a relationship between variables can be assessed, and not causality.   The reporting of these studies should be in accordance with the STROBE statement as described previously for the reliability study(53).

Systematic review

In the General Medical Council’s (GMC) guidance on good clinical practice, they state that doctors must keep their professional knowledge up to date and be familiar with developments that affect their work(151). Many medical practioners in the UK, are however already overstretched, with little time available for the identification and appraisal of the vast array of clinical evidence(152). The availability of a methodologically robust summary of the literature is therefore paramount. Systematic reviews have hence been designed to assist practioners in establishing whether scientific findings of interest are both reliable and generalizable to the patient population within their practice(152, 153).   In addition, to their importance for assisting practioners, systematic reviews often form the basis of clinical guidelines and are commonly required as a prerequisite stage for obtaining funding from granting agencies(154).

According to the Cochrane Handbook of Systematic Reviews, the undertaking of a review should involve the collation and appraisal of all empirical evidence that meets pre-defined eligibility criteria allowing a specific research question to be addressed(155). It is essential that a systematic approach is adopted at this stage to reduce the risk of selection bias(152, 155). The data is then analysed, with a summary and discussion of the study characteristics and findings. In addition, a statistical analysis can be performed, most commonly a meta-analysis, dependent upon the heterogeneity of the studies. This decision is based upon the similarity of the primary studies with regards to the comparisons made, the outcomes assessed, and the presence of bias(156). The Cochrane statistical methods group advocates the use of the same general framework for analysing the data. The framework involves addressing four questions (see figure 3).

Figure 3 - Cochrane framework for data analysis

1	What is the direction of the effect?
2	What is the size of the effect?
3	Is the effect consistent across studies?
4	What is the strength of evidence for the effect?

Historically, the quality of the reporting of systematic reviews has been poor, hindering the readers' ability to draw conclusions from the findings(157-159). In order to address this plethora of suboptimal reporting, an international group published the Quality of Reporting Of Meta-analyses (QUOROM) statement in 1999, to improve the reporting of meta-analyses(153, 160). Following a number of conceptual, methodological and practical advances in the undertaking and reporting of systematic reviews, the QUOROM statement was replaced in 2009 with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement(153). The PRISMA statement provides authors with an evidence based 27-item checklist of items to include within the report and a four phase flow diagram(153).

Although, the PRISMA statement does not directly assess the quality of the review, it has been well documented that poor reporting in clinical trials is associated with systematic error(161, 162). Similar evidence is now emerging for systematic reviews, strengthening the use of the PRISMA statement in the undertaking of future reviews(163, 164).

Mixed methods research studies

Mixed methods research emerged as an independent methodology in the 1980s, as researchers from several disciplines and countries simultaneously decided to move away from using solely quantitative or qualitative research strategies(165). Creswell suggests it has emerged due to the increased complexity of problems faced by researchers and policy makers, and the need for more sophisticated answers(165). Several definitions have been touted for mixed methods research, focusing upon the research processes, designs, methods and underlying philosophy to differing extents. I have chosen to adopt Creswell and Plano Clark's definition, as it refers to both the philosophical stance and research methods used:

'*Mixed methods research is a research design with philosophical assumptions as well as methods of inquiry. As a methodology, it involves philosophical assumptions that guide the direction of the collection and analysis and the mixture of qualitative and quantitative approaches in many phases of the research process. As a method, it focuses on collecting, analysing and mixing both quantitative and qualitative data in a single study* *or series of studies. Its central premise is that the use of quantitative and qualitative approaches, in combination, provides a better understanding of research problems than either approach alone'.* (Creswell and Plano Clark, 2007, p5).

Since this time, mixed methods research has evolved with regards to both the research procedures and the underlying philosophical viewpoints. Hence, numerous designs have arisen, differing with regards to how the quantitative and qualitative components interact, the priority given to each component and the timing when each occurs.

Unlike either qualitative or quantitative studies, mixed methods studies tend to have a varied and pragmatic approach to the philosophical stance taken(166). For example, the combined use of post-positivism and constructionism is advocated for the different phases in sequential studies(166).

Thesis aims

In this thesis, I have explored the journey of patients undergoing operative management for a dorsally displaced fracture of their distal radius. There are three pivotal stages in their journey that I will investigate: firstly, the initial consultation with the formulation of the surgeons' management plan; secondly, the operative treatment of the patient, and lastly, the recovery of the patient in both the initial post-operative period and in the longer term.

In the first stage of the patient's journey, a complex decision-making process occurs between the patient and surgeon. During this process there will be an exchange of beliefs, preferences, and technical information about the fracture and its management, resulting in a decision to manage the fracture either operatively or non-operatively(167). Operative rates for fractures of the distal radius have been shown to vary with geographical location, despite a similar distribution of injury patterns(168). This suggests a number of factors may be involved in the decision-making process. These can be broadly categorised as patient, surgeon, and context-related factors. Patient-related factors might include the severity of the fracture, the patient's occupation, age, and concomitant illnesses. Surgeon-related factors are perhaps less apparent, for example their personal preference, level of expertise, training, and specialism(168, 169). Lastly there are context-related factors, including the local culture of the orthopaedic department, and resource availability. In this thesis, the decision-making of senior orthopaedic surgeons and the factors affecting their decisions has been explored. This has allowed an insight into the discrepancies that exist in the management of these patients, highlighting where improvements in clinical practice might be made to enhance patient outcomes.

Once the surgeon has decided the patient requires an operation, the next decision is which type of operation should be performed. In the UK, patients tend to undergo either open-reduction internal fixation with a volar locking plate, or closed reduction with Kirschner wire fixation(170). In 2003, Handoll and Madhok published a Cochrane review of randomised controlled trials investigating operative interventions for the management of distal radius fractures. No clear evidence was found to support the use of a particular surgical intervention(170). Since this review was undertaken, a number of trials have been performed investigating the functional outcome of patients managed with either wire or plate fixation. A systematic search of the literature comparing the functional outcome of patients treated with either fixation was therefore performed to appraise this new evidence.

Post-surgery, it is important to accurately assess the patients' recovery, to allow the detection of an impairment in their wrist function(171). Traditionally, patient monitoring has relied upon radiographic features and surgeons' assessments, which can provide a limited portrayal of the patients' function and satisfaction (120, 171). Patient Reported Outcome Measures (PROMs) were introduced to provide a reliable and reproducible assessment of patient satisfaction and perception of their own recovery (117, 124, 172). Extremity specific measures, such as the PRWE and DASH scores, have been shown to be responsive to changes in pain and function for patients with a distal radius fracture(117). However, these measures may underestimate the level of impairment to the hand and wrist, leading to insufficient information necessary for clinical practice(173).

Physical outcome measures instead offer an individualised assessment of the patient that may be more responsive to early changes in the post-operative period(117, 174). Unlike the PROMs, which solely detail the presence of impairment, they instead provide information about what the impairment is. The combined use of patient reported and physical outcome measures has been advocated to provide a complete assessment of the patient(117, 124, 175, 176).

The measurement of the physical function of the wrist, has relied upon the use of manual equipment (e.g. hydraulic dynamometers), providing only limited data capture of a small number of a priori selected key functional characteristics (e.g. pinch strength) (118). Electronic analogues of the manual measuring systems are now becoming more widely available, providing a much greater breadth of measurements, capacity for data extraction, and post capture analysis (177-182). Despite the increasing use of electronic systems, limited comparisons with their manual counterparts have been performed. Therefore, a comparison was undertaken to ensure the electronic equipment demonstrated a similar degree of reliability and usability for both patients and practitioners in the following correlation chapters.

The radiological outcome also forms part of routine outpatient monitoring. The post-operative radiograph is assessed to determine the adequacy of the fixation and to assess for late collapse of the fracture. Fixation devices such as volar locking plates strive to achieve an anatomical reduction of the fracture and hence restoration of the radius on the post-operative radiograph(183). The introduction of these devices has led to the reduction in the use of traditional methods of fixation such as closed reduction and percutaneous wiring, even though the association between the radiological and functional outcome remains unclear(184, 185). The association of the functional and radiological outcomes of these patients for the immediate 12 months following their operations was consequently investigated.

The outcome of these patients beyond the initial 12 months post-operative period has received little attention in current literature. Only a limited number of quantitative studies are available, showing that some patients continue to have severe symptoms at 12 months after sustaining their fracture(186, 187). No studies have considered patients' perspectives of their long-term wrist function or their recoveries. Therefore, patients' perspectives concerning their recoveries were explored to provide insights into the longevity of their symptoms, and the processes involved in their recoveries.

In summary, I have attempted to improve the evidence base of patients managed with an operation for their distal radius fracture, by investigating the following overarching aims:

1. To explore senior orthopaedic surgeons' decision-making when deciding upon operative management for patients who have sustained a dorsally displaced distal radius fracture.
2. To systematically identify and critically appraise clinical trials comparing the functional outcome of adult patients with a dorsally displaced fracture of the distal radius treated with either closed reduction and percutaneous wire or open reduction and volar locking plate fixation.
3. To examine the reliability of electronic and manual dynamometry and goniometry in the assessment of hand function in healthy participants, and patients with an operatively managed fracture of the distal radius
4. To assess the strength of association (correlation) between radiological parameters and patient reported and physical functional outcome measures in patients with an operatively managed distal radius fracture
5. To explore patients' perspectives of the long-term consequences of their operatively managed distal radius fractures.

2. An exploration of orthopaedic surgeons' decision-making when deciding upon operative management for distal radius fractures

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Ethical Approval

The protocol for this study was given ethical approval by the Bristol Research Ethics Committee on the 24th July 2013

The orthopaedic care of patients with a dorsally displaced fracture of the distal radius often commences in the fracture clinic, where their treatment is decided. Patients are initially assessed as to whether they will require operative management and subsequently a range of potential treatment options are considered. The decision to adopt a particular method of management can be influenced by a number of factors that will be explored within this chapter. In subsequent chapters the critical examination of the evidence supporting common operative interventions; the assessment of those patients; and the outcome of their management has been explored.

Introduction

Fractures of the distal radius are a common injury that can be managed with a range of treatment options; broadly these involve either an operation or immobilisation with a plaster cast or external brace. Variation in the utilisation of surgical services is widespread for this group of patients, with operative rates shown to vary with geographical location, despite a similar distribution of patients(168, 188). Similar findings have been shown for a number of conditions, such as joint replacement surgery of the hip and knee (189, 190). Differences in healthcare policy and service availability do not sufficiently account for these discrepancies(191-193). This instead suggests that variation may also arise from the processes integral to the individual surgeon's decision-making and the influence of factors such as patient attributes upon those processes.

Variation in healthcare utilisation

Variation in the treatment of patients can be detrimental to patient care, and result in the waste of resources(194). It is therefore important to identify potential sources of variation and inefficiency(194). In Spain, New Zealand, USA, and the UK, healthcare atlases have been established in order to document national variations in the distribution, and usage of medical resources(195-198). They collect data on numerous aspects of health and social care provision, including rates of; medications prescribed, referral for specialist intervention, admission to intensive care beds etc., with respect to the age, gender and geographical location of the patient(195, 196). Policymakers, healthcare analysts, and researchers, have utilised this data to better understand health care systems, thus enabling improvements to be made in both efficiency and effectiveness(189).

Through this scrutiny of healthcare utilisation, a number of variations have been detected. These variations can be categorised as either warranted or unwarranted. Warranted variations are those that can be explained by differences in rates of illnesses, patients' preferences, characteristics, and the cost of supplies between areas(194).

This is best illustrated by conditions where a certain treatment option is commonly recommended, such as surgery for fractures of the hip(199). In Hawaii, the incidence of patients sustaining a hip fracture is lower than other areas of the US, hence, the corresponding reduction in rate of surgery can be attributed to the incidence of sustaining a fracture as opposed to differences in surgeons' recommendations(196). Unwarranted variations typically result from differences amongst providers, and constitute the largest cause of variation in the NHS and USA healthcare systems(194). These variations can be considered in reference to the type of care they effect: Preference sensitive care, supply sensitive care, and effective care.

Preference sensitive care

Preference sensitive care is when there are a number of treatment options available, which may impact to different extents upon the quality, and duration of the patient's life(194, 196). For example, plate fixation of distal radius fractures can allow earlier mobilisation of the wrist in comparison to immobilisation in a plaster cast, which may enable some workers to return to work sooner(200). However, plate fixation carries a greater risk of tendon injury and infection, which may require another operation(51). In view, of the implications to patients, they should be provided with sufficient information about the risks and benefits of the treatment options available to ensure they can make an informed decision(199). Often, this does not occur, and patients delegate the decision-making to clinicians, who often have an inaccurate grasp of the patients' views and preferences(194). This has been shown with the rates of mastectomy and breast conserving surgery, which vary despite little evidence to suggest patients view the trade off between procedures differently across areas(199, 201). Caldon *et al.* found the rate of mastectomy varied with both the style of consultation and the decision-making experiences of patients with breast cancer(202). Patients in low mastectomy units tended to have paternalistic consultations, where they were provided with less information and were often guided into the surgeon's favoured decision(202). In comparison, in medium to high mastectomy units decision-making was patient centred, with the surgeon supporting the patient by providing information and discussing each option until the patient felt ready to come to their decision(202).

Variation can also arise due to differences in clinicians' opinions regarding the efficacy and the indications for treatment, as a result, clinicians may base their recommendations upon their own experiences(194, 203). This variation has been shown for the rates of tonsillectomy performed on children in the UK. Glover *et al.* demonstrated in the 1930s that the rate of school children referred for tonsillectomy varied according to the judgement of the medical officer responsible for their care(203). Forty years after this study was performed, rates of tonsillectomy were again found to vary, however, this variation arose from differences in the importance consulting surgeons placed upon patients' physical symptoms of tonsillitis(204, 205).

Supply sensitive care

Supply sensitive care refers to diagnostic interventions, hospital admission rates, availability of new technology, and specialist consultations(194). Variation in the utilisation in this care, can arise from differences in local availability and capacity instead of need, which may result in the of overuse of resources(194). For example, the Dartmouth atlas project found that more than half the variations in hospitalisation rates for medical patients were related to the availability of staffed beds instead of need(195, 196, 206). Similarly, the number of patients with a distal radius fracture managed with plate fixation instead of Kirschner wire fixation increased with the introduction of volar plate technology(207).

Effective care

Lastly, there is effective care incorporating treatments proven to be of value, supported by clinical effectiveness data(195). Despite, encompassing treatments with little clinical uncertainty, the uptake of this care can be variable. In a study performed by the Rand corporation only 55% of patients in the US were taking the recommended medications for their condition(208). Similar findings have been shown in the NHS with a fivefold variation in the uptake of nine care processes recommended by the National Institute for Health and Clinical Excellence(195).

This underuse of resources means patients are frequently inadequately treated for their condition, leading to changes such as diabetic retinopathy being picked up at a later time, as patients don't receive their annual eye checks(195). These variations are considered to arise from organisational failings that occur with the involvement of multiple clinicians and a lack of an overseeing structure to coordinate patients' care(194). Patients treated by either fewer clinicians, or in areas where 'team medicine' is practiced, tend to have better care(195).

Factors influencing decision-making

We have already seen that clinical decision-making constitutes a major cause of unwarranted variation in healthcare provision. A number of factors have been found to influence clinical decision-making. These can be broadly categorised as patient, clinician, and context-related factors(209, 210).

Patient-related factors include; the patient's age, ethnicity, gender, occupation, socio-economic class and concomitant illnesses (191, 193, 209-211). Adams *et al.* for example, demonstrated differences in clinicians' decision-making when diagnosing and referring patients for cardiovascular services, in response to the patient's age(115, 212). Clinicians' were less likely to use their 'knowledge structures' in the diagnosis of older patients with cardiovascular disease, in comparison to midlife patients. O'Malley, similarly found lower socioeconomic class and increasing age were associated with a lower rate of referral for mammography(211). Age in conjunction with gender was also found to vary clinicians' diagnosis, with a greater degree of uncertainty with regards to the patient's diagnosis demonstrated with middle-aged women in comparison to male patients(213).

It is also well documented that decision-making varies with race, with black patients less likely to receive high quality care in comparison to white patients(214). Part of the cause for this discrepancy, arises from the effect of clinicians' implicit racial biases and explicit racial stereotypes upon the cognitive processes involved in their decision-making(214, 215). Van Ryn *et al.* suggests when clinicians are influenced by their racial biases, they can prompt stereotype threat, impacting upon the patients' cognition and behaviour(214). These alterations can result in a breakdown in communication in the consultation, and the propensity of the clinicians'(214). The patients' negative associations of disrespect and discrimination from their consultation, can then lead to poor adherence with treatment, a delay in seeking medical assistance, and a reluctance to partake in screening(214).

Clinician-related factors encompass the clinicians' age, gender, training, their level of expertise, specialism, preferences for the management options available and their concern regarding malpractice (168, 169, 209, 210, 216-219). Irwin *et al*. found younger orthopaedic surgeons tended to recommend spinal fusion and instrumentation for degenerative lumbar disorders in comparison to their older neurosurgical peers (217). The influence of the clinicians' expertise and specialism on the diagnosis and management of patients with breast cancer has also been demonstrated by McKinlay *et al* using a factorial experimental design study(210). Physicians practicing for less than 15 years were more likely to diagnose breast cancer and suggest tissue analysis in the presence of an ambiguous breast lump, in comparison with either senior or surgical colleagues(210). In addition, following mastectomy, surgeons were more likely to recommend reconstructive surgery compared to physicians(210).

Lastly there are context-related factors, including the type of health care system, local culture of the department, and resource availability (168). In Adams' examination of the influences upon the diagnosis and referral of patients with cardiovascular disease, differences between the US and UK health care systems were also examined(115). Clinicians within the predominately private US healthcare system were influenced to a greater extent by the risk of malpractice, whilst decisions made by UK clinicians were affected by the difficulties they had experienced in accessing diagnostic tests(115). Rates of operative procedures have similarly been shown to vary with financial incentives. Physician owned practices able to accept financial incentives in the US have demonstrated higher rates of procedures, in comparison to hospital based practices which can not(199). This is less likely to be a problem for patients treated within the UK, as there is a proportionally smaller private practice, with most patients treated within the NHS. The introduction of new technologies and surgical procedures, however, has a common effect on the decision-making in both the UK and US(199). Surgeons have been shown to disagree on both the efficacy of the new treatment, and the indications for the procedure, resulting in disparity in operative rates e.g. the first regions to introduce laparoscopic cholecystectomies had a disproportionate increase in operative rates compared to regions mainly performing open cholecystectomies(220).

Clinical decision-making

In addition, to having an appreciation of the influences upon clinicians' decision-making, it is important to grasp the cognitive processes involved in formulating those decisions. This assessment will provide the basis for determining how decision-making can be improved, in order, to reduce variation in decision-making.

Clinical decision-making has been widely considered in the literature with a number of models proposed to depict the cognitive processes that occur in the decision-making of both nurses and physicians(92, 93). Traditionally these models were assigned to either; the systematic-positivist stance, whereby decisions arise from analytical reasoning e.g. the information-processing model, or the intuitive-humanist stance, with decisions based upon the clinicians' intuition and pattern recognition(92, 94, 96).

A number of models have since been introduced incorporating both stances; the dual-processing model and the classification model(93, 112). The dual processing model suggests decisions are made through the employment of two systems, the intuitive and the analytical systems, both with the ability to override the other system(112). The classification model instead suggests the hypothetico-deductive and pattern recognition approaches constitute classification processes(93). Decisions are formulated from three linked classification tasks: diagnosis, assessing potential outcomes and making intervention decisions(115). Each task involves the selection and integration of relevant cues and contextual information into; diagnostic, outcome and intervention classes(115). These models are explored in greater depth in chapter 1.

Bias and Uncertainty

In addition to the models proposed to explain the cognitive processes occurring during clinical decision-making, two theories have emerged from Chassin and Wennberg to further expand upon how this disparity arises(101, 169, 221).

Chassin postulates that surgeons are influenced by their enthusiasm for a given procedure, and variation results from a difference in the prevalence of these 'enthusiasts' (221, 222). In the example of carotid endarectomy; Chassin found areas where high volumes of carotid endarectomies were performed, there was a greater number of surgeons individually performing larger numbers of the procedure in comparison to low volume areas(221).

Wennberg, however, suggests that in the absence of a clear management framework, professional uncertainty ensues (101, 223). This absence of a framework is derived from the lack of clinical effectiveness data that persists for many treatments despite significant advances in evidence-based medicine. In response to this lack of data, it is argued that clinicians' are instead influenced by their prior clinical experience, training, expertise, local practice and idiosyncratic factors e.g. personality and values (101, 224). As these factors differ between clinicians, it is possible therefore clinicians will opt for different treatment options, and hence disparity in healthcare provision ensues. In regards to the management of patients with a fracture of the distal radius, a recent review undertaken by the Cochrane collaboration found no clear evidence for the optimal management of this group of patients (170). Professional uncertainty may therefore provide a reason for the disparity in the operative rates of these patients.

Clinical relevance

A consideration of clinical decision-making may have important implications for clinical effectiveness and education (93, 110). Processes used to guide clinical decision-making can be enhanced to reflect those that occur in practice, and managers responsible for quality assurance can be better educated, improving their ability to implement clinical governance (93, 110). For the practitioner, Buckingham *et al.* suggest an awareness of their own decision-making will allow them to 'consolidate those elements that lead correctly to predicted outcomes and re-evaluate those which do not', affording an improvement in clinical effectiveness (93). The skills and processes involved in the successful decision-making of expert clinicians can also be incorporated into clinical education programmes, thus optimising the training of junior practitioners (110).

Therefore, in this study, the decision-making of senior orthopaedic surgeons in the management of patients with a fracture of the distal radius will be considered. The patient attributes, the context within which the decision was made, and the characteristics of the surgeon making the decision will be addressed. A model will be generated to depict the decision-making processes involved. By interrogating this process of decision-making it is hoped that greater transparency will be achieved allowing for new insights to be gained. Such insights may enable a clearer understanding of the discrepancies that exist in the management of these patients, leading to improvements in clinical and organisational effectiveness, and hence better outcomes for patients.

Aims

The main aim of this study was to explore senior orthopaedic surgeons' decision-making when deciding upon operative management for patients who have sustained a dorsally displaced fracture of the distal radius. Factors relating to the patient, the surgeon and the context of the decision were examined, to gain an understanding of how surgeons formulated their decisions and what factors provided the greatest influence.

Research Questions

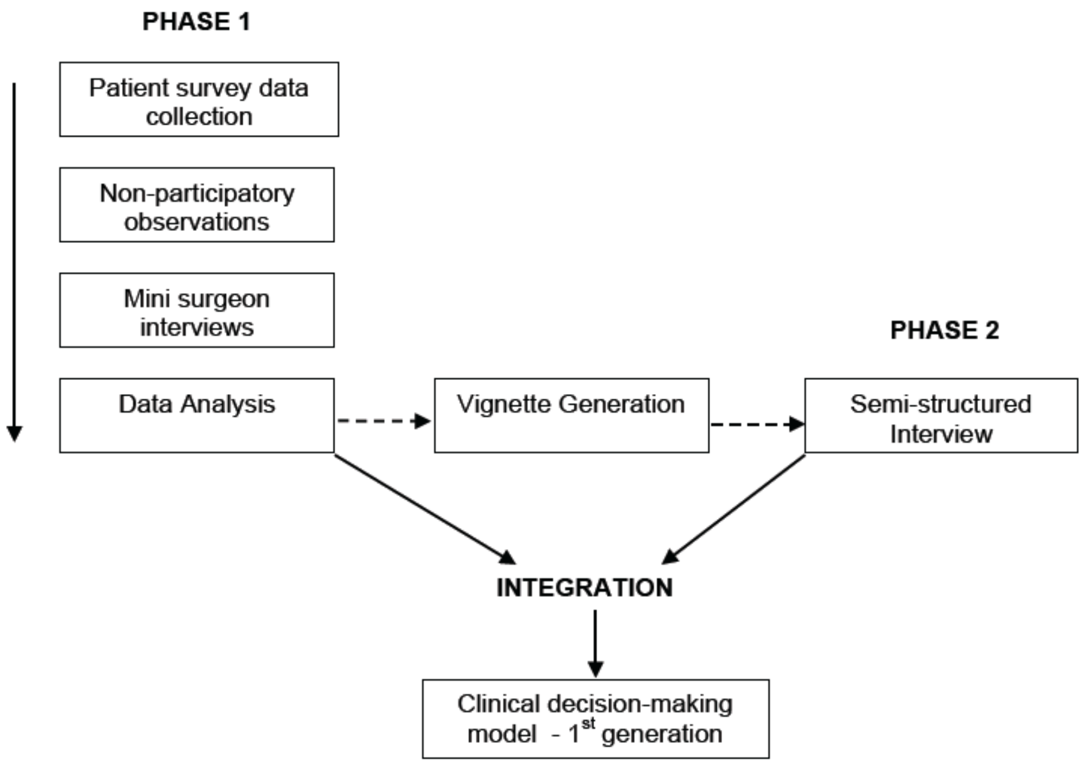
In order to meet the study aims, I addressed the following research questions in this study:

1. Which patient, surgeon, and context-related factors are associated with operative and non-operative management for patients presenting with a dorsally displaced fractures of the distal radius?
2. How do senior orthopaedic surgeons formulate their decisions when deciding upon operative management for fractures of the distal radius?
3. How do patient, surgeon, and context-related factors influence orthopaedic surgeons' decision-making when deciding upon operative management for acute dorsally displaced distal radius fractures?

Study Design

The study was comprised of two phases. During the first phase I undertook structured patient interviews to determine the characteristics of patients presenting to a district general hospital and a university teaching hospital with an acute fracture of the distal radius. This was followed by a non-participatory observation of the consultation between the patient and orthopaedic surgeon. I then conducted mini-interviews with the surgeons immediately after the consultation, to identify the main patient factors that influenced the surgeon's management plan. The data collected from phase 1 was then used to inform the generation of the clinical vignettes, which formed the basis of in-depth semi-structured surgeon interviews in the proceeding phase. The two phases of the study were therefore integrated early during the analysis process and in production of the interpretation, see figure 4.

Figure 4 - sequential mixed methods study design



Theoretical basis of study design

The research questions posed in this study require exploratory research to be undertaken, to clarify the processes involved in the decision-making of orthopaedic surgeons and the influence of patient, surgeon and context-related factors upon their decisions.

I therefore, adopted a mixed methods approach in order to facilitate a thorough analysis of this complex process that cannot be grasped by either quantitative or qualitative methods alone. A quantitative approach has the capacity to determine if correlations exist between patient, surgeon and contextual factors and the resultant management, whilst also determining the strength of such an association. A solely quantitative approach, however, would fail to ascertain how surgeons process the information gleaned from their consultations with patient in order to formulate their management plans. Similarly, a qualitative approach could be employed to provide rich and in-depth accounts of surgeons' experiences of managing patients with a fracture of the distal radius. However, determining what factors influence their decision-making in practice would be time and resource consuming. The integration of these two approaches would provide more rigorous data by negating the limitations of either approach alone, and the interaction between the two approaches may reveal new insights and offer a more comprehensive understanding.

I adopted a principally qualitative, quantitative preliminary model based upon the priority-sequence model suggested by Morse (1991) and Morgan (1998), as it is straightforward and it can be undertaken by a sole researcher(225, 226). The preliminary quantitative phase was comprised of structured interviews with patients and orthopaedic surgeons, and non-participatory observations. This phase allowed a determination of the factors associated with the surgeon's decision to opt for either operative or non-operative management that were then integrated into the generation of clinical vignettes in the second phase and the overall analysis.

The qualitative phase encompassed semi-structured interviews with senior orthopaedic surgeons. Semi-structured interviews were chosen to provide richly detailed open-ended responses, whilst ensuring the data was comparable amongst all interviewees. Clinical vignettes of patients with a dorsally displaced fracture of the distal radius were presented during the interviews to form the basis of the discussion and to provide context to the surgeon interviews.

Clinical vignettes have been shown to be a valid tool for measuring clinician decision-making in outpatient practice (227-229). In the assessment of physician practice; the quality of care measured with the vignettes was found to be comparable to the gold standard, standardised patients where a trained actor presents unannounced(227, 228). Using the vignettes, it was possible to detect both unnecessary care and a range in the quality of care with varying levels of physician training(227, 228). Vignettes therefore offer an inexpensive tool that can be used for a variety of disorders, settings and with physicians from all disciplines, whilst controlling for patient-mix(227, 229)

Phase 1

Objectives

The objective of this phase was to determine what patient, surgeon, and context-related factors were associated with operative and non-operative management of patients with dorsally displaced fractures of the distal radius who presented to University Hospital Coventry and Rugby Hospital St Cross.

Sampling

A consecutive sample of 19 patients presenting with a dorsally displaced distal radius fracture were recruited from the daily fracture clinics held at a university teaching hospital and a district general hospital. One to three consultants staffed each clinic, changing daily, which ensured a greater diversity of consultants was also recruited. Recruitment was from October 2013 until March 2014, in order to encapsulate the winter months, which typically have a greater incidence of distal radius fractures(230-232).

Eligibility Criteria

Patients meeting the following eligibility criteria were approached to enter this study:

- Aged 18 years and older
- Closed, dorsally displaced fracture of the distal radius within 3cm of the radio-carpal joint identified on the presenting radiograph
- Presented within 2 weeks of the original injury
- Able to give informed consent

Patients were excluded from participating in the study if:

- They had sustained multiple injuries requiring treatment in addition to their distal radius fracture

Orthopaedic surgeons meeting the following eligibility criteria were approached to enter this study:

- Either consultants or senior trainees post-FRCS
- They had experience with managing fractures of the distal radius as part of their current general trauma practice, involving either the diagnosis of the fracture or performing the operative procedure

Patient Structured interview

Structured interviews were conducted with all eligible patients consenting to enter the trial immediately prior to their fracture clinic appointment. I used an interview schedule to collect data regarding the patient's demographic details, occupation, current state of health, level of independence and injury (appendix 1)(193, 213, 219, 229, 233-246). These factors were chosen as they have been shown to influence surgeons' decision-making, and because they provide an indication of the patient's previous wrist function and the risks associated with performing an operation.

Two orthopaedic surgeons (an upper limb specialist and a generalist) from the university teaching hospital reviewed the schedule during its development, to ensure that sufficient patient information could be extracted to formulate realistic clinical vignettes to be used in the surgeon interviews in phase 2. The schedule was piloted on the first patient prior to the commencement of the designated recruitment period from January to March 2014, the schedule was found to capture all the relevant information and hence no adjustments were required.

Observation of consultation

Following the structured interview, I accompanied the patient into their consultation with the orthopaedic surgeon, to gain an insight into the interaction between the surgeon and patient and the exchange of information within a typical consultation. Prior to the consultation, I stressed to both the patient and the surgeon that as an observer I would not actively participate in the consultation. I subsequently positioned myself discreetly in the room to reduce the effect of my presence on the consultation (36). Consultations were short in duration typically lasting 5-10 minutes and were often situated in small cubicles. Therefore, further measures to reduce the risk of bias such as: the presence of two independent observers, and the inclusion of an adjustment period to normalise the participant to the presence of an observer, were not possible in this study (36).

A structured observational schedule was used to record information on the interaction between the patient and surgeon, the setting and the types of information exchanged (appendix 2)(247). The schedule was based upon the key elements comprising a normal orthopaedic consultation and was developed from a search of the literature(247). Following the observation the schedule was embellished with the any further impressions, and interpretations that could not be recorded during the observation(248, 249). The schedule was again piloted with the first patient interaction, however upon reflection I deemed no adjustments to be necessary. Although the schedule offered the opportunity to capture unexpected events, none occurred during any of the patient observations(247). In situations where the surgeon did not feel they had sufficient time to participate in the study, the surgeon's management plan for the patient was extracted from the electronic patient notes.

Surgeon mini-interviews

The structured mini-interviews were conducted with the consulting orthopaedic surgeons to briefly explore the reasoning behind their decision for operative or non-operative management. The interviews took place in the patient consulting room immediately after the observation period and lasted approximately 1-2 minutes in duration. The surgeon was asked to reiterate how they would manage the patient, the reasons for their decision and what it was specifically about the patient that had prompted their choice of management. The dialogue was recorded using an electronic audio-recording device. As the audio-recordings were short in duration, analysis was performed directly from the recordings. The gender, specialty and level of expertise of the surgeon were all recorded on the observation schedule.

Data analysis

The patient interview data, observations and surgeon mini-interviews were integrated into a descriptive assessment of the factors that contributed to the surgeons' decision-making at the University teaching hospital and District General Hospital and to form the basis of the clinical vignettes.

The following data was extracted from the patient interview schedules and observation field notes regarding the patient, the surgeon, the management plan and the setting of the consultation:

- Patient: demographic details, occupation, hobbies or activities deemed important to the patient, mechanism and hand dominance of the injury, concomitant illnesses, level of independence, smoking and alcohol usage
- Surgeon: the age, gender, speciality and level of experience
- Context: the hospital setting and the duration of the interview
- Management plan: the surgeon's suggested management plan and the agreed management plan.

As the surgeon interviews were short in duration, I analysed the data directly from the audio recordings, extracting the surgeon's preferred management plan and reasons for their decision, as opposed to transcribing the recordings and analysing the transcriptions. All the extracted data was then amalgamated into one table to provide a summary of each patient to be used as a basis for the clinical vignettes. Descriptive statistics were performed to determine whether associations were present between the patient, surgeon and contextual factors and either operative or non-operative management.

Phase 2

Objective

The objective of the second phase was to explore the influence of patient attributes, surgeon characteristics, and the clinical context, on orthopaedic surgeons' decision-making when presented with clinical vignettes for patients with an acute fracture of the distal radius.

Sample size

A purposive sample of 14 senior orthopaedic surgeons based in the United Kingdom (UK) was recruited. Attempts were made to recruit surgeons from hospitals situated around the UK of varying expertise, level of experience, gender, and training background.

Eligibility criteria

Orthopaedic surgeons meeting the following eligibility criteria were approached to enter the study:

- Either consultants or senior trainees post-FRCS
- Experience with managing wrist fractures as part of their current practice

Vignette generation

Four paper-based clinical vignettes were generated from patient interview data. The predominate factors were identified and categorised as follows:

- Age: Older patient (>60 years) and younger patient (18-60 years)

- Gender: Male and female
- Mechanism of injury: high or low energy
- Hand dominance of injured wrist: dominant or non-dominant
- Occupation: Retired/ unemployed, employed (physical/manual) and employed (office based)
- Level of independence: Dependent (poor mobility and requiring care assistance) and independent
- Comorbidities: Multiple comorbidities impacting upon daily health, mild comorbidities and none
- Alcohol use: heavy (greater than advised weekly levels), moderate (maximum weekly allowance) and minimal (within lower limit of weekly allowance).
- Smoking use: smoker and non-smoker.

The age and gender categories were combined first, to create the basis for the four clinical vignettes: Older male, older female, younger male, and younger female. These patient groups were chosen specifically as they reflect the bimodal distribution of patients (as discussed in the Chapter 1) presenting to orthopaedic surgeons, and as such a potential difference in bone quality and functional demand. Additionally, patients' gender has also been shown to be an important factor influencing clinicians' decision-making. The remaining characteristics were then combined to generate vignettes that would represent realistic cases UK-based orthopaedic surgeons would be likely to manage in practice as part of their normal orthopaedic trauma practice (Figure 5).

Figure 5 – Clinical Vignettes presented during surgeon interviews

Vignette 1
An 85 year old man presents to the acute fracture clinic in a wheelchair with a below elbow 'back slab' applied by Accident and Emergency department for a right distal radius fracture. He fell out of bed two days ago in his nursing home after trying to get up to go to the toilet. He has no other injuries. *He is a right hand dominant, non-smoker and normally walks with a frame around the home, and needs some help with bathing. He has several medical problems including angina, hypertension and 2 prior TIAs.*
Vignette 2
An active 63 year old lady presents to the acute fracture clinic with a below elbow 'back slab' for a fracture of the right distal radius that has been manipulated by Accident and Emergency department. She sustained this injury after tripping on paving slabs in her garden. She also has a bruise on her left knee but no lacerations or bony injuries. She is right hand dominant. *She is a retired librarian but now looks after her grandchildren two days a week and enjoys*

gardening and walking. Normally she is fit and well, with hypertension controlled with medication. She is an ex-smoker of 7 years and has a moderate alcohol intake of approximately 14-20 units per week. She is fully independent
Vignette 3
A43 year old left hand dominant female ambulance technician presents to the acute fracture clinic. She has a below elbow 'back slab' for a fracture of the right distal radius that has been manipulated by the Accident and Emergency department. She was thrown off her horse forwards, knocking her head on the ground and landing predominately on her wrist and then taken to hospital via ambulance. In A&E she had an unremarkable full trauma CT, and the radius fracture was noted on the secondary survey. She has some bruising and grazing to the forehead and left knee. *She is an active horse rider, and has four children aged 5 to 13 and lives with her partner. She has exertional asthma and is a non-smoker with a minimal alcohol intake.*
Vignette 4
A left hand dominant 26-year old man presented to the acute fracture clinic with a right distal radius fracture, after slipping on wet floor in the pub. It was his sole injury. He has a below elbow 'back slab' put on in A&E. *He has a managerial role working with computers based in London, regularly goes to the gym. He is fit and well with no medical problems. He smokes 20 cigarettes per day and has a moderately high alcohol intake of 30 units.*

I had intended to use a factorial experimental design to combine patient characteristics in the generation and assignment of the vignettes to the participating surgeons. This approach has been used in prior studies in order to estimate the unconfounded influence and interaction of patient, clinician and context-related factors upon clinical decision-making. Typically, the vignettes in these studies maintain the same clinical details for the patients, and alter demographic factors for the patients instead. For example, in a study of clinicians' decision-making; clinicians were presented with two patient vignettes with cardiovascular disease and depression(191). The clinical details for the two vignettes remained the same, whilst the following patient factors were altered; age, gender, race and socioeconomic status(191). Each vignette tested two variables, meaning a total of $2^4 = 16$ unique vignettes were required to assess the patient characteristics alone(191). In order to estimate physician factors as well, and to repeat each combination twice, a total of 256 clinicians were required to participate(191).

I chose not to adopt this design for several reasons; firstly, this study was designed to be exploratory to determine the factors orthopaedic surgeons deemed important to their decision-making, as opposed to detecting bias towards certain characteristics e.g.

ageism or sexism. The factors of interest also included clinically relevant factors such as the mechanism of injury and number of comorbidities, which if randomly combined would generate a number of unrealistic vignettes. For example, a 90-year old wheelchair patient with significant comorbidities would be unlikely to sustain a high-energy distal radius fracture through a sporting injury or road traffic injury. Lastly, to assess all of the chosen patient factors, the sample size required would be both beyond the resources available during this PhD and unrealistic to achieve in the UK alone, in particular with regards to achieving a sufficient sample of female orthopaedic consultant surgeons.

Each surgeon was presented with the same four vignettes of closed dorsally displaced distal radius fractures, and four antero-posterior and lateral anonymised radiographs varying in the degree of displacement (figure 6). Patients were shown both displaced and minimally displaced radiographs to allow a greater assessment of surgeons' thresholds for their decisions. The order of the presentation of both the vignettes and radiographs was randomised using a computer generated random sequence.

Figure 6 - Vignette radiographs

(a)

(b)

Surgeon Interviews

I conducted individual semi-structured interviews with all participating surgeons about their experience of managing acute fractures of the distal radius. The semi-structured interviews allowed the interviewee to direct the interview towards topics deemed important to them. The interviews were conducted either face-to-face for surgeons participating within the west midlands or via telephone for those based further afield. In both types of interview the dialogue recorded was using an electronic audio recorder with the permission of the surgeons.

The interviews commenced with questions regarding the surgeon's specialism, training history, and their experience and preferences when managing acute distal radius fractures (144). I then presented each surgeon with one of the vignettes and radiographs at a time, in order, and asked how they would mange the patient and the reasons for their decision.

The vignette acted as a probe in the interview to elicit a response that was as close as possible to their normal management of patients with this injury. Prompts were used to further explore the influence of the patient-related factors specific to the vignette on their decision-making. At the conclusion of the interview, surgeons were asked whether there were any constraints from the hospital system within which they worked that might alter their decision-making in normal practice. Feedback was also sought during an early interview regarding whether the vignettes were representative of typical consultations with this group of patients(191). The vignettes were deemed representative and hence no alterations were made for subsequent interviews. The anonymised audio recordings were transcribed using a professional transcription service bound by a confidentiality agreement, and the transcription checked against the audio recording for accuracy.

Coding and analysis

The transcripts were analysed for the processes involved and the differences between surgeon's decision-making with respect to each of the 8 scenarios, where each vignette conferred 2 possible scenarios with a displaced and less displaced fracture pattern.

The process of analysis commenced with immersion into the data, involving listening to the audio-recordings, reading and re-reading the transcripts(250, 251). Preliminary interview transcripts were coded thematically using the NVIVO coding software. A broad coding framework was initially formulated (see Table 1). From the coded text I generated summaries of surgeons' decision-making for each scenario (see examples in Table 2). As I had carried out the interviews, to distance myself during the coding procedure and reduce the risk of reporting bias, I reassigned each surgeon a participant identifier consisting of a letter that did not correspond to their name.

Table 1 – Broad coding framework

Code	**Description**
Decision making	Decisions made by the surgeon with respect to the patient's management and the reasons for their decisions
Scenario 1	85 year old man with a minimally displaced fracture

Scenario 2	85 year old man with a displaced fracture
Scenario 3	63 year old woman with a minimally displaced fracture
Scenario 4	63 year old woman with a displaced fracture
Scenario 5	43 year old woman with a minimally displaced fracture
Scenario 6	43 year old woman with a displaced fracture
Scenario 7	26 year old man with a minimally displaced fracture
Scenario 8	26 year old man with a displaced fracture

Table 2 - Examples of decision-making summaries

Scenario 1 - 85 year old man with a minimally displaced fracture	
Participant E	As soon as you said he's from a nursing home, that's enough information for me to say that patient is going to be treated in a cast for four weeks, and then mobilised early. I'd put him straight into a cast, and I would x-ray him, I would get the plaster off at four weeks and pop him into a future splint, or a plaster for a little bit longer if he's sore, and think about physiotherapy The main aim with him is to maintain finger dexterity, rather than wrist function If it heals like that, or if it collapses a bit more, he will lose some pronation-supination, or a little bit of flexion extension, but this is going to have an impact on this guy's life.
Participant M	I would manage this none surgically. I would put this patient in a plaster, accept the position as it is, we could do some gentle moulding in the plaster to just ensure it didn't slip further. I wouldn't even re x-ray it, I would take the plaster off in six weeks. He's a very low demand patient, and they're fairly high risk for surgery, so it would automatically take me … I would only operate on a patient like that, for example, if we had to, if they had a nerve injury or an open fracture that would necessitate surgery. Other than that I would try and avoid that, because the risk of surgery is probably higher, and certainly the risks outweigh the benefits for that patient.
Participant X	He'd get a hematoma block, a well moulded cast in the plaster room, and put a complete cast on it, and then I'd bring him back in six weeks time, get his cast off, get him going, wouldn't re x-ray him His age, he's got a lot of co-morbidities, and we know actually if we can get into a reasonable position in an 85 year old, and it heals in that position, that it's unlikely to have any issues in the longer term, so I think that would be perfectly acceptable
Participant H	I would manage this conservatively Look that's an acceptable position," and I would just put him in a complete cast

	and I would probably repeat the x-ray. So a well molded cast, no blocks or anything and just check the positioning, I think this guy would do fine from just a cast Bit too old to give an 85 year old with medical issues a Bier's Block for what looks to be a pretty… a fracture that will do pretty well

Together with supervisory FG, I reviewed 5 of the decision-making summaries, discussed them and developed a refined coding scheme for the surgeons' decision-making (252). Both CP and FG then coded 25% of the summaries independently, and compared their coding to finalise the coding scheme (Table 3) (252, 253). Agreement was reached for 90% of the coded sections, with disagreement arising with regards to what constituted the potential for re-displacement. For example, a well-moulded cast might suggest the surgeon has chosen this management to prevent displacement of the fracture. However, it would not be possible to ascertain whether this assumption was correct. Therefore, we decided that unless the surgeon specifically stated their reasoning it would be discounted.

The refined coding scheme was then used to code the remainder of the decision-making summaries for each vignette scenario.

Table 3 - Refined coding scheme for surgeons' decision making processes

Code	Description
No process described	Surgeon did not describe their decision-making process
Bone position	Appearance of the fracture configuration on the radiograph
Future function	Long term functional outcome of the patient, taking into consideration the patient's current functional demand
Bone quality	Appearance of the bone density on the radiograph
Potential for re-displacement	Stability of the fracture configuration on the radiograph and the risk of displacement of the fracture
Anaesthetic risk and Co-morbidities	Risk of anaesthesia, taking into consideration co-morbidities and age of the patient

Interpretation phase

A model was then formulated based upon the decision-making of surgeons in both phase I and phase II, to provide a diagrammatic representation of the processes involved in the surgeons' decision-making and the interplay with the patient, surgeon and context-related factors.

Study Procedures

Recruitment

Phase I

At the start of the fracture clinic, all the eligible orthopaedic surgeons were informed about the study and invited them to participate. Potential patients were identified from the fracture clinic patient list and eligible patients presented with an information sheet and informed about the study. All participants were given the opportunity to discuss any issues related to the study.

Phase II

Surgeons were approached from surrounding West Midlands NHS trusts and from previous collaborators of the DRAFFT trial. Individuals were invited to participant in the study either via email or in person and provided with a participant information sheet and given time to consider the information and discuss any questions prior to consent.

Consent

Phase I

I obtained informed consent, from both the surgeons and the patients expressing an interest in participating in this study. Participants were given the opportunity to consider the study information and commitment. All participants agreed to consent and data collection was completed on the same day. On two occasions, the surgeons declined to participate in the study, stating they were unable to participate due to time constraints within the clinic. On both occasions the patient interviews were conducted without either the observation of the consultation or the surgeon mini-interviews.

Ethical considerations

Patient Structured Interviews

There was a low risk of harm from this study, interviews typically lasted 10-20 minutes of the patient's time and were carried out within the fracture clinic to prevent disruption to the patient's appointment. The interview focused upon the patient's injury, current state of health, employment and level of independence; sensitive topics were not discussed.

Observation of the consultation

Although the observation of patient-surgeon consultations can potentially cause distress to the participants under study, none appeared to demonstrate or voice any signs of distress. This was most likely due to the nature of this injury; patients were neither significantly exposed during the examination or divulged sensitive information that might have been difficult to reveal in the presence of an observer.

Surgeon interviews

The surgeon interviews lasted several minutes for the mini-interviews and approximately 10-15 minutes for the in-depth interviews. The interviews only focused upon the surgeons' professional opinion regarding their management of acute distal radius fractures. No sensitive topics were discussed, and no incentives were offered to encourage participation in the study.

Data Management

All electronic participant-identifiable information was held on a secure, password-protected database accessible only to myself. Paper forms with participant-identifiable information were held in secure, locked filling cabinets within a restricted area of Warwick Medical School. Participants were identified by a code number or letter only. All paper and electronic data will be retained for at least five years from the completion of the study.

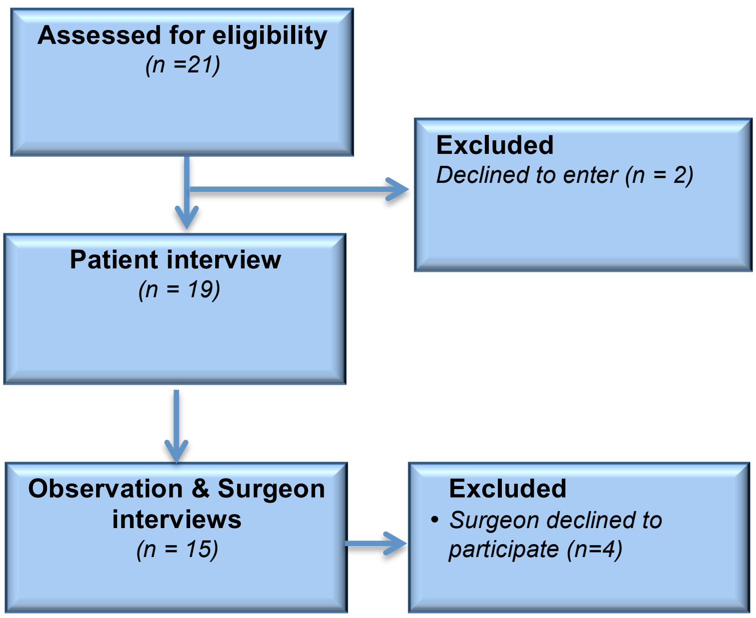
Results

Phase 1

Patient characteristics

A total of 21 patients were invited to participate in the study of which 2 declined, of the two, one stated their reason as due to a recent admission to hospital for hip fracture. The remaining 19 patients consisted of 1 man and 18 women aged 25 to 94 years old, with a mean age of 60 years old (SD 18.6). Figure 7 depicts the flow of patients through phase 1.

Figure 7 - Patient flow during phase 1



Operatively managed patients

Operative management was indicated for 6 patients; 1 patient was initially referred to the specialist upper limb team who then decided on operative management and 1 patient decided to opt for non-operative management although operative management was advocated by the surgeon, hence they have been included in the operative group. All the operatively managed patients were women aged 25 to 83 years old (Mean= 60years, SD = 18.1), with minimal comorbidities posing a minimal anaesthetic risk, and were independent with regards to their mobility, self-care and activities of daily living. Three of the patients were retired but remained active with hobbies such as childcare, and 2 were employed in computer-based and physical roles. The patients had all sustained dominant wrist injuries, involving both high and low impact mechanisms. Table 4 details the characteristics of patients operatively and non-operatively managed.

Table 4 - Characteristics of the operatively and non-operatively managed patients

Patient characteristic		**Surgeon's decision**	
		Operative	**Non-operative**
No. Patients		6	13
Mean age (years)		60	60
Gender	Male	0	1
	Female	6	12
Occupation	Unemployed	3	7
	Employed	3	6
Level of independence	Independent	6	10
	Walks with a frame or stick	0	3
	Requires assistance with self care	0	1
	Requires assistance with activities of daily living	0	3
Social habits	Smoker	0	1
	Above recommended weekly limits alcohol consumption	1	0
Injury characteristics	Dominant injury	6	8
	High energy injury	3	1

Non-operatively managed patients

Non-operative management was decided on for 13 patients, consisting of 1 man and 12 women aged 25 to 94 years old (Mean = 60, SD = 19.6), of which 10 were full independent, 2 required either a stick or the occasional use of an electric wheelchair and some assistance with domestic duties, and 1 resided in a nursing home requiring a walking frame, assistance with self care and was unable to perform any domestic duties. The patients requiring additional assistance were also the only patients to suffer from a number of significant comorbidities, such as spinal stenosis, epilepsy, angina etc. The group however, consisted of an equal number of employed and retired patients, the employed group had both office-based and physically demanding roles. The retired independent and employed patients enjoyed a variety of hobbies similar to the operative group.

Surgeon Characteristics

A total of 9 surgeons were approached to enter the study, of which 8 agreed to participate. One surgeon, who was already entered into the study and had participated with 1 patient, later withdrew their consent when approached for 1 further patient. The surgeons consisted of 1 woman and 8 men, of which 6 were of white-British origin and 3 of Asian-British origin. All the surgeons were consultant level having graduated a mean of 21.8 years ago (SD = 9.7), with 6 specialising in lower limb surgery and 3 in upper limb surgery, of which 1 sub-specialised in hand and wrist surgery.

Surgeons' decision-making

Non-participatory observational data

The observations of the patient-surgeon consultations were all undertaken in fracture clinics at two hospitals; a district general hospital (n =1) and a university teaching hospital (n = 14). In the teaching hospital, consultants commenced the consultation by reviewing the radiograph of the patient's injury outside of the clinic room and then proceeded with the consultation. In the district general hospital, the computer with access to the patient's radiographs is present in the clinic appointment. In this case, the surgeon commenced their greeting and history and then proceeded to review the radiograph of the patient's injury. All the consultations followed the same format, whereby the patient was greeted, asked the mechanism and timing of their injury and whether they had any concomitant illnesses. The affected limb was then examined and the management plan suggested by the surgeon discussed. This discussion involved an explanation of the injury and the risks and benefits associated with the surgeon's suggested management plan.

Surgeon mini-interviews

Upper limb and lower limb specialists, and those of different levels of expertise equally advised operative management. During the mini-interviews, all the surgeons based their decision-making firstly upon the radiographic appearance of the fracture, and then upon patient factors. For example, surgeon 2, "it's mostly based on the radiology" and surgeon 1, "the injury itself determines the management plan….it's mostly the fracture pattern".

In regards to the decision to operatively manage patients, hand dominance, age and activity level were all mentioned as important when deciding upon this course of treatment. Surgeon 2 for example:

> The patient is still fairly active, it's her right dominant hand and it's not unreasonable to treat and manage this with surgery. If the patient was elderly, relatively immobile and it wasn't that functional regarding her wrist you could possibly consider non-operative management.

Similarly, surgeon 3, "She's a fit lady I want to get the best outcome for her wrist".

In the non-operative group, patient-related factors were mentioned for 6 patients. However, these factors were only deemed important in the decision-making of three of the patients. For all three, the contributing patient factors included the age, functional demand and anaesthetic risk of the patient, for example, surgeon 8 explains; "She's an elderly lady with low demand, she'd be a high risk surgical candidate". Similarly, for surgeon 1, "because of her medical problems and her limited mobility".

Phase II

Surgeon characteristics

All 14 surgeons approached to enter the study agreed to participate; they included 4 female surgeons and 10 male surgeons, with 2 surgeons of British-Asian origin and the remainder of white-British origin. The surgeons were all orthopaedic surgeons with either an upper limb or lower limb elective practice, currently practicing in 7 hospitals in the UK. All the surgeons were trained in the UK from 7 training regions and have practised as medical practioners for 18.9 years (SD = 9.0). The majority of surgeons however were based at University Hospital (n = 6) and were trained in the west midlands (n = 7).

Management decision

Table 5 – Recommend management for the clinical scenarios

Patient characteristics	**Number of surgeons**					
	Displaced Fracture			**Minimally displaced fracture**		
	Operative	Non-operative	Onward referral	Operative	Non-operative	Onward referral
85 year old man Low demand	3	11	0	1	13	0
63 year old woman High functional demand	9	4	1	4	9	1
43 year old woman	11	2	1	7	7	0

High functional demand						
26 year old man **High functional demand**	11	2	1	8	6	0

Operative management tended to be reserved for younger patients with a displaced fracture, for example, 11 of 14 surgeons chose operative management for the younger patient, compared with only 3 for the elderly patients, both with the same displaced fracture configuration. A similar number of surgeons opted for operative management for the 43-year old woman and 26-year old man, less however recommended an operation for the 63-year old woman, despite the patient being active with a high functional demand.   Overall, significantly fewer surgeons opted for operative management with the minimally displaced fracture in comparison to the more displaced fracture (Table 5).

The operative rates were also found to vary with the gender of the surgeon, their level of orthopaedic experience, specialty and training region (Table 6). Gender and the training region were found to have the greatest impact of the surgeon factors. However, both groups were similar; the female surgeons' group consisted of 1 lower limb and 3 upper limb surgeons, and the west midlands deanery group consisted of 4 upper limb surgeons and 1 a lower limb surgeon. Similarly, both upper limb surgeons and those with fewer than 20 years experience tended to have moderately higher operative rates than their senior and lower limb colleagues.

Minimal difference was demonstrated in operative rates of surgeons currently practising at University Hospital Coventry, in comparison to surgeons based elsewhere.

Table 6 – Surgeons' treatment decisions in response to the eight clinical vignettes of patients with a distal radius fracture.

Surgeon characteristics		**Decision to operate**			**Operative rate**
		Yes	**No**	**Onward referral**	**(No. Yes decisions/ total no. decisions)**
All surgeons (n=14)		54	54	4	48%
Gender	**Female (n=4)**	23	9	0	72%
	Male (n=10)	31	45	4	39%
Specialty	**Upper limb (n=8)**	36	27	1	56%
	Lower limb (n=6)	18	27	3	38%
No. Years since graduation	**< 20 years (n=10)**	43	36	1	54%
	> 20 years (n=4)	11	18	3	34%
Hospital of	**University Hospital Coventry**	26	30	0	46%

employment	**(n=7)**				
	Alternate hospital (n=7)	28	24	4	50%
Training deanery	**West midlands (n=5)**	32	7	1	80%
	Alternate deanery (n=9)	22	47	3	31%

Interview analysis

The processes involved in the surgeons' decision-making were found to be predominately based upon the radiographic appearance of the fracture and the patient's age, functional demand and anaesthetic suitability. Subtle variations in these processes were demonstrated between all the case scenarios, with a noticeable difference between the oldest and youngest cases. Tables 7-14 detail quotations from the surgeon interviews illustrating these processes.

Case Scenarios 1: 85 year old man, minimally displaced fracture

In the first case, the surgeons' decision-making was based upon a risk benefit analysis, between; the anaesthetic risks due to the patient's multiple comorbidities and achieving an acceptable bone alignment in view of his low functional demands, for example with surgeon O,

> He's a considerable anaesthetic risk given that history and also his functional demand is very low. So I would be willing to accept a degree more of malalignment.

Firstly in the decision-making process, bone alignment was considered. Upon recognising the bone alignment was unsatisfactory the surgeons then assessed the treatment options in regard to the functional demand of the patient, for example surgeon X recognised the initial position of the fracture was not satisfactory, however a significant improvement was not required to meet the patient's functional demand,

> If we can get into a reasonable position in an 85 year old, and it heals in that position, that it's unlikely to have any issues.

The bone alignment was then considered in regards to the anaesthetic risk, with the invasiveness of the operative procedure dampened to suit the associated risk, for most of the surgeons this entailed a closed manipulation and casting. Surgeons O and B, however, also considered the risks of displacement as a further stage in formulating their decision, opting to monitor the patient with repeated radiographs and either re-manipulate the fracture or proceed to an operation if it displaced at a later stage.

> I would accept that and I would see him…. I think it's a high risk of re-displacement …. The result of re-displacement would probably be a re-manipulation and new application of cast

Bone quality, was the only factor not to be considered by any of the surgeons.
In addition, no processes were mentioned in the decisions of three surgeons (Table 7).

Table 7 – Quotations from surgeon interview transcripts illustrating codes from scenario 1 - *85 year old man with a minimally displaced fracture*

Refined Codes	Examples from surgeon transcripts
No process described	Put that in plaster (*surgeon J)* Non-operative treatment *(surgeon Q)* Cast and that would be it *(surgeon S)*
Bone alignment	Reduce it *(surgeon C)* If we can get into a reasonable position *(surgeon X)* Make it in a slight position to hold it *(surgeon Y)* That's an acceptable position… I would just put him in a complete cast *(surgeon H)* I would accept that and I would see him, I tend to go for about four, four and a half weeks in plaster *(Surgeon O)* Manipulation under haematoma block *(surgeon P)*
Future function	Get him going *(surgeon X)* If we can get into a reasonable position in an 85 year old, and it heals in that position, that it's unlikely to have any issues *(surgeon X)* That won't improve your function ……. Might change the way that you pronate your forearm *(surgeon A)* Loss with supination and pronation can be an issue with someone who walks… with sticks or a frame ….. If you don't get enough pronation you can't walk with a frame anymore, therefore mobility goes *(surgeon B)* Mobilised early … think about physiotherapy …. the main aim with him is to maintain finger dexterity, rather than wrist function…… he will lose some pronation/supination, or a little bit of flexion/extension, but this isn't going to have an impact on this guy's life *(surgeon E)*
Bone quality	
Potential for displacement	Do some gentle moulding in the plaster to just ensure it didn't slip further *(surgeon M)* if he deteriorates at all then I would probably, up to three weeks, would treat him operatively *(surgeon B)* I think its high risk of re-displacement and I would want to know but that ... the result of re-displacement would probably be a re-manipulation and new application of cast rather than necessarily rushing him to surgery. *(surgeon O)*
Anaesthetic risk	Under regional block *(surgeon C)* Fairly high risk for surgery *(surgeon M)* He's got a lot of co-morbidities *(surgeon X)* Accept that position in someone with a high anaesthetic risk *(surgeon Y)* At 85 with his comorbidities ……I can't think that the balance is in his benefit to sort out *(surgeon A)*

	Bit too old to give an 85 year old with medical issues a Bier's Block *(surgeon H)* he's a considerable anaesthetic risk given that history and also his functional demand is very low. So I would be willing to accept a degree more of malalignment *(Surgeon O)*

Case scenario 2: 85 year old man with a displaced fracture

This was the only scenario in which all processes were reflected in the surgeons' decision-making (Table 8). Similar to the first scenario, the management decision was based again upon a risk-benefit analysis of the bone alignment, anaesthetic risk and functional demand of the patient. A greater number of surgeons considered the bone alignment and functional demand of the patient to a greater extent than in the prior scenario.

The decision again commenced for most with the recognition of a poor bone alignment; "Clinically deformed, you can see that so I would straighten the wrist" (surgeon H), which was then reasoned against the functional demand of the patient, for example surgeon X, "It's so displaced and it would give him some significant issues if it was left that bad". Next, the anaesthetic risk of the patients was considered, with most surgeons still deeming the patient too unfit to undergo an operative procedure and instead opting for a manipulation, such as surgeon O:

> I wouldn't want to give him a general anaesthetic of course with all his comorbidities….the position it is in at the moment, I would prefer to improve it… I would like to manipulate it.

With this scenario the risk of displacement prompted only one surgeon to monitor the fracture after the initial manipulation despite the unstable fracture configuration:

> In the first two weeks, if it was to fall back badly then I would proceed to a surgical stabilisation.

This risk, however, was acknowledged by two other surgeons, with one prompted to immediate operative management, whilst the other recognised the risk, but would not act upon it with further procedures.

Table 8 - Quotations from surgeon interview transcripts illustrating codes from scenario 2 - *85 year old man with a displaced fracture*

Refined Codes	**Examples from surgeon transcripts**
No process described	He'd probably get a volar plate (Surgeon B)
Bone alignment	What I would do is realign that fracture …..maintaining the exact position of the wrist isn't that important …., I'd reduce the fracture, put it into a plaster (Surgeon M)

	Reduce it if it was in a reasonably satisfactory position (Surgeon X) You might try to manipulate that into a better position (Surgeon A) If it heals in that position it will probably do him absolutely fine (Surgeon E) Clinically deformed, you can see that so I would just straighten the wrist (Surgeon H) The position it is in at the moment, I would prefer to improve it…. I would like to manipulate it (Surgeon O) Manipulate it. I'd probably do it myself, haematoma block in the fracture clinic with this patient try and improve the position (Surgeon P) Even if it's significantly displaced I'd leave it (Surgeon Q) Will have manipulated that (Surgeon S)
Future function	If he uses his wrist for walking with the frame, then it would be nice, in some ways, to get him out of the plaster sooner rather than later (Surgeon J) It's so displaced and it would give him some significant issues if it was left that bad……. if we can get into a reasonable position in an 85 year old, and it heals in that position, that it's unlikely to have any issues in the longer term (Surgeon X) even if it healed in that position it would be functionally fine for this patient probably……. that actually in low functional demand patients they tolerate malunion very well…… I'd still want to manipulate that but accepting that anything approaching adequate would be satisfactory for that patient (Surgeon P) He needs his wrist function for his sticks so he'd need some home support and he wouldn't be able to weight-bear for six weeks afterwards but I think this would need a minimum of manipulation and fixation with K wires (Surgeon R) Someone in a nursing home….. do very well in a plaster cast (Surgeon S)
Bone quality	There would be concern about osteoporotic bone quality here (Surgeon Y)
Potential for displacement	Accepting the fact it might…It may well fall back into the original position (Surgeon A) In the first two weeks, if it was to fall back badly then I would proceed to a surgical stabilisation. (Surgeon H) I think if you were to manipulate this, the likelihood is with the dorsal comminution that he's got that it wouldn't hold it adequately…… I'd use 2mm K-wires *(surgeon R)*
Anaesthetic risk	I would try and avoid him having a GA *(surgeon J)* Fairly high risk for surgery … I would only operate on a patient like that, for example, if we had to….. the risk of surgery is probably higher (Surgeon M) He's got a lot of co-morbidities (Surgeon X) Make an aesthetic assessment…. it could be done under a block (surgeon Y) I wouldn't want to give him a general anaesthetic of course with all his comorbidities (Surgeon O)

Case Scenario 3 – 63 year old woman, minimally displaced fracture

In this scenario neither the anaesthetic risk of the patient nor the bone quality were considered in the surgeons' decision-making despite the patient age being suggestive of an increased risk of osteoporosis (Table 9). Instead the decision was based upon the acceptability of the bone alignment, for example:

> I'd just haematoma block, reduce it, and just bring them back, six weeks, because that's not particularly displaced in the first place, and it's impacted so it won't shift around much (Surgeon X)

The functional outcome of the patient was also not considered to the same extent as with the elderly patient in scenarios 1&2, even though this patient had a higher functional demand. Only two surgeons acknowledged the role of function in their decision-making, both focusing upon the risk of a rotational impairment if a suitable reduction was not achieved, for example surgeon E: "She's likely to have a restricted pronation-supination if it's left to heal in this position". The risk of displacement however, was considered similarly to the prior scenarios, and influenced the management plan of 3 surgeons:

> I suspect very much it may collapse into a worse position, if she's treated conservatively I would manipulate that and wire it.

Table 9 - Quotations from surgeon interview transcripts illustrating codes from scenario 3 – *63 year old woman with a minimally displaced fracture*

Refined Codes	Examples from surgeon transcripts
No process described	MUA and K wire (Surgeon S)
Bone alignment	I would accept that position (Surgeon C) I think that could do with manipulating because there is some dorsal tilt …. I would manipulate that I think, and get it into a better position (Surgeon J) I think this is acceptable in the position (Surgeon M) I'd just haematoma block, reduce it, and just bring them back, six weeks, because that's not particularly displaced in the first place, and it's impacted so it won't shift around much (Surgeon X) I wouldn't be happy with that position…. if I could reduce it into an acceptable position I would again hold it with K-Wires. If there was any concern about reduction then I would consider plating (Surgeon Y) I think I would try to cast her into a better position (Surgeon A) It is actually going through the DIEJ, so I'd probably get a CT of that, because I want to see where that's coming out (Surgeon B) I think that position could be slightly improved … you could definitely improve that I think by doing a closed reduction (Surgeon H) In terms of position but you tend to be managed conservatively having had manipulation under a local anaesthetic (Surgeon O) I'd be happy treating that non-operatively … should heal up fine in that position

	(Surgeon P) Probably recommend she has manipulation…. if the position ended up like this I would continue to manage it none operatively (Surgeon Q) I think you've got to maintain anatomical reduction so it's good to use a volar locking plate (Surgeon R)
Future function	Often it becomes an issue from a supination, pronation (Surgeon B) She's likely to have restrictive pronation-supination if it's left to heal in this position (Surgeon E)
Bone quality	
Potential for displacement	Monitor it over the next few weeks to make sure it didn't displace (Surgeon C) Even if that slipped back and healed in that position, I don't think she would be particularly disadvantaged (Surgeon J) That may sublux backwards a little bit further. So, what I would do in this scenario is put this patient into a plaster, with a bit of gentle moulding in the plaster….. I would re x-ray then at a week to make sure that it's stayed put (Surgeon M) I suspect very much it may collapse into a worse position if she's treated conservatively I would manipulate that and wire it. (Surgeon E)
Anaesthetic risk	

Case scenario 4 – 63 year old woman, displaced fracture

This scenario conferred a more complicated decision-making process in comparison to scenario 3, with the minimally displaced fracture configuration (Table 10). The decision commenced with the recognition of the bone alignment:

> A haematoma block, manipulated into position, if it looks like it's in a reasonable position she'd go in a cast…. If it's really displaced to this position she'd get a MUA and k-wires (surgeon X)

For some surgeons this was the only process mentioned, however, others vocalised that the risk of further displacement and functional demand would also contribute to their decision. In regards to the risk of displacement, this contributed to the initial decision to operate:

> I think there's a very high chance that this will re-displace, so I would discuss surgery with this patient (surgeon M)

The functional demand of the patient, however, was considered both when the surgeon initially decided upon operative management and secondly when the type of fixation was decided, for example with surgeon B; "I think that she would get back to function quicker if I put a plate in there"

Lastly, the quality of the bone was also considered, but only for the second stage of the decision when operative management had been decided. The decision at this stage was to determine which metal implant should be used and hence was influenced by the surgeons' perception of the degree of osteoporosis from the radiograph. For example surgeon E:

> I think because of the bone quality, it looks poor, there is some comminution …. I would probably end up plating that

Only one surgeon did not describe their decision-making process.

Table 10 - Quotations from surgeon interview transcripts illustrating codes from scenario 4 - *63 year old woman with a displaced fracture*

Refined Codes	Examples from surgeon transcripts
No process described	I'd fix that with a volar locking plate
Bone alignment	I would reduce it under general or regional anaesthetic, and transfix the distal radial fragment with K-wires…. it's the amount of displacement (Surgeon C) A haematoma block, manipulated into position, if it looks like it's in a reasonable position she'd go in a cast……. if it's really displaced to this position she'd get MUA and K wires (Surgeon X) If you can get good position K-Wire it, if not I'd open it and plate it (Surgeon Y) Will need some sort of metal work in that fracture to keep it in a position (Surgeon E) I'd certainly want to reduce that fracture to check the position…If the position is acceptable then they would refer to my next fracture clinic for repeat x-rays and completion of a cast … If it was unacceptable I would do two K-Wires (Surgeon H) If it's manipulated and stable, then I leave it…..or, I'd make a decision if it's unstable to put a volar plate on. (Surgeon Q)
Future function	To supinate and pronate a hand adequately, I would put to her that it's worth the risk of a deep infection from the K-Wires or whatever else that could be wrong with the K-Wires …….I think that if she ended up with a normal shaped wrist that rotated properly, that she would do better for 20 odd years (Surgeon A) I think that she would get back to function quicker if I put a plate in there (Surgeon B) Given a functional status, this wrist will be a big problem to her if it's left in that position (Surgeon E) It's displaced to the point where almost certainly that would affect her later function so I'd want to manipulate that fracture (Surgeon O) I think this is a relatively high demand patient and therefore we're looking for reasonably anatomic reduction here (Surgeon P)
Bone quality	If her bone quality was good enough I would put simple K-wires in (Surgeon J) Looking at the type of bone quality, my preference here would be open reduction, so the fixation of a plate and screws (Surgeon M) I think because of the bone quality, it looks poor, there is some comminution …. I would probably end up plating that (Surgeon E)
Potential for displacement	If it re-displaced I would take her to theatre (Surgeon J) I think there's a very high chance that this will re-displace, so I would discuss surgery with this patient (Surgeon M)

	It's so unstable it's not going to stay there if you manipulate it, for the long run, it will end up exactly like that again. I would expect this to displace and I would be inclined to fix it (Surgeon O) I think there's a significant risk that will re-displace… I'd be happy to treat that non-operatively at this stage but it needs watching like a hawk and I think a one week x-ray…. may well come to surgery if that displaces again at one week (Surgeon P)
Anaesthetic risk	

Case scenario 5 – 43 year old woman, minimally displaced fracture

This case evoked less of a discussion amongst the surgeons, hence the limited number of examples presented in table 11. Decisions in regards to this case were made primarily upon the position of the fracture,

> I would try putting on a well-molded cast and finger traps first to see if, without any risk of precision surgery, I would try and restore her radial length (Surgeon A)

The risk of displacement was also considered, by 3 surgeons, prompting them to either opt for follow up of the fracture for signs of displacement or to immediately choose operative management to reduce the risk of displacement,

> The volar cortex isn't reduced, it's never going to stay there …She's got a few signs of it being likely to slip…. there's the dorsal comminution, and it's a high-energy injury. She would be treated operatively. (Surgeon E)

There was only one reference to the functional outcome of the patient, from Surgeon P, "it should heal up fine in that position and that lady will do fine with that". The bone quality and anaesthetic risk were not mentioned in the decision-making of any of the surgeons.

Table 11 - Quotations from surgeon interview transcripts illustrating codes from scenario 5 - *43 year old woman with a minimally displaced fracture*

Refined Codes	Examples from surgeon transcripts
No process described	Treat it none operatively in a cast (Surgeon C) I'd leave it (Surgeon Q)
Bone alignment	As long as the position was adequate, I would plaster it and keep an eye on it (Surgeon J) K-Wire I mean I'd go in as long as I can reduce it properly (Surgeon Y) If it was the same sort of alignment I'd be happy treating that non-operatively (Surgeon P) I would try putting on a well molded cast and finger traps first to see if, without any risk of precision surgery, I would try and restore her radial length (Surgeon A) I probably wouldn't bother reducing it… I'd just get on and operate on her soon. (surgeon B)

	You need to ensure that she gets absolutely anatomical reduction (Surgeon R)
Future function	It should heal up fine in that position and that lady will do fine with that. (Surgeon P)
Bone quality	
Potential for displacement	If I manipulated I would want to see her at one week and two weeks with an x-ray on arrival to make sure she hasn't gone back to her previous radial position (Surgeon A) The volar cortex isn't reduced, it's never going to stay there …She's got a few signs of it being likely to slip…. there's the dorsal comminution, and it's a high energy injury. She would be treated operatively. (Surgeon E) Keep an eye for displacement (Surgeon O)
Anaesthetic risk	

Scenario 6 – 43-year old woman, displaced fracture

In comparison to scenario 5, more processes were described as part of the surgeons' decision-making, in particular the bone position, functional demand, risk of displacement and bone quality (Table 12). Surgeons often acknowledged several of these processes in their decisions, for example surgeon X considers the bone position, risk of further displacement and the resultant function:

> I'd reduce that, if that was in a satisfactory position I'd just put it into a cast. Bring her back in a week, if it really displaces MUA and K-wires. In a younger patient, … I'd be more concerned about having any residual displacement, and having a bigger impact on the function.. I probably would re x-ray this patient at two weeks as well, just to make sure that it doesn't shift to an unsatisfactory position.

Similarly, surgeon Q considered the functional demand, risk of displacement and the bone quality:

> I think the chances of it re-displacing back to this position are very high. In that age group I wouldn't consider leaving it, they don't do as well with a deformity and a shortening, and certainly with a positive ulnar …. I would make that decision on the table after an MUA whether it needed K-wires or a plate. If the bone quality is good, definitely K-wires, if the bone quality is suspect or if she's had previous osteoporotic fractures, I'd probably plate it.

In this scenario, only one surgeon did not describe the processes involved in his decision despite opting for operative management, and none mentioned the risk of anaesthesia. However, this is mostly likely because the patient was well with only exertional asthma.

Table 12 - Quotations from surgeon interview transcripts illustrating codes from scenario 6 - *43 year old woman with a displaced fracture*

Refined Codes	Examples from surgeon transcripts
No process described	Send that down to the hand surgeons (Surgeon S)
Bone alignment	I think I'm after anatomical positioning here in this patients, so I would operate on this patient and I'd offer them surgery …. Most reliable thing here is open reduction with some fixation to get an anatomical reduction (Surgeon M) I'd reduce that, if that was in a satisfactory position I'd just put it into a cast (Surgeon X) It's not suitable to stay like that, and she will either need wires or a plate (Surgeon E) I would do a closed reduction …. If it's acceptable then fracture clinic, if not then to elevate the arm overnight in a Bradford sling just to reduce the swelling (Surgeon H) Manipulative reduction under general or regional anaesthesia, and transfixion with K-wires (Surgeon C)
Future function	In a younger patient, … because I'd be more concerned about having any residual displacement, and having a bigger impact on the function (surgeon X) She's got high functional demand …. I would probably treat that operatively (Surgeon B) There's no evidence between correlation of the displacement and the function (Surgeon A) I don't think we've got any evidence at all that anatomic reduction affects function (Surgeon P) In that age group I wouldn't consider leaving it, they don't do as well with a deformity and a shortening, and certainly with a positive ulnar (Surgeon Q) I think in somebody this age you need to ensure that she gets absolutely anatomical reduction (Surgeon R) I feel my most reliable thing here is open reduction with some fixation to get an anatomical reduction, and to start early mobilisation in the wrist to avoid plaster afterwards as well (surgeon M)
Bone quality	She's likely to have good bone quality and it's extra articular, so K-wires would almost certainly be adequate (Surgeon J) If the bone quality is good, definitely K-wires, if the bone quality is suspect or if she's had previous osteoporotic fractures, I'd probably plate it. (Surgeon Q)
Potential for displacement	With this amount comminution and dorsal displacement are very highly likely to re-displace (Surgeon M) Bring her back in a week, if it really displaces MUA and K-wires …. I probably would re x-ray this patient at two weeks as well, just to make sure that it doesn't shift to an unsatisfactory position (Surgeon X) Chances of it re-displacing back to this position are very high (Surgeon Q) I think that she's got some dorsal comminution so MUA alone is unlikely to work

	(Surgeon A)
Anaesthetic risk	

Scenario 7 – 26-year old man, minimally displaced fracture

Similar to scenario 3, the bone position was a key process in formulating the surgeons' decision (Table 13). In contrast to scenario 3, however, surgeons gave greater consideration to the intricacies of the fracture pattern and suggested more invasive procedures. For example, surgeon M, "I'd be really worried about not getting his DRUJ absolutely anatomical, and restoring his dorsal angulation" and surgeon X,

> It's not in a satisfactory position at the minute…. So, I would just put him onto the theatre listing, MUA and K wire, and then bring him back in four weeks' time

The functional demand, risk of displacement and bone quality, feature to a lesser extent in this scenario, and the anaesthetic risk not considered al all, although this is unsurprising as this patient was young and with no comorbidities. In regards to the functional demand, the three surgeons represented two opposing views regarding whether anatomical reduction should be sought to provide the patient with an adequate function, for example surgeon R

> I think in somebody this age you need to ensure that he gets absolutely anatomical reduction and that's maintained

In contrast to surgeon H,

> If they just kept that fracture in that position I think he would do pretty well … clinically he would do absolutely fine if you just left this well alone|

Only 3 surgeons voiced concern regarding the risk of displacement with one opting for operative fixation and the remaining surgeons choosing to monitor the patient closely. This could be because more surgeons chose operative fixation after assessing the bone position than in prior scenarios, hence negating the need to consider re-displacement, and may be suggestive of a pattern recognition decision-making. Lastly, surgeon A provided an alternative insight into the importance of bone quality. Instead of concern regarding whether the bone would displace or would be unable to withstand K-wires, the surgeon considered whether the bone stock was sufficient to negate the need for wires.

> MUA plus some K-wire but he's got a 25% chance of avoiding a K-wire because he may have the bone stock to actually to be able hold that position without me doing it for him. (Surgeon A)

He was the only surgeon however to consider the bone quality for this scenario.

Table 13 - Quotations from surgeon interview transcripts illustrating codes from scenario 7 - *26 year old man with a minimally displaced fracture*

Refined codes	Examples from surgeon transcripts
No process described	
Bone alignment	It'll manipulate back into an adequate position….I don't think that I would necessarily open him up and put volar plates on, unless I couldn't get a good position. (Surgeon J) I'd be really worried about not getting his DRUJ absolutely anatomical, and restoring his dorsal angulation (Surgeon M) It's not in a satisfactory position at the minute…. I would just put him onto the theatre listing, MUA and K wire, and then bring him back in four weeks time (Surgeon X) If it was in this position… I would offer him an MUA and K-Wire of that is his extra articular (Surgeon Y) It's a little bit more distal, some mild dorsal comminution, I think that is about probably collapsed a little bit, and he's lost some of his radial height. I'd probably use a volar rim plate on that, so a plate specifically designed to go right up to the rim, and angle the screws a bit more approximately so you avoid the joint (Surgeon B) So he would be manipulated, see what the position is like…. Maintain it in an acceptable position then I would carry on with conservative treatment (Surgeon O) It should heal up fine in that position (Surgeon P) Probably, looking at this position, if it healed in this position he'll do entirely well (surgeon Q) I'd have a look how it comes out and how it reduces closed. Obviously if I can't get a closed reduction he's … when he's having it opened he would get a plate on it. (Surgeon E)
Future function	I'd be much more aggressive in this scenario with this patient, because he's so young and the type of work he does, and the function, his demand is much much higher (Surgeon M) If they just kept that fracture in that position I think he would do pretty well … clinically he would do absolutely fine if you just left this well alone (Surgeon H) I think in somebody this age you need to ensure that he gets absolutely anatomical reduction and that's maintained (Surgeon R)
Bone quality	MUA plus some K-wire but he's got a 25% chance of avoiding a K-wire because he may have the bone stock to actually to be able hold that position without me doing it for him.(Surgeon A)
Potential for re-displacement	In a cast, non operatively and monitor the position (Surgeon C) He's having some sort of metal work in that if I take him to theatre, because it's highly unlikely to stay where it is (Surgeon E) I would re-x-ray that in a week for the dorsal culmination again, that may just

	slip back (Surgeon H)
Anaesthetic risk	

Scenario 8 – 26-year old man, displaced fracture

The surgeons' decision-making processes for this case were similar to those of the previous scenario, despite a significant difference in the fracture configuration. Bone position was again a key component of the surgeons' decision, however in this scenario the anatomical position was considered by more of the surgeons (Table 14).

> I would fix it with a plate and screws, because I can get the reduction to anatomical or near anatomical and maintain it really. This is a quite a severely angulated fracture, it's quite shortened and there's dorsal comminution so it's inherently unstable so I feel I can get, recreate the anatomy and maintain stability with a plate and screws (Surgeon O)

Again, future function of the wrist, bone quality and the risk of displacement were considered but to a lesser extent than in previous scenarios. Three surgeons considered the impact of the fracture on the later function of the wrist, firstly in regards to the immediate management of the patient, with the need for a reduction in the emergency department to prevent nerve damage, and then in relation to the definitive management, for example surgeon B,

> I'd put a volar plate on that, because I think there's very low risk of complications, and quick mobility, and I think he would get a better earlier outcome.

The consideration of bone quality in this scenario was a secondary consideration regarding the optimal fixation of the patient, once the decision to operate had been decided.

> Depending on the bone quality ….. then I think K-wires would be absolutely fine to use in this situation …. If there was some comminution, either into the articular surface, or dorsally, and there was a sign that the bone quality wasn't very good, then I would plate it (Surgeon M)

In contrast, the risk of displacement was only considered by one surgeon and constituted the deciding factor in deciding upon operative fixation of the patient. The risk of anaesthesia was again not a contributing factor to the decision in this case.

Table 14 - Quotations from surgeon interview transcripts illustrating codes from scenario 8 - *26 year old man with a displaced fracture*

Refined Codes	Examples from surgeon transcripts
No process described	

Improving bone alignment	It's not in a satisfactory position at the minute because he's got a shortened distal radius, he's also lost his natural inclination at the distal radius. So, I would just put him onto the theatre listing, MUA and K-wire (Surgeon X) very displaced so again I would want to consider stabilisation (Surgeon Y) I'd be more inclined to think that the K wires would give a better reduction ….. I would CT them so that I can do very fragment specific fracture fixation (Surgeon E) I would fix it with a plate and screws. Because I can get the reduction to anatomical or near anatomical and maintain it really. This is a quite a severely angulated fracture, it's quite shortened and there's dorsal comminution so it's inherently unstable so I feel I can get, recreate the anatomy and maintain stability with a plate and screws (Surgeon O) I would manipulate it first and have a look at the position. (Surgeon Q) I'd want to fix this by a volar approach, FCR approach and fixing with the volar locking plate, because I think in somebody this age you need to ensure that he gets absolutely anatomical reduction and that's maintained (Surgeon R) I would reduce K-wire it (Surgeon C) This needs a reduction, and it needs to heal in an anatomical position for me (Surgeon M) Do a close reduction with a Bier's Block, repeat the x-rays, check the position. If it's acceptable, fracture clinic in a week and if it was unacceptable then bring the patient in for K-Wire fixation (Surgeon H)
Future function	I'd put a volar plate on that, because I think there's very low risk of complications, and quick mobility, and I think he would get a better earlier outcome, (Surgeon B) It needs to heal in an anatomical position for me, for this gentleman to have a good return of his function. (Surgeon M) I think there's risk to the median nerve there and also it would be uncomfortable for the patient. So I think a manipulation in the emergency department's entirely reasonable. (Surgeon P)
Bone quality	Depending on the bone quality ….. then I think K-wires would be absolutely fine to use in this situation …. If there was some comminution, either into the articular surface, or dorsally, and there was a sign that the bone quality wasn't very good, then I would plate it (Surgeon M) Bone quality is normally a lot better and there's less comminution, I'd certainly consider K-wire (Patient Q)
Potential for re-displacement	It's very displaced so again I would want to consider stabilisation because I think this would potentially be unstable ….. a high risk that it will displace as there's dorsal comminution … I would, again, offer MUA and K-Wire (Surgeon Y)
Anaesthetic risk	

Constraints within the hospital system

The final aspect of the surgeon's decision-making to be considered in this study was the effect of constraints from the hospital systems within which the surgeons are normally based. A number of constraints arose with regards to the initial management of the patient, the logistics involved with operating upon them, and late referral to a specialist hand team.

Poor closed reduction and casting within the emergency department and fracture clinic at the point of presentation, was mentioned as an issue by three surgeons. One surgeon reported that although it did not directly affect their own decision-making, it was prompting colleagues to opt for operative fixation as patients often needed to return to theatre for a re-manipulation of the fracture,

> One of the main problems is getting a good closed reduction. I think we're losing the skills in out junior staff and the time in fracture clinic, to be able to do this…. We are erring more and more towards not doing good closed reduction of these injuries, and not treating them properly in a closed fashion. Sometimes I think we are erring towards operating on them because we are probably going to need to take them to theatre to re-manipulate the fracture and we think while we're there, why not make sure it stays there by putting metal work in. (Surgeon E)

Surgeon P also suggested that poor casting meant that the reduction was often not held sufficiently thus increasing the risk of displacement, and potentially resulting in a poor outcome for the patient. However, similar to surgeon E, they did not consider that this would affect their own decision-making. Finally, poor closed reduction technique in conjunction with a resultant late referral to surgeons Q and O often meant that the surgeon no longer had the option to opt for a closed reduction, hence the decision was essentially made for them to proceed to internal fixation.

> One of the reasons I plate some fracture that I could otherwise treat by closed means, because they are sent in to me late and I can't then reduce them closed anymore so I am sometimes opening and reducing fractures simply because I haven't seen them at three weeks or something like that.
> (surgeon O)

Logistical constraints with regards to operating capacity and implant availability were also described by a number of the surgeons, however, again none considered that this would affect their decision-making.

> There's always the difficulty with the logistics, in terms of operating space and theatre time for trauma patients such as wrist fractures which are ambulatory trauma…… ultimately I thinks it's a clinical decision, so I wouldn't really let that affect my judgment. So if I felt that a patient needed an operation, we would obviously have to work around that
> (Surgeon M)

Overall, the majority of surgeons involved in phase II of this study did not consider their decision making to be constrained by the hospital system within which they worked.

Surgeon decision-making model

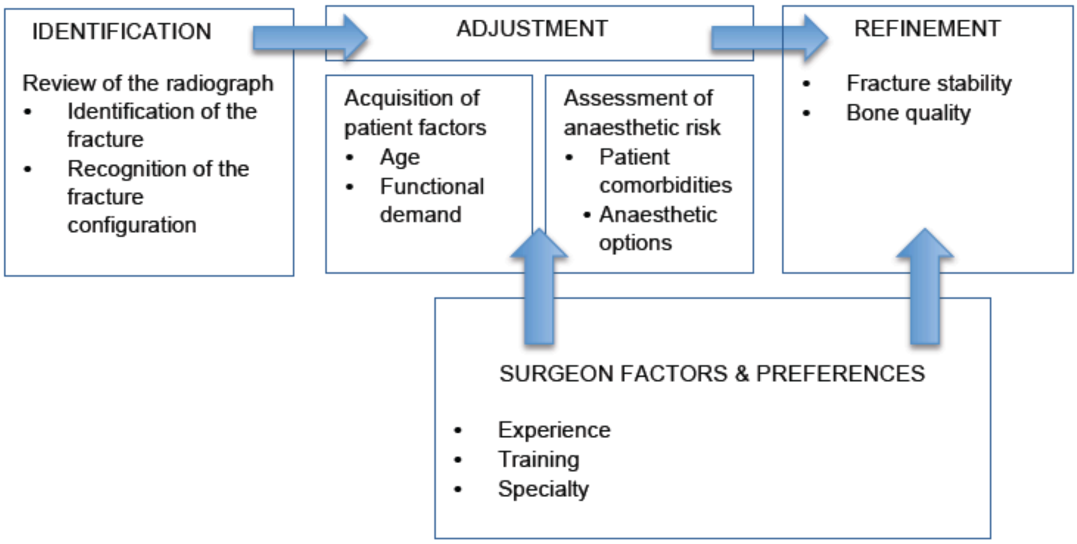
Based upon the information extracted from the analysis of the surgeons' decision-making with both patients and the clinical vignettes, the following model has been generated (Figure 8). The model is based upon a number of key questions that the surgeon must answer when deciding upon the management of a patient with a fracture of the distal radius and the factors that influence their decision-making. These can be broadly considered in terms of two key stages in the patient's management; firstly, the decision whether an orthopaedic intervention is required and secondly, what should constitute that intervention.

The first stage involves a review of the radiograph to identify the presence of a fracture and recognition of the fracture configuration to determine if it warrants an orthopaedic intervention. Information about the patients' age and functional demand is then acquired, and the decision refined in the context of both factors. This refinement is dependent upon the surgeon's preconceived ideas developed from their clinical experience regarding what level of function can be achieved with a varying amount of fracture displacement, and secondly how that relates to the patient's functional demands. An assessment of the patient is then undertaken to work out if they are fit for the considered intervention, and if not the decision is adjusted accordingly.

In the second stage, the decision is made regarding which intervention should be performed, and is based upon both the risk of displacement and the bone density, and is again influenced by surgeon related factors such as experience, training, specialism etc. Two key decisions result from this stage; firstly, if the patient has an operation, what type of fixation should be performed and secondly for both operatively and non-operative managed patients; how often the patient should be followed up to assess for fracture displacement.

Therefore, through the interplay of the various decision-making processes within this model, a number of outcomes can be generated. The 85-year old and the 26-year old patients with the displaced distal radius fracture in scenarios 2 and 8 illustrate this variation in outcomes that can be generated, despite presenting with the same fracture configuration. In both scenarios, the surgeons recognised the fracture was severely displaced in the identification stage and assigned the fracture their preconceived idea of the resultant wrist function associated with that degree of displacement e.g. poor wrist function. During the adjustment stage, the acquired patient factors and anaesthetic risk were assessed and the surgeons' preconceived ideas adjusted in line with these factors. This resulted in the majority of surgeons opting for non-operative management for the 85-year old patient with the low functional demand and significant anaesthetic risk in scenario 2, and operative management for the high functional demand 26-year old patient in scenario 8. In the final refinement stage the risks of re-displacement of the fracture and bone quality were considered, prompting surgeons recommending operative management for the 26-year old patient to chose either plate or percutaneous wire fixation. In regards to the 85-year old patient, this prompted those recommending non-operative management to suggest manipulation with cast application, with or without radiographic monitoring for fracture displacement.

Figure 8 - Surgeon decision-making model



Discussion

Description of results

In this study I have demonstrated disparity in the decision-making of orthopaedic surgeons when deciding upon operative management for fractures of the distal radius. Surgeons' decisions were found to vary with factors relating to the patients, the surgeons and to a lesser extent the context within which the decisions were made.

Patient related factors

In both phases of this study, patient factors including the patient's age, functional demand and anaesthetic risk were all found to contribute to the surgeon's decision-making. In phase I, operatively managed patients were independent with either none or a limited number of comorbidities, whilst non-operative patients suffered from a number of significant comorbidities and had a lower functional demand. Similarly, in phase II, the high functional demand 26-year old male patient, was 3 times more likely to be offered operative management in comparison to the 85-year-old male patient with a low functional demand and multiple comorbidities. In both phases, surgeons specifically mentioned these factors as influences upon their decision-making.

Conversely, gender was not mentioned in the interviews for either phase as a determining factor. However, it was difficult to fully assess the influence of the patients' gender as only one male patient was recruited in phase I. In phase II, operation rates were comparable for both the male and female high functional demand scenarios, suggesting gender was not an influential factor.

Surgeon related factors

Operative rates also varied with the gender, specialty, level of expertise and training of the orthopaedic surgeons in phase II. Female surgeons and surgeons who trained in the west midlands, were twice as likely to suggest operative management as their colleagues, however, these findings are based upon a small number of surgeons and hence are unlikely to be generalizable to the larger population of female orthopaedic surgeons and others trained within the west midlands. No other factors specific to the surgeons were shown to definitely alter their decision-making.

Context-related factors

The surgeons in this study identified the inadequate reduction and casting of patients' fractures in the emergency department, insufficient time in clinic to manipulate patients' fractures under local anaesthesia, and the late referral of patients, as potential factors that would prompt themselves or their colleagues to opt for operative management for patients who they may have managed without an operation. Limited operating capacity and implant availability were identified as constraints upon the surgeons' practice, which might lead to patients experiencing delays in their treatment, but they did not alter the surgeons' decision-making.

Comparison with other studies

Disparity in the operative rate for fractures of the distal radius has been shown to vary with patient and surgeon related factors mirroring the findings in this study(168, 188, 223). In the US Medicare population, Fanuele *et al*. found the age and geographic location of the patient had the greatest impact upon the operative rate(168). Operative rates varied across states from 4-40%, and from 9-22% amongst different age groups(168). An explanation for the specific influence of these factors however, was not provided(168). Instead Fanuele hypothesised this disparity was due to professional uncertainty resulting from the large number of treatment options available and the lack of consensus in the literature regarding the optimum management of these patients(168). Fanuele *et al.* suggested in the presence of uncertainty, decisions were instead based upon the surgeons' preferences and local cultural biases(168).

Chung *et al.* similarly demonstrated disparity in the rate of patients receiving internal fixation associated with the patients' ethnicity, gender, the surgeons' specialism and the geographical location(188, 223). Women, white patients, and those treated by a hand surgeon were more likely to undergo operative management with internal fixation, than their counterparts(188). Chung provides a number of hypotheses to explain these findings; firstly, white female patients have a higher incidence of osteoporosis, hence they may receive internal fixation to provide better stabilisation for their fragility fracture(188). Secondly, hand surgeons are frequently referred patients with severe fractures amenable to internal fixation, as well as an enhanced awareness of new technology(188, 223). Similar to Fanuele, Chung also suggests specialty related disparity may result from uncertainty regarding the optimal treatment of this group of patients(223). This is in keeping with Wennberg's uncertainty theory; in the absence of a clear management strategy, surgeon factors such as preferences and training take priority instead(101). Although, each of these studies has provided a number of hypotheses to explain these disparities, the specific effects upon the processes involved in the surgeons' decision-making were not considered.

The influence of non-medical factors upon clinicians' decision-making has been widely demonstrated for a number of other medical conditions(169, 191, 210, 216, 234). Similar to decision-making studies for the distal radius fracture, little consideration has been given to how patient and clinician factors individually affect the processes involved in clinicians' decision-making. Dunn and Wright *et al.* theorise that differences in orthopaedic surgeons perceptions and decision-making may result from clinical uncertainty and enthusiasm for a particular procedure, in keeping with the theories proposed by Chassin and Wennberg (101, 169, 216, 221). Neither however, specifies how the surgeon's cognitive processes may be affected. Adams *et al.* provides an exception, with the consideration of the effects of the patients' age upon the clinicians' cognitive processes when deciding upon the management of patients with coronary heart disease (CHD)(115). A difference in the use of knowledge structures was detected when diagnosing midlife and older patients(115). UK clinicians' were more likely to be informed by prototypes (textbook descriptions) for midlife patients in comparison to older patients(115). US clinicians' in contrast, were more likely to be informed by exemplars (previously encountered patients) with midlife patients(115). In a separate analysis of this larger trial, a gender bias was also detected in particular amongst female clinicians, with a greater number of age-related diagnostic hypotheses generated for the male patients in comparison to female patients(212). A number of reasons were suggested to explain this gender bias, including clinical uncertainty resulting from the under representation of female presentations of CHD in the literature and the translation of stereotypical conceptualisations as a male disease amongst women to female clinicians, resulting in the greater bias detected amongst female clinicians(212). The lack of consideration of the specific influence of non-medical factors upon clinical decision-making is indicative of the challenges that are faced by the researcher when trying to decipher the complex processes that are likely to be occurring when clinicians formulate their management plans.

Decision-making processes

In this section, the processes involved in surgeons' decision-making in relation to cognitive models of decision-making, and how patient, surgeon and contextual factors relate to those processes has been explored. The possibility of whether there is a 'correct' decision and how the decision-making of orthopaedic surgeons can be improved is then considered.

Cognitive decision-making processes

The decision-making processes of orthopaedic surgeons has been shown to be complex, with differences in their thresholds in the decision process, resulting in marked variation in the surgeons' recommended management plans. Several processes were detected in the formulation of the surgeons' decisions. These included; the detection and recognition of the fracture configuration, the acquisition of patient factors, the assessment of the anaesthetic risk, the stability of the fracture and the density of the affected bone. Each of these processes was considered in succession, as a number of key questions were answered; is an operation required? Is it safe to perform an operation? What specific management should be offered? A model was generated to depict how these decision-making processes are likely to occur in practice (figure 6).

The processes in this model show similarities to the information-processing and Bayes theorem models discussed in the introduction chapter. During the cue acquisition and hypothesis generation stages of the information-processing model, the clinician acquires preliminary information about the patient and forms provisional hypotheses(92, 94). Similar processes occur in the identification phase of this model, with the identification of the fracture configuration and the formulation of a provisional diagnosis. However, this stage is based solely upon the patients' radiograph and notes, reviewed prior to the patient encounter. In the adjustment phase of this model, the surgeon acquires further patient cues and interprets them, displaying similarities to the cue acquisition and interpretation stages of the information-processing model(92, 94). Instead of confirming a diagnosis during this stage, the surgeon starts to decide between operative and non-operative management, specifically deciding upon whether it is safe for the patient. In the final evaluation and refinement stages of both models, the management plan is finalised taking into consideration the specific risks and benefits to the patient(92).

The Bayes theorem model provides some explanation for the differences in surgeons' thresholds for their decisions in the adjustment and refinement stages of the model. The model suggests surgeons exert degrees of belief in relation to the likelihood of a diagnosis or outcome for a procedure, for example, a surgeon may have a stronger belief in the efficacy of operative management for a younger patient in comparison to an older patient(92). The presentation of new evidence, however, may alter the degree of certainty the surgeon has in their hypothesis. This evidence can either strength their assertion for the hypothesis, lessen their assertion potentially leading to its refute, or have no affect on the hypothesis. Using the previous example, if additional clinical information is presented for an elderly patient suggesting they have significant comorbidities, the surgeon's prior belief that elderly patients have poorer outcomes may be strengthened by this information, prompting them to recommend for non-operative treatment. Alternatively, contradictory evidence from a high quality randomised controlled trial for a surgeon's favoured procedure, may cause them to alter their practice accordingly.

In addition to the similarities with these models, Wennbergs and Chasis's theories also play an important role in understanding surgeons decision-making(101, 221). Both theorists suggest in the absence of convincing clinical evidence, surgeon factors, such as the surgeon's experience and enthusiasm for a procedure, play an important role in both how patient factors are interpreted and in how decisions are refined. In this study, surgeons' recommendations for operative management were similarly shown to vary with factors such as the surgeons' level of expertise and specialty. Possible explanations for variation may be that; Hand surgeons frequently perform operations on the wrist, and hence may feel better able to offer operative management in comparison to a generalist. Alternatively, surgeons trained in areas where a particular treatment was favoured e.g. closed reduction casting, may be inclined to treat a greater proportion of their patients similarly. These surgeon-specific influences seemed to effect both the adjustment and refinement stages of the surgeons' decision-making processes.

Is there a correct decision?

In order to improve discrepancies in the utilisation of healthcare services, it is important to address if there is a correct decision when deciding upon the management of patients with a dorsally displaced distal radius fracture. We have seen in this study that not all patients will receive an operation despite having the same fracture configuration. Additionally, surgeons' decisions have been shown to vary when provided with the same patient information and fracture configuration, suggesting surgeons have different thresholds when formulating their decisions.

In this section, the management of patients with this fracture will be considered to determine if there is evidence to support either operative or non-operative management, and what the thresholds for recommending that management might be. This will allow an assessment of whether the variation in the surgeons' decision-making in this study is due to a lack of evidence of clinical effectiveness and hence surgeons are influenced by other factors such as expertise as suggested by Wennberg(101).

At the time of the surgeon interviews in this study, guidance for deciding upon operative management was available from the American Academy of Orthopaedic Surgeons (AAOS), and from evidence provided by several Cochrane reviews of randomised controlled trials (RCTs) comparing operative versus non-operative management(77, 87, 254, 255). The AAOS guidance advocates the use of operative management for dorsally displaced distal radius fractures that have been inadequately reduced(254) . With regards to unstable fractures that are adequately reduced, and for patients specifically over 55 years old, the AAOS considers there to be insufficient evidence to preferentially advocate either operative or non-operative management(254). This guidance was based upon the limited findings of five RCTs comparing various operative fixations with closed reduction and casting(254). Three of the RCTs detected a functional advantage with operative fixation(254). However, this advantage was only statistically significant for one of the studies. The remaining two RCTs detected no functional advantage with either type of management(254).

Evidence from the three Cochrane reviews detected similar results(77, 87, 255). These trials included predominately the comparison of external fixation or percutaneous wire fixation with closed reduction casting. Only one of the included trials compared open reduction and internal fixation with casting. Overall, these reviews concluded that there was insufficient evidence to confirm a better functional result with external or internal fixation in comparison to casting, but there was some evidence to suggest an improved function with percutaneous wiring(77, 87, 255). Since these interviews, NICE has published guidance based upon a review of 25 studies (randomised controlled trials (RCTs) and systematic reviews of RCTs) of skeletally mature patients with a dorsally displaced distal radius fracture(256). The review evidence is inclusive of the evidence from the Cochrane reviews and the AAOS guidance, and was deemed to be of either low or very low quality(256, 257). The review found that operative fixation offers a better balance of benefits and harms than cast or splint immobilisation(256, 257).

With regards to determining the threshold at which surgeons should decide upon operative management, it is important to consider the role of patient characteristics. In this study, we have seen that surgeons base their decisions upon factors such as the patients' age, functional demand and comorbidities. The functional outcome of operative fixation for patients aged over 60 years old has been found to be either statistically different but not clinically meaningful or the same as non-operative management(51, 258). The role of other patient characteristics has not been considered specifically with regards to the management of this group of patients. However, there is evidence to suggest that pre-injury functional capabilities and medical comorbidities are predictive of the outcome of patients with a hip fracture(259). Similarly, depressive symptoms, kinesphobia and catastrophic thinking have been shown to be predictive of perceived disability in patients with upper extremity conditions including distal radius fractures(260, 261). Further work has been undertaken since this study, which has found patients who are non-smokers, with little concomitant illness and in full time employment prior to their distal radius fracture have better functional outcome scores(262).

Therefore, at the time of the surgeon interviews there was inconclusive evidence suggesting that operative fixation might offer some benefit, in particular for younger patients. This suggests surgeons' decisions and the thresholds for those decision may be based upon factors inherent to the surgeon such as their prior training, their perceived capabilities, preferences(101).

Improvements to orthopaedic surgeons decision-making

It is essential that surgeons' decision-making is improved in order to reduce variation in the treatment of these patients. NICE has recently produced guidance on the management of patients with a dorsally displaced distal radius fracture based upon the latest available evidence, which could assist surgeons' decision-making(256). However, this guidance is limited with respects to its evidence base and the specific advice surgeons are given for managing these patients(256). Firstly, the evidence demonstrating a benefit with either external fixation, internal fixation or Kirschner wires was of low to very low quality and for several studies had serious imprecisions(256). In addition, many of the studies found there to be no difference in the outcomes of these patients(256). The guidance NICE provides is also very broad; suggesting manipulation and casting could be considered and if surgical fixation is needed to offer Kirschner wire fixation or open reduction and internal fixation(256). The guidance does not specify which patients might benefit from operative management with respect to the fracture configuration, fracture or patient characteristics(256). It is unlikely that such generalised advice will result in uniformity in surgeons' decision-making.

In consideration of this limited guidance, there are a number of improvements that can be made. Broadly, these include adopting a shared decision making approach with the patient, addressing the lack of clinical consensus, and improving the cognitive skills of surgeons in training.

Despite many surgeons striving towards shared-decision making, consultations still remain predominately surgeon-led and paternalistic(263). Have *et al.* suggests in the event of limited evidence there should be a greater emphasis upon involving the patient in the decision-making process ensuring their preferences are taken into consideration(263). This can be achieved with the use of decision-making aids providing information about the patient's condition and possible treatment options prior to the patient's fracture clinic appointment(199, 264). These aids have been shown to improve the patient's knowledge, reducing any decisional conflict and resulting in better engagement in the decision-making process(264-266). For patients presenting with a distal radius fracture, this improved knowledge may lead to more realistic expectations for their injury and treatment, and possibly better engagement with post-operative instructions and exercises during their recovery(265, 267). Patients may also be able to start considering what type of treatment might suit their individual needs, and hence they may be able to give more fully informed consent to operative treatment(265, 266). However, these aids are dependent upon patients' willingness and ability to comprehend the material(268). In addition to the patient acting as a barrier to the use of these aids, the surgeons' over confidence in their ability to convey the information to the patient without the need for an aid and difficulty implementing the aids into routine practice may also act as barriers(269). Lastly, even with the use of these aids, surgeons may continue to take a paternalistic approach dismissing the potentially useful role of these aids.

Another option is to address the lack of consensus regarding the management of these patients, in particular the thresholds for making decisions(101, 254). This can be achieved by undertaking high quality randomised controlled trials (RCTs) addressing this comparison with a sufficient sample size to allow a subgroup analysis to be performed(101). Alternatively, other research methodologies such as qualitative methods can be explored, to gain insights into whether patients' perceptions of their treatment vary with non-fracture factors, and to clarify the processes involved in complex interventions such as these(270, 271). These options would address the lack of clinical evidence and provide the basis for more useful guidance(101). However, to undertake such studies would require a considerable amount of resources, and there would be a significant time delay before this information would be available(272). An interim measure would be to gain a consensus amongst prominent hand surgeons and traumatologists to develop guidance on the treatment of specific subgroups of patients to be followed by generalists and training surgeons(101). In consideration of the lack of evidence it might be difficult to reach such a consensus, and there is the risk surgeons might not accept such guidance(101). This process would at least allow specific uncertainties in patients treatment to be identified for the undertaking a further studies(101).

Lastly, we can consider the cognitive processes of training surgeons involved in decision-making. Training of orthopaedic surgeons is changing from an apprenticeship where clinical acumen and decision-making skills are gained through 'immersion' in the clinical setting, to formal competency based training(273). Non-clinical skills such as decision-making and self-reflection are now starting to be successfully taught outside of the clinical setting. Teaching skills in this structured format may improve the uniformity of the processes involved in surgeons' decision-making and eventual decisions. Their success, however, is dependent upon studying surgeons' decisions to improve our understanding of these processes and recognition of the importance of this skill set amongst surgeons(273).

There a number of ways in which these processes can be taught, including stand-alone training courses, courses in conjunction with simulated cases, virtual based teaching or 'serious games'. For example, Flin *et al* taught a number of non-technical skills including decision-making in a classroom based setting using a variety of mediums(274). These included lectures, group discussion, exercises and video-clips, considering the importance of decision-making for patient safety and assessing examples of 'good' and 'bad' decisions in an operative setting(274). In response to this course, a number of surgeons stated an intention to consider how they make decisions to a greater extent(274). An innovative alternative to this type of classroom-based teaching is to use 'serious games', which involve integrating educational content and skills into a game(275). Preliminary evidence suggests this is effective at allowing students to both consolidate and rehearse their decision-making in an enjoyable and safe environment(275).

These educational tools may also have the potential to be instructive for improving the decision-making of surgeons in the outpatient setting. However, the introduction of these tools would require additional resources in order to introduce and educate trainers, and to implement them for both senior surgeons and those in training posts. Further studies would also be required to assess surgeons' cognitive processes so as to allow such tools to be tailored to their specific needs(276). Studies would also need to be undertaken assessing the efficacy of these tools for improving both surgeons decision-making and for reducing disparity in their decisions(276). In consideration of the lack of a clinical consensus for the management of these patients, improvements in surgeons' cognitive processes may not necessarily improve agreement between surgeons with these tools alone.

Strengths and limitations

This study provides an insight into the decision-making of orthopaedic surgeons in the UK both in practice and in a simulated setting using clinical vignettes. Disparity in the management of patients with a distal radius fracture has been previously identified. However, no studies have undertaken an in depth assessment of the processes involved in formulating surgeon's decisions, or in determining at what stage in this process disparity arises between surgeons(168).

A diversity of surgeons were represented in this study, with regards to gender, ethnicity, speciality, location of practice, training history and level of experience. This ensured that the influence of a wide range of surgeon factors on the decisions that were made could be considered in this assessment. Additionally, the patient sample recruited in phase I were representative of the typical demographic spread of this group of patients with respect to age, and were varied with respect to functional demand, occupation, comorbidities and social habits. Therefore, providing rich data to base the clinical vignettes upon in phase II.

Although, this study has a number of strengths, there are also limitations that should be considered. Firstly, despite a 3-6 times greater incidence of distal radius fractures amongst women, men were still underrepresented in the patient sample in phase I (230, 277, 278). Prior studies of the influence of gender upon recommendations for total knee arthroplasty, have found that for cases where there are strong clinical indications for surgery, gender did not affect the surgeon's decision-making(234, 279). However, where the indications were less straightforward gender may influence decision-making in favour of recommending men for surgery, hence by under-representing men in this sample this influence may have been missed.

Phase I was also conducted within one hospital trust, this limited the study as both the sample of surgeons and the constraints within this hospital system may not be representative of practice across the UK. Similarly the sample of patients may also differ in ways that have not been accounted for in this study, for example patients in less affluent areas may have a greater proportion of manual workers with different functional demands or more extensive comorbidities. As the socio-economic class was not recorded for these patients, it is therefore, not possible to fully determine how representative this sample was and a potentially important influence upon decision-making might have been missed.

Phase II was potentially limited by the simulated nature of the interviews, the number of surgeon participating, the vignettes and radiographs used in the interviews, and my dual role as researcher and orthopaedic trainee. Although vignettes have been shown to be as effective as simulated patients in assessing clinicians' practice, it is important to be mindful that surgeons' responses may not necessarily be indicative of how they would act in practice. In this study, all the surgeons in the mini-interviews commenced their consultations by firstly reviewing the radiographs to assess the bone position and then acquiring patient details through history and examination. This is in keeping with the descriptions surgeons gave of their decision-making with the vignettes, providing some confidence that the vignettes were representative. In addition, although the surgeons participating in the interviews provided a variety of characteristics that may influence their decision-making, the number of surgeons representing each characteristic was small. Therefore, the influence of these characteristics may not necessarily be generalizable to the decision-making of the wider population of orthopaedic surgeons in the UK.

Flaws in the vignettes and radiographs are instead more likely to have limited this study. Responses were found to vary in depth by between the first and final vignettes; this could be suggestive of a lack of surgeon interest. The random presentation of the vignettes and radiographs ensured that all scenarios had a mixture of fuller and shorter responses, and hence inferences could be drawn for all the scenarios. A reduction in the number of scenarios presented may have generated richer responses by engaging the surgeon for longer, however, this may also have limited the patient factors that could be considered. In retrospect, the vignettes did not differ substantially enough, particularly in the case of vignettes 3 and 4, where very similar operative rates resulted. Including a vignette with a young individual afflicted by significant comorbidities may have provided more interesting insights.

Limitations with the interviews were further compounded by the use of the same radiographs of extra-articular fractures for all the vignettes. This was a purposeful decision, to provide comparability, and to focus the surgeons' attention upon patient factors. However, during the interviews there was a tendency to fixate upon the radiographs without considering subsequent vignettes as separate cases. In addition, the radiographs were from older patients. This meant they were often perceived as unrealistic for the youngest patient, and may have resulted in the surgeons considering factors such as the bone density, which they may not normally consider relevant in their decision-making for such patients.

Presenting only extra-articular fractures further limited this study by reducing the applicability of the study findings. Although, extra-articular fractures constitute 60-75% of all distal radius fractures, they represent a simpler fracture configuration to treat in comparison to intra-articular fractures(231, 277). Therefore, the surgeons' decision-making in this study and the wider orthopaedic community might differ if, for example, a minimally displaced intra-articular distal radius fractures was presented, in comparison to a minimally displaced extra-articular fracture.

Lastly, in my role as both a researcher and orthopaedic trainee, I was aware that when partaking in both the mini and in-depth interviews with some of surgeons with whom I work, the interviews had a tendency to take on the format of a normal clinical discussion. This may have had a stifling effect upon some of the responses, and hence the full decision-making processes may not have been represented with these surgeons.

Overall, although limitations can be detected, this study has provided a greater exploration of the factors influencing orthopaedic surgeons' decision-making when deciding upon the management of patients with a distal radius fracture, than has been previously undertaken. In addition this research has resulted in the generation of a model that can be tested in further studies.

Implications for policy, practice and future research

Disparity has been shown in the decision-making of orthopaedic surgeons when presented with the same patients. This was present for a number of key stages in their decisions, firstly when determining whether an operation should be performed, and then when deciding what that should entail, for example, type of fixation. The secondary decisions of some of the surgeons were also not supported by recent evidence although surgeons were aware of these developments, for example the continued use of volar locking plates as opposed to Kirschner wires(278).

Training was found to be a key factor influencing less experienced surgeons' decision-making, hence addressing the cognitive processes involved in decision making during this period as suggested by Buckingham *et al.* in addition to improving the dissemination of recent research findings may assist in reducing this disparity(93).

The findings presented in this study could be furthered by testing and refining the model suggested in this study in the clinical setting, and by establishing agreed upon guidelines for each stage of the decision making model, which trainees can then follow.

3. A systematic review of the functional outcome of closed reduction and percutaneous wire fixation versus volar plate fixation for dorsally displaced distal radius fractures in adult patients

Declarations

None

Orthopaedic surgeons' decision-making when deciding upon operative management for patients with a dorsally displaced distal radius fracture has been shown to be a complex process. The surgeon must firstly consider the potential risks and benefits of performing an operation for each patient, and then consider which operation to perform. In chapter 2, the processes involved in surgeons' decision-making for the first part of this decision were explored. In this chapter, the current evidence available to assist orthopaedic surgeons with the second part of their decision has been critically appraised for two commonly performed operations for this fracture.

Background

Fractures of the distal radius represent one of the most common fractures affecting the UK population, with an annual incidence of 38/10000 women and 9/10000 men over 35 years old(34, 36). A bimodal distribution occurs, with a peak in the young typically resulting from high-energy sports related injuries and motor vehicle collisions, and in the osteoporotic elderly due to low-energy falls(35). The impact to the patient can be catastrophic if poorly managed, resulting in a disabling loss of function and deformity.

Broadly, the management of these patients is based upon the displacement of the distal fragment. Undisplaced fractures are typically treated non-operatively with a period of immobilisation in either a cast or splint(258). The optimal management of unstable dorsally displaced fractures in contrast remains contentious, with a plethora of operative fixations available(51, 258, 280). Historically, these fractures have been fixed with either percutaneous wires and closed reduction casting or in conjunction with an external fixation device, offering a minimally invasive approach(281). The fracture is manipulated closed and the wires passed either across or through the fracture site to maintain the reduction. Malunion with a loss of radial height is a common problem in osteoporotic patients with wire fixation, as the wires are not load-bearing devices and hence are unable to protect against late collapse(282, 283).

Advances in plate technology with the introduction of the volar locking plate, has seen an increase in their use for dorsally displaced fractures(207, 282, 284). For example in the US, there has been a 30% decrease in the number of these fractures fixated with percutaneous wires in favour of plate fixation(207). Volar plates are considered to be biomechanically superior, allowing the anatomical restoration of the fracture, whilst supporting it against the physiological loads placed upon the wrist(207). Advocates of this type of fixation, suggest these biomechanical advantages result in an earlier and better functional outcome for the patient(10, 258). Plate fixation, however carries a number of inherent risks to the nerves, vessels and tendons of the volar aspect of the wrist(51, 282, 285, 286).

In the most recent Cochrane review (2003) comparing operative fixation, the evidence for the optimal management of unstable fractures of the distal radius was found to be inconclusive(255). Since that review, a number of randomised controlled trials have been undertaken, providing a comparison of the functional improvement with wire and plate fixation(207, 278, 282). A review is therefore necessary to examine these advances in the literature, and to determine whether wire or plate fixation provides the superior wrist function with minimal risk of harm.

Methods

This review was performed in accordance with the guidelines from the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement(153).

Objectives and research questions

The aim of this review was to determine whether volar locking plate fixation provides a greater improvement in function, measured with patient reported and physical outcome measures, after a dorsally displaced fracture of the distal radius in adult patients in comparison to closed reduction and percutaneous wire fixation.
In order to achieve the aforementioned objective, the following research questions were addressed:

- Does volar locking plate fixation for dorsally displaced distal radius fractures in adult patients provide a greater improvement in wrist function in comparison to percutaneous wire fixation, signified by an improvement in validated patient reported outcome measures and physical measures of function?

Criteria for the consideration of studies

Studies meeting the following eligibility criteria were considered in this review.

Types of studies

All randomised and quasi-randomised (treatment allocation does not adhere to strict randomisation e.g. allocation based on date of birth) clinical interventional studies.

Types of interventions

Interventional studies investigating closed reduction and percutaneous wire fixation in comparison to open reduction and internal fixation with a volar locking plate for the management of dorsally displaced distal radius fracture.

Types of participants

Skeletally mature adult patients (≥18years old) of either gender with an acute dorsally displaced fracture of the distal radius.

Types of outcome measures

a) Primary outcome measures

The primary outcome measure was wrist function determined from validated patient reported outcome measures (PROMs) and physical measures of impairment, responsive to a clinical change in patients with a fracture of the distal radius

- Patient reported outcome measures - Patient-Rated Wrist Evaluation (PRWE), the Disabilities of the arm, shoulder and hand (DASH), Michigan Hand Assessment and the physical component of Short form (SF-36) (117, 255)
- Physical measures of function - grip strength, lateral pinch strength and range of motion (flexion/ extension, radial/ulna deviation and supination/pronation)(117).

b) Secondary outcome measures

The secondary outcome measures were clinical and radiological outcomes, consisting of:

- Clinical outcomes: early and late complications associated with the fracture and interventions(46, 47, 255, 287)
- Radiological parameters: dorsal angulation, radial shortening, radial inclination, ulnar variance, step off and gap deformity for intra-articular fractures(288, 289).

Search Strategy

Electronic search

A search of the literature was performed for the predominant electronic databases indexing orthopaedic studies; MEDLINE (1946 to August 2014), MEDLINE (In-process & Non-indexed citations, August 2014) and EMBASE (1974 – August 2014) using the OVID search platform, and the Cochrane Central Register of Controlled Trials (*The Cochrane library*, August 2014) (290-292). Slobogean *et al* found this combination of electronic databases, resulted in 97% retrieval of primary studies previously identified from orthopaedic meta-analyses(290). The remaining 3% were derived from a search of the grey literature(290).

Despite the considerable cross-over in the indexing of medical reports in these databases, searches of each have been shown to retrieve reports unique to the others(290, 291). This was demonstrated by Suarez-Almazor *et al.* in a search of controlled clinical trials from the EMBASE and MEDLINE databases(291). Two hundred and forty-three reports were retrieved, of which EMBASE contributed 16% more reports than MEDLINE. However, when the searches were combined EMBASE retrieved 85% of the total number of papers and MEDLINE 73%(291).

The individual search strategies are detailed in the appendices (appendix 3). The following search filters will be applied to identify randomised controlled trials in MEDLINE and EMBASE for use with the OVID search platform:

- Cochrane Highly Sensitive Search strategy for identifying randomised controlled trials in MEDLINE: sensitivity-maximising version (2008). OVID format(293)
- Scottish Intercollegiate Guidelines Network randomised control trial search filter for EMBASE, OVID format (www.sign.ac.uk).

No language restrictions were applied to the search, however only English language reports were selected at the study selection stage.

The Current Controlled Trials (www.controlled-trials.com, accessed August 2014) and UK National Research Registers (http://www.nihr.ac.uk/Pages/NRRArchive.aspx, up to October 2007) were searched to identify any trials recently completed, or those due to be completed before the completion of the review.

Other sources

A comprehensive search of the literature would be incomplete without a search of the grey literature(294-296). Systematic reviews excluding grey literature have been shown to over-estimate treatment effect sizes and disproportionately represent studies with statistically significant results(294-296).

Therefore, hand searches were conducted of the supplemental issues of the British and American volumes of the Journal of Bone and Joint Surgery (2001 - 2014) and American Volumes of the Journal of Hand Surgery (1989 - 2014), and for the following conference proceedings: the American Association for Hand Surgery annual meetings (2007-2013), the American Orthopaedic Trauma Association annual meetings (1996-2013), the American Academy of Orthopaedic Surgeons annual meeting (2011-2013), the British Society for Surgery of the Hand annual meetings (2007-2013), and the British Orthopaedic Association Congress (2002-2013). In addition, a search of the references for the reports retrieved from the electronic and hand searches was undertaken.

Data collection

Study selection

All reports generated from the electronic and hand searches were assessed by two independent reviewers (CP & HJ), to reduce the risk of discarding potentially relevant reports(297). The exclusion of these reports could result in selection bias with either the under or overestimation of the studied treatment effect and thus altering the final outcome of the review(298). Edwards *et al* found the identification of trials increased by 9% with the participation of two reviewers in the selection process, instead of solely one reviewer(297).

Blinding of reports during the review process has been shown to be time consuming and unnecessary(299, 300). Therefore, the reviewers were presented with the original, unblinded reports at each stage of the review process. The titles and abstracts were examined first, to remove obviously irrelevant reports(301). The full text was then retrieved for the remaining reports and examined in depth against the eligibility criteria(301).

Reports were either included into the review or excluded and assigned to one of the following categories:

a. Not dorsally displaced distal radius fracture
b. Not adult patient
c. Wrong intervention or only one treatment arm assessed
d. Not a prospective randomised controlled study
e. Functional outcome not measured

All disagreements between reviewers were resolved through discussion, without the need for an independent reviewer. The study selection process has been summarized in a flow diagram, as recommended in the Preferred Reporting Items for Systematic Reviews (PRISMA) statement(153).

Data Extraction

A single reviewer CP extracted data from all eligible articles. The following participant, intervention, outcome and study related information was extracted:

- Participant: the number of participants, demographic details, number of fractures and fracture configuration
- Intervention: the type of intervention and number of participants per treatment group.
- Outcome measures: type of outcome measures applied and the time points for data collection.
- Study – study design, number of centres involved and the publication details

Data analysis

Assessment of the treatment effect

The mean difference and standardised mean difference are commonly presented for the assessment of the treatment effect for continuous data. The mean difference represents the difference between the mean values for the volar locking plate and percutaneous wire fixation groups(302). It is presented in the units of the outcome measure, meaning it can be interpreted against the minimum clinically important difference (MCID) for that measure (Table 15).

Table 15 - Minimum clinically important difference for functional outcome measures

Outcome measure	Minimum Clinically Important Difference	Condition for which the MCID was derived
PRWE	11.5 (303)	Distal radius fractures
DASH	10(304)	Distal radius fractures
EQ-5D	0.12(305)	Osteoarthritis
Grip Strength	19.5% of strength of contralateral wrist or 6.5kg(306)	Distal radius fractures

The usefulness of the mean difference is however limited when a number of different outcome measures are used to assess the overall treatment effect. Alternatively, the standardised mean difference can be presented, it represents the mean difference of the two groups relative to their variability(156):

$$\text{SMD} = \frac{\text{Difference in mean outcomes between groups}}{\text{Standard deviation of control group/ intervention group/ combined groups}}$$

The treatment effect is therefore converted to a universal unit of standard deviations, allowing the comparison of multiple outcome measures(302). In view of the differences in the interpretability and generalizability of these measures, the RevMan5 software was used to calculate both measures with 95% confidence intervals for the DASH, PRWE and EQ5D scores, grip strength, and wrist range of motion.

Missing data

Additional information was sought from the authors of two studies where the published data was incomplete. Only one of the studies provided the additional information requested.

Risk assessment

The methodological adequacy of a trial is an important determinant of the potential risk of bias(161). The relationship between methodological quality and estimation of treatment size has been assessed(161, 162, 307, 308). Deficiencies in trial design e.g. poor or unclear allocation concealment were associated with an exaggerated treatment size(161, 162, 307, 308). This could have profound consequences, potentially misleading health professionals of the efficacy of the studied treatment.

Traditionally the methodological quality of a trial has been assessed with scoring systems based upon the reporting as opposed to the appropriateness of trial characteristics(162). Many of these scales have been shown to be unreliable and containing items not relevant to assessing internal validity(309). In addition, in an evaluation of the influence of 25 quality scales on the interpretation of the clinical trials within meta-analyses, Juni *et al* found opposing interpretations of the treatment effect for the same trial arose from different quality scales(309). The assessment of risk within a study is instead advocated as opposed to the use of quality scales(309).

In this review, the risk of bias was assessed alongside the data extraction phase for all eligible reports(307). The unblinded reports were assessed by a single reviewer CP, using the revised Cochrane risk of bias tool for randomised controlled trials(299, 310). The tool offers a ‘domain-based evaluation’ of the risk of selection, performance, detection, attrition, reporting and other sources of bias, without attempting to quantify the level of bias(310). Quality scoring scales were not performed in addition to this tool.

Results

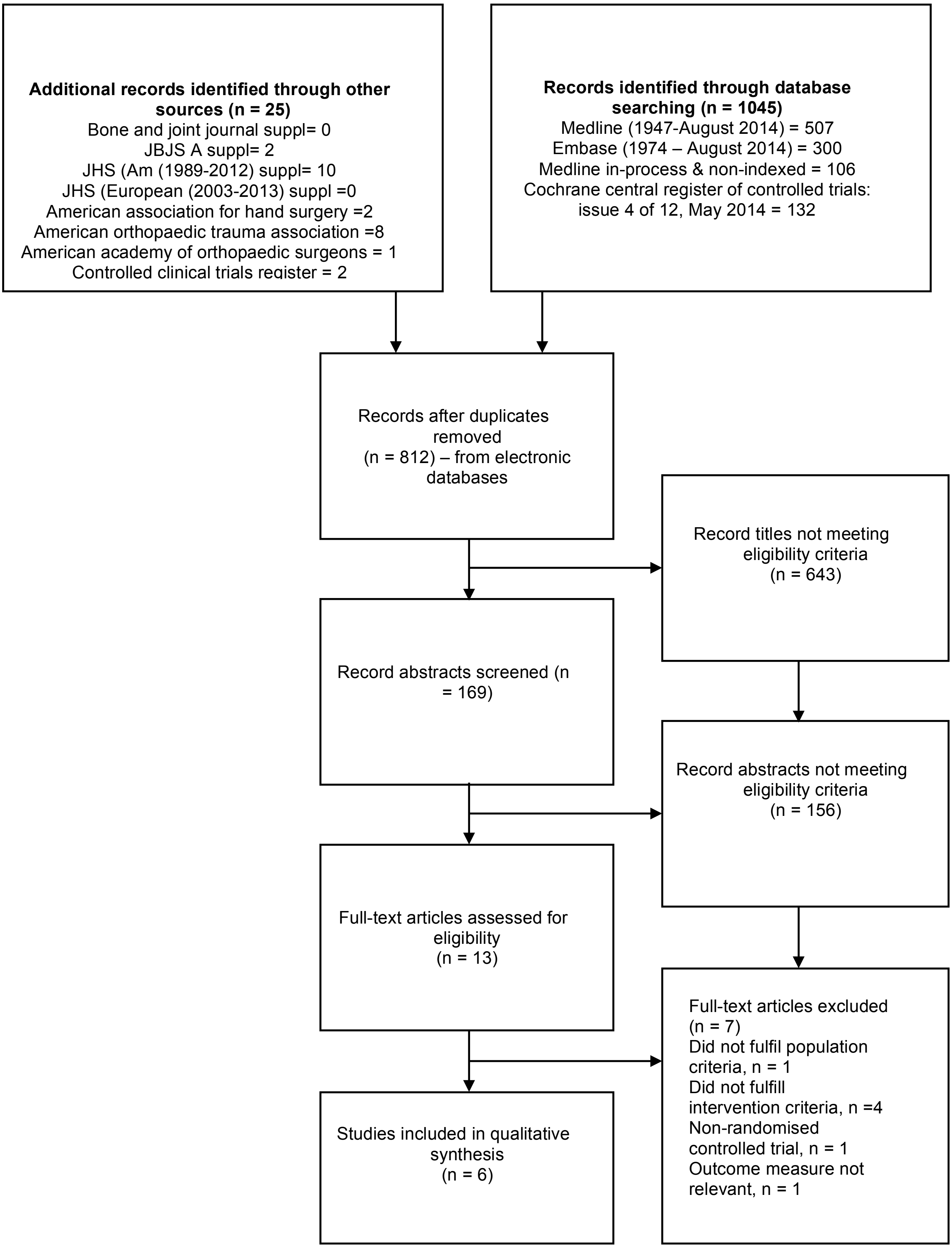
Search Results

The literature search strategy identified 1007 records, of which 258 were found to be duplicates. Examination of the titles and abstracts revealed a further 799 records to be irrelevant to the search strategy. A total of 13 full records were assessed, of which 6 were included into the review and 7 excluded. Reasons for exclusions included not assessing both treatment arms, adoption of a non-randomised study design, wrong fracture configuration and lack of a validated patient reported outcome measure. Figure 9 depicts the flow of records at each stage of the search.

Study characteristics

The 6 included studies were all randomised controlled trials, published in English between 2009 and 2014, set in 5 countries. The majority of the studies recruited from either a single centre or 2 centres. Only Costa 2014 provided a multicentre study recruiting from 18 centres across the UK. The characteristics of each study are presented in Appendix 4.

Figure 9 - Search strategy



Sample sizes

The sample sizes of the studies were predominately small, with the exception of Costa 2014 and Marcheix 2010. The total number of participants recruited into each of the studies is detailed below:

- Rozental 2009: 45(281)
- Marcheix 2010: 103(311)
- Hollevoet 2011: 42(70)
- Costa 2014: 461(278)
- McFadyen 2011: 56(207)
- Goehre 2014: 40(312)

Participants

A total of 747 participants were included in these studies, with the majority contributed by Costa 2014 (461 participants). The study populations consisted of predominately women (n= 611), with men contributing only 18% of the recruited participants. Three of the studies included all adult participants, whilst the other three included only those either over 50 years or 65 years old. The average age of patients ranged from 50-75years for all the studies.

Only patients who had sustained dorsally displaced distal radius fractures were included. Two studies specified the degree of dorsal angulation and ulnar variance, and one study only accepted extra-articular fractures. A more pragmatic approach however was taken by the remaining 3 studies. The majority of the fractures had an extra-articular AO type A configuration (64%), the remaining fractures were AO type C with the exception of 8 AO type B fractures.

Interventions

All the fractures were treated with either closed reduction Kirschner wire fixation or with a fixed angle volar plate. The application of the Kirschner wires varied, with wires applied either intrafocally, extrafocally or mixed pinning. Rozental 2009 and McFayden 2011 for example opted for extrafocally applied 1.6 mm wires. Costa 2014 however, did not specify the number, type or method of application of the wires, allowing the surgeon to opt for their preferred method. In that study, the majority of fractures were treated with 2-3 1.6mm wires applied with one of three available techniques. All studies, immobilised the wrist with a plaster caster for between 5 and 6 weeks post-operatively.

In the plate group, a fixed angle volar plate was applied with predominately locking screws. Rozental 2009 however, did not state whether locking or non-locking screws were applied. Immobilisation of the wrist varied from no immobilisation to the application of a plaster cast for up to 6 weeks matching the wire treatment group such as McFayden 2011

Outcome measures

Primary outcome measures

The DASH score, grip strength and range of motion were the most commonly reported functional outcome measures. The DASH score for example, was reported by all the studies apart from McFayden 2011, which opted instead for the quick DASH. In addition to these measures, the PRWE, EQ5D, and Herzberg scores were also reported. McFayden 2011 and Costa 2014 were the only trials to present only PROMs data.

Secondary outcome measures

All the studies reported radiographic parameters at various time points including the: ulnar variance, radial inclination, radial shortening, palmar tilt and dorsal comminution, as well as both major and minor adverse outcomes.

Risk of bias

Overall the reporting of the included studies was poor, with insufficient information to determine the risk of systematic error for a number of the studies. This risk has been summarised in figure 10, with full details of the risk assessment included in appendix 5.

Figure 10 - Risk of systematic error within included studies

	Adequate sequence generation?	**Allocation concealment?**	**Binding (Participants and personnel)**	**Binding (Patient reported measures)**	**Binding (Physical measures)**	**Incomplete outcome data? (Patient reported measures)**	**Incomplete outcome data? (Objective measures)**	**Selective outcome reporting?**	**Other sources of bias**
Rozental 2009	+	?	?	+	+	+	+	+	-
Marcheix 2010	+	+	?	?	?	+	+	+	?
Costa 2014	+	+	+	+	n/a	+	n/a	+	+
Hollevoet 2011	+	-	+	+	+	-	-	?	+
McFadyen 2011	+	?	?	?	+	+	+	?	?
Goehre 2014	+	+	?	?	?	?	?	?	-

Key

+ Low risk   - High risk   ? Unclear risk   n/a Not applicable

Sequence generation and treatment allocation

Treatment groups were allocated randomly for all the studies, commonly using a computer generated sequence or block randomisation. Only three of the studies adequately concealed the treatment allocation via either a centralised allocation service or sealed opaque envelopes.

The concealment for the remaining three studies was either inadequate or unclear. For example, Hollevoet 2011 made no attempt to conceal the patients assignment. Rozental 2009 and McFadyen 2011 in contrast assigned the treatments with sealed envelopes, but did not provide any further details such as whether the envelopes were opaque to determine if adequate measures had been taken to ensure allocation concealment.

Blinding

All of the studies either did not blind participants, key personnel or outcome assessors (for radiographic and physical measures of function) to the treatment allocated, or they did not provide sufficient information to determine if blinding had occurred. In surgical trials such as this, blinding would be impractical, due to the presence of different surgical scars and the respective metal implants on the radiographs. It could also be argued that as patients would not be blinded to their treatment in practice, this constitutes part of the treatment effect and hence the lack of blinding provides a pragmatic advantage.

Although Rozental 2009 and Costa 2014 did not blind participants to their treatment, they attempted to reduce their risk of reporting bias by blinding key personnel. Rozental 2009 for example, used an independent examiner to perform all outcome assessments, and Costa 2014 blinded all staff members involved in both the administration and analysis of the patient reported outcome measures.

Incomplete outcome data

Patient flow was reported clearly for 4 studies, 3 of which were found to have either no loss to follow up or equivalent losses for both groups in regards to the numbers and reasons for missing data. The fourth study (Hollevoet 2011) in contrast, was imbalanced for numbers of missing data for the patient reported outcome measures and for the reasons for the loss to follow up for the physical outcome measures.

Goehre 2014 and Rozental 2009 failed to present complete outcome data, meaning a determination of bias could not be made solely from the study report. Upon contacting both authors, Rozental 2009 was found to confer a low risk of attrition bias, whilst Goehre 2014 could not be reached and hence it was not possible to determine whether the missing outcome data may have affected the overall outcomes.

Selective reporting

Published protocols were only available for three of the studies. Costa 2014 provided a detailed protocol published in the BMC musculoskeletal journal, whilst Rozental 2009 and Marcheix 2010 published their study protocols solely on the www.controlled-trials.com website. All three studies adhered to the trial procedures, reporting the outcomes and schedule for data collection in concordance with their study protocols. Although, McFayden 2011 published their protocol on the www.controlled-trials.com website, there was insufficient detail regarding the specific outcomes and schedule for data collection to determine if the study was free from selective reporting. Neither, Hollevoet 2011 or Goehre 2014 published their study protocols, hence it was not possible to assess whether the study was subject to high or low risk of bias.

Other sources of bias

The risk of bias from other sources could be determined in four of the six studies. In two of these studies no other sources of bias could be detected. These studies included participants with similar baseline demographic and functional characteristics, and a large number of surgeons of varied expertise. Rozental 2009 and Goehre 2014 in contrast demonstrated a high risk of bias. Both studies were undertaken in single centres with a minimal number of experienced surgeons increasing the risk of surgeon bias. In addition, neither study provided a baseline assessment of the participants' wrist function. Goehre 2014 also failed to perform a sample size calculation, including a relatively small number of participants, hence the study may have been underpowered.

The two remaining studies lacked sufficient information to determine the risk of bias from other sources. These studies did not present information to determine whether the participants differed in their baseline wrist function, whether there was a risk of a surgeon-specific effect or what change in function was used to determine the sample size.

Effects of interventions

Although all of the studies broadly considered the same comparison of percutaneous wires and plate fixation for patients with an unstable fracture of the distal radius, clinical heterogeneity was present deeming pooling of data inappropriate. Differences between the studies were apparent with regards to the participants' age; with three of the studies accepting only elderly patients, and the remainder including all adult patients. The mechanism of injury and fracture configuration sustained similarly varied, for example, McFayden 2011, included only extra-articular fracture configurations and Hollevoet 2011 only low-impact fractures. In contrast, Costa 2014 accepted both high and low impact fractures with intra and extra-articular fracture configurations.

Differences also arose with the application and duration of immobilisation following plate fixation, and the technique used to apply the Kirschner wires. Marcheix 2010 and Hollevoet 2011, stipulated the immobilisation of all patients undergoing plate fixation for either 3 or 5 weeks, whilst Rozental 2009 immobilised patients for 1 week and then converted to a splint with early range of movement exercises.   The technique used to apply the percutaneous wires similarly varied, Rozental 2009 and McFayden 2011, applied all the percutaneous wires extra-focally only. Goehre 2014 and Costa 2014 in comparison chose a pragmatic approach to both the immobilisation of the wrist and the wiring technique used. Neither trial stipulated the presence or duration of immobilisation, or the wiring technique to be used, instead these decisions were at the discretion of the operating surgeon. In light of the variations between these studies, a narrative analysis with some exploratory analysis is therefore presented, however due to the small numbers within each subgroup, an analysis of the subgroups was not performed.

Patient reported outcome measures

Details of the patient reported outcome measures used in the included studies are detailed in the characteristics section. The majority of the studies considered the functional outcome of the patients at 3, 6 and 12 months post-operatively.

A superior early improvement in function with plate fixation was demonstrated by McFadyen 2011 and Rozental 2009, with standardised mean differences (SMDs) for the DASH score ranging from -1.1 (-1.8, -0.5) at 6 weeks to -0.8 (-1.4, -0.2) at 12 weeks and mean differences greater than the minimally clinical important difference (MCID) of 10 points (Table 16)(304). In contrast, Costa 2014, Hollevoet 2011 and Marcheix 2010 found a minimal improvement of the DASH and PRWE scores for both interventions at 3 months with SMDs ranging from -0.1 to -0.4.

Table 16 - Summary of effect sizes for the DASH score *(A positive SMD denotes a greater effect with wire fixation and a negative SMD denotes a greater effect with plate fixation and effect sizes greater than the minimum clinically important difference are highlighted in bold italics.)*

Study	Plate fixation			Wire fixation			Mean Difference (95% CI)	Standardised Mean Difference (95% CI)
	Mean	SD	No.	Mean	SD	No.		
3 Months								
Rozental 2009	11	13	21	26	23	21	***-15.0 (-26.3, -3.7)***	***-0.8 (-1.4, -0.2)***
Marcheix 2010	25	21	50	33	22	53	-8.0 (-16.3, 0.3)	-0.4 (-0.8, 0.0)
Costa 2014	28.9	21.1	207	31.1	20.6	203	-2.2 (-6.2, 1.8)	-0.1 (-0.3, 0.1)
Hollevoet 2011	21	21	16	27	24	19	-6.0 (-20.9, 8.9)	-0.3 (-0.9, 0.4)
6 Months								
Marcheix 2010	10	14	50	22	22	53	***-12.0 (-19.1, -4.9)***	***-0.6 (-1.0, -0.3)***
Costa 2014	19.2	17.5	199	21.1	18.5	195	-1.9 (-5.5, 1.7)	-0.1 (-0.3, 0.1)
12 months								
Rozental 2009	4	8	21	9	18	21	-5.0 (-13.4, 3.4)	-0.4 (-1.0, 0.3)
Costa 2014	13	15.6	195	16.2	17.9	201	-3.2 (-6.5, 0.1)	-0.2 (-0.4, 0.0)
Hollevoet 2011	14	16	18	13	20	16	1.0 (-11.3, 13.3)	0.1 (-0.6, 0.7)

At 6 months however, both McFadyen 2011 and Marcheix 2010 demonstrated a functional advantage with plate fixation, with a SMD of -0.6 (-1.0, -0.3) and a mean difference greater than the MCID for the DASH score. Costa 2014 however, found no difference in the functional improvement with either the DASH or PRWE scores for the two interventions, with SMDs of -0.1 (Table 17). By 12 months, all of the studies reported no difference in function between the wire and plate fixation with either the PRWE or DASH score.

Table 17 - Summary of effect sizes for the PRWE score *(A positive SMD denotes a greater effect with wire fixation and a negative SMD denotes a greater effect with plate fixation)*

Study	Plate fixation			Wire fixation			Mean Difference (95% CI)	Standardised Mean Difference (95% CI)
	Mean	SD	No.	Mean	SD	No.		
3 Months								
Costa 2014	31.5	22.4	211	33.9	22.3	212	-2.4 (-6.7, 1.9)	-0.1 (-0.3, 0.1)
6 Months								
Costa 2014	20.6	17.7	206	22.3	18.6	208	-1.7 (-5.2, 1.8)	-0.1 (-0.3, 0.1)
12 months								
Costa 2014	13.9	17.1	204	15.3	15.8	211	-1.40 (-4.57, 1.77)	-0.1 (-0.3, 0.1)

Goehre 2014 was the only study to provide solely a graphical portrayal of the DASH and PRWE scores. The findings demonstrated for the DASH scores was similar to Costa 2014 with no difference between the two interventions at all time points. The PRWEs scores however differed slightly, with a small difference detected at 3 months for Goehre 2014 that decreased in magnitude by 6 months, to no difference by 12 months.

Table 18 - Summary of effect sizes for the EQ5D score *(A positive SMD denotes a greater effect with wire fixation and a negative SMD denotes a greater effect with plate fixation)*

Study	Plate fixation			Wire fixation			Mean Difference (95% CI)	Standardised Mean Difference (95% CI)
	Mean	SD	No.	Mean	SD	No.		
3 Months								
Costa 2014	0.7	0.2	207	0.7	0.2	205	0.0 (-0.0, 0.0)	0.0 (-0.2, 0.2)
6 Months								
Costa 2014	0.8	0.2	194	0.8	0.2	200	0.0 (-0.0, 0.0)	0.0 (-0.2, 0.2)
12 months								
Costa 2014	0.9	0.2	194	0.8	0.2	204	0.1 (0.1, 0.1)	0.5 (0.3, 0.7)

No difference was detected for the EQ5D scores at either 3 or 6 months. A moderate treatment effect was detected at 12 months in favour of plate fixation, although it did not exceed the MCID of 0.12 and hence may not be clinically relevant(305).

Grip strength

Grip strength was measured by 4 of the studies at 6 and 9 weeks, and 3, 6 and 12 months post-operatively. At both 6 and 9 weeks, Rozental 2009 detected a clinically important difference in grip strength of 10kg greater with plate fixation (Table 19). Marcheix 2010 similarly detected greater grip strength with the plate group at 6 months, however, neither the mean difference nor the 95% CI exceeded the MCID of 19.5 suggesting it is unlikely to be clinically relevant. At 3 and 12 months, none of the studies detected a difference in strength between either of the interventions, with standard mean differences of 0.1 to 0.4.

Table 19 - Summary of the treatment effect for grip strength *(A positive SMD denotes a greater effect with wire fixation and a negative SMD denotes a greater effect with plate fixation. Effect sizes greater than the MCID of 19.5 are highlighted in bold and italics)*

Study	**Plate fixation**			**Wire fixation**			**Mean Difference (95% CI)**	**Standardised Mean Difference (95% CI)**
	Mean	**SD**	**No.**	**Mean**	**SD**	**No.**		
3 months								
Marcheix 2010	54	21	50	45	25	53	9.0 (0.1, 17.9)	0.4 (0.0, 0.8)
Hollevoet 2011	60	30	16	56	31	19	4.0 (-16.3, 24.3)	0.1 (-0.5, 0.8)
6 months								
Marcheix 2010	70	21	50	58	24	53	12.0 (3.3, 20.7)	0.5 (0.1, 0.9)
12 months								
Hollevoet 2011	82	30	16	94	40	15	-12.0 (-37.0, 13.0)	-0.3 (-1.0, 0.4)

Range of motion

Again, 4 of the studies assessed the recovery of wrist motion at 6 and 9 weeks, then at 3, 6 and 12 months post–operatively. Similar to grip strength, Rozental 2009 detected a superior range of motion in the plate fixation group in all planes of motion for the 6 and 9-week measurements. Effect sizes for these early measurements of wrist of motion ranged from 0.6 to 1.7 with the exception of the pronation and radial deviation at 9 weeks where no significant difference was detected between the groups (Table 20).

Rozental 2009 continued to demonstrate moderate effect sizes in extension, supination and ulnar deviation at 3 months, but only small effect sizes at 6 months. Marcheix 2010 and Goehre 2014 similarly presented moderate effect sizes for flexion and supination respectively at 3 months, and for supination at 6 months. The remainder of the effect sizes were however small at both 3 and 6 months.

At 12 months the difference between the groups was minimal, with effect sizes ranging from 0.0 to 0.5. Rozental 2009 provided the only exception with an effect size of 0.9 for ulnar deviation.

Table 20 - Summary of treatment effect for range of motion of the wrist *(A positive SMD denotes a greater effect with wire fixation and a negative SMD denotes a greater effect with plate fixation)*

		Study	**Plate fixation**			**Wire fixation**			**Mean Difference (95% CI)**	**Standardised Mean Difference (95% CI)**
			Mean	**SD**	**No.**	**Mean**	**SD**	**No.**		
3 months	**Pronation-supination**	Hollevoet 2011	89	15	16	89	11	19	0.0 (-8.9, 8.9)	0.0 (-0.7, 0.7)
	Pronation	Goehre	87.5	14.9	21	84.4	18.7	19	3.1	0.2

		2014							(-7.5, 13.7)	(-0.4,0.8)
		Marcheix 2010	75	12	50	74	15	53	1.0 (-4.2, 6.2)	0.1 (-0.3,0.5)
		Rozental 2009	85	11	23	80	20	21	5.0 (-4.7, 14.7)	0.3 (-0.3, 0.9)
	Supination	Goehre 2014	90.7	12.1	21	79.9	17.7	19	10.8 (1.3, 20.3)	0.7 (0.1, 1.4)
		Marcheix 2010	68	18	50	63	25	53	5.0 (-3.4, 13.4)	0.2 (-0.2,0.6)
		Rozental 2009	84	13	23	72	26	21	12.0 (-0.3, 24.3)	0.6 (-0.0, 1.2)
	Flexion-extension	Hollevoet 2011	74	15	16	73	17	19	1.0 (-9.6, 11.6)	0.1 (-0.6,0.7)
	Flexion	Goehre 2014	73.2	17	21	70.3	20.5	19	2.9 (-8.8,14.6)	0.2 (-0.5,0.8)
		Marcheix 2010	49	14	50	41	17	53	8.0 (2.0, 14.0)	0.5 (0.1,0.9)
		Rozental 2009	58	13	23	55	19	21	3.0 (-6.7,12.7)	0.2 (-0.4,0.8)
	Extension	Goehre 2014	79.8	18.7	21	72.7	17.2	19	7.1 (-4.0, 18.2)	0.4 (-0.2,1.0)
		Marcheix 2010	42	12	53	41	12	53	1.0 (-3.6, 5.6)	0.1 (-0.3, 0.5)
		Rozental 2009	58	14	23	48	18	21	10.0 (0.4, 19.6)	0.6 (0.0, 1.2)
	Radio-ulnar deviation	Hollevoet 2011	74	16	16	68	22	19	6.0 (-6.6, 18.6)	0.3 (-0.4,1.0)
	Radial deviation	Goehre 2014	74.2	19.6	21	72.6	26.2	19	2.9 (-8.8, 14.6)	0.1 (-0.6,0.7)
		Rozental 2009	22	9	23	20	10	21	3.0 (-6.7, 12.7)	0.2 (-0.4,0.8)
	Ulnar deviation	Goehre 2014	75.3	17.7	21	77.5	24.1	19	-2.2 (-15.4, 11.0)	-0.1 (-0.7,0.5)
		Rozental 2009	35	6	23	30	8	21	5.0 (0.8, 9.2)	0.7 (0.1,1.3)
6 months	**Pronation**	Goehre 2014	93	9.3	21	91.3	11	19	1.7 (-4.7, 8.1)	0.2 (-0.5,0.8)
		Marcheix 2010	77	5.8	50	78	5	53	-1.0 (-3.1, 1.1)	-0.2 (-0.6,0.2)
	Supination	Goehre 2014	94	6.7	21	86.8	12.2	19	7.2 (1.0, 13.4)	0.7 (0.1,1.4)
		Marcheix 2010	81	6.8	50	70	23	53	11.0 (4.5, 17.5)	0.6 (0.2,1.0)

	Flexion	Goehre 2014	81.4	14.2	21	77.4	18.8	19	4.0 (-6.4, 14.4)	0.2 (-0.4,0.9)
		Marcheix 2010	53	16	50	47	16	53	6.0 (-0.2, 12.2)	0.37 (-0.02,0.76)
	Extension	Goehre 2014	85.8	16.3	21	80.4	17.2	19	5.4 (-5.0,15.8)	0.3 (-0.3,0.9)
		Marcheix 2010	50	16	50	47	10	53	3.0 (-2.2, 8.2)	0.2 (-0.2, 0.6)
	Radial deviation	Goehre 2014	81.2	15.9	21	80.8	24.6	19	0.4 (-12.6, 13.4)	0.0 (-0.6, 0.6)
	Ulnar deviation	Goehre 2014	84.3	15.5	21	83.4	22.1	19	0.9 (-11.1, 12.9)	0.1 (-0.6, 0.7)
12 months	**Pronation-supination**	Hollevoet 2011	97	8	16	98	6	15	-1.0 (-6.0, 4.0)	-0.1 (-0.8, 0.6)
	Pronation	Goehre 2014	96.1	5.9	21	95.9	6.5	19	0.2 (-3.7, 4.1)	0.0 (-0.6, 0.7)
		Rozental 2009	88	4	21	88	4	21	0.0 (-2.4, 2.4)	0.0 (-0.6,0.6)
	Supination	Goehre 2014	95.6	7.8	19	93.8	5.7	19	1.8 (-2.5, 6.1)	0.3 (-0.4, 0.9)
		Rozental 2009	88	5	21	87	9	21	1.0 (-3.4, 5.4)	0.1 (-0.5, 0.7)
	Flexion-extension	Hollevoet 2011	90	8	16	86	15	15	4.0 (-4.5, 12.5)	0.3 (-0.4,1.0)
	Flexion	Goehre 2014	86.7	14.7	21	80.5	18.4	19	6.2 (-4.2, 16.6)	0.4 (-0.3, 1.0)
		Rozental 2009	68	14	21	72	15	12	-4.0 (-14.4, 6.4)	-0.3 (-1.0, 0.4)
	Extension	Goehre 2014	91.2	14	21	85.4	16.5	19	5.8 (-3.7, 15.3)	0.4 (-0.3,1.0)
		Rozental 2009	64	17	21	66	20	21	-2.0 (-13.2, 9.2)	-0.1(-0.7, 0.5)
	Radio-ulnar deviation	Hollevoet 2011	90	17	16	89	18	15	1.0 (-11.3, 13.3)	0.1(-0.7,0.8)
	Radial deviation	Goehre 2014	81.5	24.2	21	86.2	21.1	19	-4.7 (-18.7, 9.3)	-0.2(-0.8,0.4)
		Rozental 2009	28	15	21	22	10	21	6.0 (-1.7, 13.7)	0.5(-0.2,1.1)
	Ulnar deviation	Goehre 2014	88	15.2	21	86.7	17.5	19	1.3 (-8.9, 11.5)	0.1(-0.5,0.7)
		Rozental 2009	40	11	21	32	7	21	8.0 (2.4, 13.6)	0.9(0.2,1.5)

Secondary outcome measures

Radiological parameters and post-operative complications were reported in all the included studies.

Radiological parameters

All the studies assessed the post-operative radiological outcome, however, they did not all assess the same parameters and at the same time points. Hollevoet 2011 demonstrated no significant difference between the groups for any of the parameters assessed at 5 weeks. However, a loss of reduction was detected in eight patients with wire fixation and two with plate fixation at a later time point that was not specified in the study article.

The radiological outcome at 6 months was assessed in three studies. Goehre 2014 and Mcfayden 2011 demonstrated a deterioration in the fracture position, with a loss of 4-8° of palmar inclination in the wire group only. In contrast, Marcheix 2010 detected a loss of ulnar variance and palmar inclination with both groups at 6 months, but no significant difference between the groups.

Rozental 2009 and Costa 2014 were the only studies to assess the radiological outcome at 12 months. Rozental 2009 detected no late collapse or malunion, with minimal change detected in the radiological parameters assessed immediately post-operatively and at 12 months for both groups. Costa 2014, similarly demonstrate no late collapse, however, a larger (more positive) dorsal angle and ulnar variance was detected with the wire group in comparison to the plate group at 6 weeks and 12 months post-operatively.

Complications

Post-operative complications were reported in all the studies for both the wire and plate fixation groups. Costa 2014, Goehre 2014 and Hollevoet 2011 demonstrated similar rates of complications between both groups. The Rozental 2009, McFayden 2011 and Marcheix 2010, however, demonstrated a higher rate of complications, in the wire fixation group. For example, McFayden 2011 detected no complications in the plate group but 8 in the wire group.

In the plate fixation group, the most commonly reported complication was neurological injury. Infection, tendon injury, chronic regional pain syndrome, carpal tunnel syndrome and re-fracture were also reported. In the wire fixation group pin-site infections were most commonly reported. Other complications reported included deep infections, neurological injury, tendon injury, chronic regional pain syndrome, carpal tunnel syndrome and re-fracture.

Discussion

Summary of main results

Six studies fulfilled the eligibility criteria to be included in this review. All of these studies were randomised controlled trials comparing volar locking plate and percutaneous wire fixation in 747 patients. The majority of these studies included small sample sizes, with the exception of the one multi-centre trial contributing 60% of patients. Clinical heterogeneity was deemed to be present, hence pooling of data with the presentation of overall effect sizes was not performed. Individual effect sizes for each trial with complete data were instead presented allowing a number of inferences to be drawn.

At the12 month final outcome, there was a marginal difference in the treatment effects for the patient reported and physical outcome measures in favour of the volar locking plate fixation. The individual effect sizes did not exceed the minimal clinically important differences that were available for the patient reported measures and grip strength. Therefore, it is unlikely that the differences between these two types of fixation would be discernible to the patient at 12 months post-fixation based upon these findings.

Conflicting evidence was conversely presented for the early recovery of wrist function. Rozental 2009 and McFayden 2011 reported a superior functional outcome with plate fixation, whilst the remaining studies demonstrated either no difference or a small difference in function at both 3 and 6 months post-operatively. These differences may be a reflection of the differences in the post-operative treatments of patients with plate fixation as opposed to an inherent sequelae of plate fixation. Rozental 2009 for example, commenced an early range of movement protocol after 1 week with the plate fixation group, whilst Hollevoet 2011 immobilised both groups for 5 weeks. It is hardly surprising therefore that with these differences in treatment the early functional outcome differed between trials.

Evidence for the radiological outcome and rate of complications similarly varied amongst trials in this review. The radiological outcome at 12 months was demonstrated to be either worse in the wire fixation group with a greater degree of dorsal angulation and ulnar variance, or equivalent to the plate fixation group. Importantly, late collapse, which is often touted as a complication of wire fixation, did not occur for either type of fixation in any of the trials.

Lastly, the rate and severity of the complications was found to be similar for both fixation groups in three of the trials. Common complications included superficial and deep infections, pain, neurological and tendon injury. The remaining three trials reported a higher rate of complications with the wire fixation group. However, these were predominately minor complications with limited detrimental effects for the patient.

Limitations of the review evidence

The evidence in this review was derived from a limited number of clinically heterogeneous randomised controlled trials of varying quality.

Systematic bias was detected in three of the studies for the concealment of the treatment allocation, the reporting of outcome data, and with the inclusion of participating surgeons and treatment centres. It was not possible to disprove all other sources of bias assessed as part of the Cochrane risk of bias assessment tool for all apart from two of the trials. The generation of the randomisation sequence was the only component to confer a low risk of bias for each of the trials.

In addition to the varying quality of evidence, this review was further limited by the choice of outcome measure. Although, the DASH score was recorded for all of the trials with the exception of McFayden 2011, which presented the quick DASH score, this score is only limb specific as opposed to specific to injuries of the wrist. Only one trial assessed the PRWE score despite it being the more responsive to clinical change in patients with a distal radius fracture in comparison to the DASH score(117).

Limitations of the review processes

The quality of the review process has been considered against the PRISMA 2009 checklist for reporting systematic reviews, and any limitations identified incorporated into this section (see appendix 6). Broadly, the sources of error can be considered in terms of the identification and selection of included studies, the extraction, synthesis and risk appraisal of study data.

Firstly, although, the objectives, methods and inclusion criteria were pre-defined, the corresponding protocol for this review was not published prior to the undertaking of the review process. The reader is therefore unable to appraise the review with regards to deviations from the original review intentions and hence there is a greater risk of publication bias.

The identification and selection of sources offers another potential limitation of this review. Although a combination of databases known to be successful in the identification of primary orthopaedic trials were used, the number of potential trial reports identified may have been limited firstly by the search strategy and secondly by the limits upon the strategy. Search filters designed by Cochrane and the Scottish Intercollegiate

Guidelines Network were combined with the subject search to identify a manageable number of studies to be screened. It is possible by using these filters some reports may have been missed that did not meet the search terms. The search was further limited by the exclusion of all non-English language trials, due to the lack of sufficient resources to translate the reports.

The selection of the included studies however, was undertaken by two independent assessors using a recognised system of screening the titles and abstracts followed by the assessment of the full reports of those meeting the search criteria. It is unlikely therefore that bias was introduced at this stage. In contrast, only one assessor performed the extraction and appraisal of the study data and quality. It is highly likely, therefore, that error may have been introduced again at this stage with either data inaccurately extracted or interpreted.

Lastly, the synthesis of a larger study with a number of smaller studies can result in the findings from the larger study dominating those of the smaller studies due to the larger sample size. This could be misleading if the larger study had been poorly undertaken with a number of systematic errors. In regards to this review however, the larger study was well designed and conducted, with a low risk of bias in comparison to the smaller trials. Hence, any 'dominance' effect upon the earlier functional outcome can be considered appropriate. In addition, the findings at the 12-months post-injury were in agreement between the smaller and larger trials.

Application of the evidence to current practice

Clinical heterogeneity was detected between the trials included in this review, which may hamper the generalizability of the findings presented here. Subtle differences arose between trials in the inclusion of patients, the interventions undertaken and the number of participating surgeons, with studies adopting either a pragmatic approach mirroring typical practice in the UK or a more selective approach. Despite their differences, the findings at 12 months were similar for all of the trials. *In addition, the functional outcome data presented are derived from outcome measures recognised by the upper limb and trauma community, responsive to clinical changes in patients with a fracture of the distal radius, further enhancing the applicability of these findings.*

Agreements and disagreements with other studies or reviews

At the conception and undertaking of this review, no recent systematic reviews had been published providing a direct comparison of wire and plate fixation for dorsally displaced distal radius fractures in adult patients.

Diaz-Garcia *et al.* for example had provided the most recent assessment of function following several surgical and non-surgical interventions for the management of adult patients over 60 years old(51). Even though trials assessing the outcome of both volar plate and percutaneous wire fixation were included, none provided a direct comparison of the two interventions. Similarly, the 2003 Cochrane review of surgical interventions for unstable distal radius fractures concluded there was insufficient evidence available to detect a difference between these interventions(255).

Since the completion of the review process, two meta-analyses have been published assessing the comparison of volar locking plate and wire fixation. Both reviews came to the same conclusion, that plate fixation provides a small functional advantage at 12 months that it is unlikely to confer a clinically important benefit to patients. Despite reaching the same conclusion, this review differs from both of these alternate reviews with respect to the inclusion criteria, the synthesis of data and assessment of the risk of bias.

In this review, wire fixation alone without external fixation adjuncts were included. This has meant the Karantana (2013) trial of plate versus wire fixation with optional adjunctive external fixation was excluded even though it was used for only 17% of patients(184). This decision was based upon the premise that through the additional use of adjunctive external fixation, the construct and hence stability of the wire fixation might be altered skewing the trial result. The remaining six trials included in this review however, mirror those included in both the alternate meta-analyses.

The handling of the review data similarly differs. In this review, pooling of the data was deemed inappropriate due to clinical heterogeneity amongst the included trials. In contrast, both the meta-analyses, pooled data for the DASH score for varying numbers of trials. However, neither review provided a qualitative assessment of the degree of clinical heterogeneity.

The assessment of the risk of bias provides the last difference amongst the three reviews. Overall, this review agreed on 54.8% of the sources of bias with Chaudhry 2015, and 52.4% with Zong 2015(313, 314). Interestingly, there was 45.2% agreement between both the meta-analyses. The sequence generation was the only source of bias to be agreed by all, with discrepancies present for the remaining sources, in particular with the evaluation of blinding and other sources of bias.

Conclusions

Implications for practice

Although the evidence presented in this review was predominately from smaller trials of uncertain quality, Costa 2014, providing the only multicentre trial with a low risk of bias, has mirrored the findings at 12 months. Estimated treatment effects for all of the studies were small and predominately in favour of the volar locking plate fixation. These findings suggest that plate fixation provides a minor functional advantage in comparison to wire fixation. However, it is unlikely that it would be clinically relevant or even discernable to patients. Therefore, it is important that clinicians and policy makers consider the importance of an early return to function for the patient and the cost implications of the intervention when deciding upon the management of these patients.

Implications for research

This review has sought to determine whether there was a difference in the functional outcome of patients treated with percutaneous wire or volar plate fixation. The studies included provide evidence for the first 12 months of the post-operative period using recognised outcome measures for the assessment of wrist function. None of these studies however provide evidence beyond 12 months, even though the wrist function of patients with these fractures has been shown to continue improving(315). Therefore, high quality trials are required to determine the long-term functional outcome of this group of patients and ultimately whether either type of fixation confers a functional advantage.

4. A comparison of electronic and manual dynamometry and goniometry in healthy participants and patients with a fracture of the distal radius

Declarations

The randomisation sequence was generated by Dr Nicholas Parsons (Statistician), Miss Kate Denninson (Research Physiotherapist) performed a number of the patient goniometry reliability measurements, and Miss Hayley Rice (Research Physiotherapist) acted as the second observer for the healthy participants. All other study procedures were undertaken by the candidate.

This work has been published:
Plant CE, Parsons NR, Edwards AT, Rice H, Denninson K, Costa ML. A comparison of electronic and manual dynamometry and goniometry in patients with fracture of the distal radius and healthy participants. Journal of Hand Therapy. 2016: 29 (1) 73-80

Ethical Approval

Ethical approval was granted by the Coventry & Warwickshire NHS Research Ethics Committee and the University of Warwick Biomedical Research Ethics Sub-committee.

Once patients have received an operation it is important to consider their outcome in both the initial stages of their recovery and in the longer term. This monitoring is essential for ensuring the adequacy of the operation for the individual patient, and to inform quality assessment processes. The patients' recoveries can be monitored with dynamometry and goniometry of the wrist and hand, using either manual or electronic equipment. The electronic equipment offers additional features in comparison to the manual equipment that may be useful in a clinical and research setting. Therefore, in this chapter the reliability of dynamometry and goniometry using both manual and electronic equipment has been assessed, in order to determine which equipment should be used for the later chapters.

Background

Impairment of the upper limb through fracture, arthritis or neurological injury can result in a detrimental loss of hand function. An accurate determination of this function is essential when monitoring the therapeutic progression of these patients throughout their treatment(120, 171). Traditionally, patient monitoring has relied upon the clinicians' assessment to indicate the presence of a deficit, yet their assessment may fail to quantify the impairment meaningfully(120, 171). Typically, clinicians' assessment involves a focused history and examination, but no formal measurement of the physical properties of hand function.

Hand function can be assessed in terms of grip strength, precision strength and range of movement; with these assessments providing important information about the condition of the articular surface, the periarticular structures, and the ability of the muscles of the hand and forearm to generate and transmit force (316-318). Grip strength is vital in the performance of gross tasks, such as turning a wrench, where a repeatedly forceful grip is required; or carrying an object that necessitates a continuous application of force (319). Such a grip is achieved through the clamping of an object between the partially flexed fingers and palm, with the thumb adducted and flexed providing counter pressure (320). Two key characteristics of grip can be measured: the maximal voluntary contraction, and grip fatigue. The maximal voluntary contraction is frequently recorded for research purposes as it is easier to measure. However, it is rare that a single episodic forceful grip is required, instead a sustained grip is more commonly used for performing most tasks(177, 319).

Precision strength involves a pinching grip between the thumb and flexor aspect of the fingers (320). It is required when performing intricate tasks such as writing, turning a page or fastening buttons. The lateral pinch, commonly referred to as the key pinch, is the most frequently measured precision grip and is between the thumb pad and the lateral aspect of the index finger (321). This precise hand function is required when turning a key or pressing buttons on a remote control(321).

Lastly, range of movement of both the wrist and forearm can be assessed using goniometry, to measure the following planes of movement; flexion/ extension, radial/ ulnar deviation and pronation/ supination. Flexion/extension results from combined movements at the radiocarpal and midcarpal joints, mediated by the forearm flexors and extensors(19). Radial/ ulnar deviation however predominately occurs at the midcarpal joint involving the scaphoid, lunate and capitate carpus, mediated by the flexor and extensor carpi radialis and ulnaris (19). Supination and pronation occur at the radioulnar joints mediated by the pronators and supinators of the arm and forearm. A reduction in any of these planes of movement would impact upon the individual's ability to perform certain tasks; for example swinging a racket would be severely limited without full rotation and flexion/ extension at the wrist.

Relevance of the project

Manual dynamometers and goniometers have traditionally been favoured in the assessment of strength and range of movement of the wrist providing discrete and objective measurements(118). Numerous reliability studies have been undertaken, showing them to be reliable in assessing both healthy and impaired participant groups(118, 119, 322-326). The introduction of electronic equivalents offering greater functionality and information, has resulted in the increased use of this more complex technology (177-182). However, limited studies have been performed assessing their reliability with either healthy participants or those with an impairment of the upper limb, with few providing a comparison with their manual counterparts.

This study aims to examine the intra-rater and inter-rater reliability of electronic and manual dynamometry and goniometry in the assessment of wrist strength and range of motion in healthy participants, and the inter-instrument reliability in the assessment of both patients with an operatively fixated fracture of the distal radius and healthy participants.

Methods

Objectives and research questions

The objectives of this study were:

1. To determine if a difference in the reliability of electronic and manual dynamometers when measuring maximum grip strength and fatigue can be detected in healthy participants and patients recovering from a fracture of the distal radius.
2. To determine if a difference in the reliability of the electronic and manual pinch

gauges for measuring the maximum pinch strength in healthy participants and patients recovering from a fracture of the distal radius can be detected.

3. To determine if a difference in the reliability of electronic and manual goniometry can be detected in healthy participants and patients recovering from a fracture of the distal radius.

These objectives will assist me in answering the following research questions:

1. Does the electronic dynamometer provide greater levels of intra-rater, inter-rater and inter-instrument reliability, than the hydraulic dynamometer, when measuring the maximum voluntary contraction and grip fatigue in healthy participants and patients recovering from a fracture of the distal radius?
2. Does the use of an electronic pinch gauge provide greater levels of intra-rater, inter-rater and inter-instrument reliability than the manual pinch gauge, when measuring the maximum voluntary pinch strength in healthy participants and patients recovering from a fracture of the distal radius?
3. Does the electronic goniometer provide greater levels of intra-rater, inter-rater and inter-instrument reliability, than the manual goniometer, when measuring the range of movement of the wrist in healthy participants and patients recovering from a fracture of the distal radius?

Participants

A healthy volunteer and a wrist fracture group were recruited for this study. Prior studies have suggested wrist dynamometry and goniometry differ with impairment in comparison to healthy volunteers(318). By including a patient group the inter-instrument reliability could be assessed in addition to the practical use of the equipment in a clinical setting on patients. The full reliability protocol, however would have been to onerous for the impaired group to have undertaken at that stage in their recovery, therefore a healthy volunteer group was also included to assess the inter-rater and intra-rater reliability.

Sample Size

A convenience sample of 50 adults patients with a fracture of the distal radius and a purposive sample of 25 healthy volunteers were recruited into the study; these numbers were selected pragmatically as being sufficiently large to reveal important differences in reliability between groups, moderated by practical constraints imposed by data collection in a clinical setting. In an audit of patients with a distal radius fracture attending University Hospital Coventry to undergo operative fixation over a 4month period, there were 32 patients that received either K-wires or a volar plate fixation. This number of patients was extrapolated to 150 potentially eligible patients over the recruitment period. In regards to the healthy volunteer group, similarly problems with recruitment were not anticipated. Warwick Medical School has approximately 492 employees, consisting of 63.2% women, with 93.7% of employees aged between 21 and 65 years old, in addition to students and visitors.

Eligibility Criteria

Adult patients were considered eligible to participate in the study if they met the following criteria:

- They had sustained a closed dorsally displaced fracture of the distal radius
- They had entered the DRAFFT trial and undergone surgical fixation with either Kirschner wires or a volar locking plate.
- They attended the University Hospital Coventry and Warwickshire NHS trust for their postoperative care

Patients were considered ineligible if:

- They had received non-operative management
- They were unable to adhere to the trial demands

Healthy volunteers were eligible to enter the study if:

- They had no on-going or prior wrist injuries including fractures, tendon and nerve injuries
- They were aged over 18 years old and able to give informed consent

Volunteers were excluded from participating if:

- There was evidence that they will be unable to adhere to the trial procedures or undergo the functional outcome measurements

Recruitment and Consent

Wrist fracture patient group

The patient group was recruited from patients entered into the Distal radius fracture fixation trial (DRAFFT) between January 2011 and July 2012(278). The DRAFFT trial is a UK National Institute for Health Research clinical trial assessing the outcome of patients with a dorsally displaced fracture of the distal radius surgically fixed with either Kirschner wires or a volar locking plate(278). As part of the trial participants completed the Patient Reported Wrist Evaluation (PRWE), Disabilities of the Arm, Shoulder and Hand (DASH) and Euro-qol outcome measures at regular intervals. I approached patients at their six-week post-operative appointment as opposed to at presentation, to ensure they did not feel overly burdened by the trial procedures preventing their initial involvement in the DRAFFT trial. An appointment was made for 3 months post-operatively for those willing to participate, and they were given the option to sign the consent form at that time or at the 3-month appointment after greater consideration of the study commitments.

Healthy volunteer group

The healthy volunteer group was recruited from Warwick Medical school employees and members of the community between August 2012 and May 2013. Attempts were made to recruit an equal number of men and women, with individuals from 3 age groups; 18-30 years, 31-50 years and over 50 years to provide a comparator to the impaired group. Volunteers were presented with an information sheet and given the opportunity to discuss any issues relevant to the study. Consent was obtained from willing volunteers and a testing session arranged at a convenient time.

Observers

All participants were assessed by myself on two occasions, the measurements were repeated on one of the occasions for the healthy participant group by a physiotherapist. Prior to commencement of the testing sessions, both undertook training on the correct use of the instrument and the testing procedures. Additional reference material was also available for the tracker freedom wireless electronic system (JTECH Medical, Salt Lake City, USA), demonstrating the correct procedure for each component.

Instruments

The Tracker Freedom wireless dynamometer, pinch gauge and goniometer (JTECH Medical, Salt Lake City, USA), using the version 5 software were evaluated in comparison with the BASELINE hydraulic hand dynamometer and pinch gauge (Fabrication Enterprises Incorporated, Elmsford, USA) and a universal goniometer (model G300, Whitehall manufacturing, City of Industry, CA, USA). All instruments are commercially available.

Reliability

The Health and Technology Assessment (HTA) document *'Evaluating patient-based outcome measures for use in clinical trials'*, reliability is defined as the extent to which the instrument is free from random error and the observed changes are due to the intervention and not the measuring instrument(327). Three facets of reliability that were assessed during this study: (i) inter-rater reliability – the reproducibility of a measurement when performed by two or more observers on a single occasion, (ii) intra-rater reliability – the reproducibility of a measurement when performed by a single observer on separate occasions, (iii) inter-instrument reliability – the reproducibility of a measurement when performed by two or more instruments

Test Procedures

At the start of each testing session all the tests were demonstrated using the manual equipment and poor positioning corrected. The order of the tests was randomly selected according to a random table generated by a statistician who was not involved in testing. The observers, however, decided the order of the instruments. During testing sessions, participants were not given any verbal encouragement to enhance their performance, and were prevented from viewing the instruments readings until the end of the test. Any comments made by the participants regarding the usability of the equipment were also noted during the testing sessions.

The patient group underwent all testing on a single occasion, performing each exercise with the manual and electronic equipment 3 times for both the injured and uninjured wrists. Testing sessions were performed at the 3-month post-operative follow up visit by either the orthopaedic trainee or one of the physiotherapists (figure 9). In order to reduce fatigue and discomfort to the patients, the group was split with half the group performing the dynamometry and the other half the goniometry tests.

The healthy volunteer group performed all the electronic and manual dynamometry and goniometry tests on two separate occasions with a minimum of 1 week between sessions (mean = 11.3 weeks, SD = 10.6 weeks). Each test was performed 3 times for both wrists, with the order of the tests randomised for each participant. The orthopaedic trainee undertook testing on both sessions, with the tests repeated on one of the sessions by the physiotherapist for fourteen of the participants (figure 10).

Grip strength

Grip strength has been shown to vary with the position of the upper limb and posture of the individual whilst performing the examination. The optimal position of the wrist has been shown to be in neutral deviation with 0-30 degrees of extension(178). Grip strength performed in dorsi-flexion and extremes of deviation is substantially reduced in comparison to a neutral wrist position. Similarly grip strength has been shown to be effected by forearm rotation and elbow position. Neutral rotation of the forearm and 90 degrees flexion of the elbow produces a superior grip strength in comparison to either pronation or supination of the forearm or extension of the elbow (178). Balogun similarly found there to be a difference in grip strength dependent upon the position of the individual. Therefore a seated posture was adopted(328).

In consideration of the potential variability in grip strength with the position of the upper limb, the maximum grip strength and grip fatigue were performed in accordance with guidelines from the American Society for Hand Therapists. Participants were sat in an upright standard chair, with their shoulder adducted and neutrally rotated. The elbow flexed at 90 degrees, with the forearm and wrist in neutral rotation and neutral flexion/extension. Matheowietz & Fess et al. has shown these guidelines to be reliable in performing grip strength(329, 330).

Participants were asked to perform the test 3 times, alternating between wrists providing a minimum of a 15 second rest between trials to prevent fatigue(330, 331). The participant was then asked to grasp the dynamometer and squeeze as hard as they can, avoiding a sudden application of force for a total of 10 seconds. A sustained grip contraction has been shown to be reliable when performed between 6-60 seconds in patients with impairment of the wrist and healthy participants(177, 179, 180). A 10 second period was chosen as it is the maximum time afforded by the electronic dynamometer. The patient was instructed when to start, the midway point and the end of the trial with the following instructions: 'Start to squeeze now'; 'you have reached half way' and 'you can now stop'.

The dynamometer has 5 available handle positions placing the fingers in different levels of extension(332). Grip strength varies according to the handle positions(332, 333). In a study of normal male and female participants 60% of participants achieved their maximum grip strength for both their dominant and non-dominant hands with the second handle position. Firrell et al showed similar findings with 89% of the 288 asymptomatic patients displaying their maximal grip strength with the second handle setting(332). In the remaining 11% of individuals there was no relationship between hand size and the grasp setting; patients who achieved a maximal grip strength with the 3rd or 4th setting did not have a larger hand size in comparison to those using the 2nd setting as might be expected. Bear-Lehaman *et* al suggest that the 2nd handle is the most effective position for engaging both the intrinsic and extrinsic muscles during grip. Therefore the 2nd handle position was used for all patients during each trial(332, 334).

The maximum voluntary contraction and the grip fatigue were recorded for each trial. The maximum voluntary contraction was defined as the maximum force exerted over the 10-second grip measured in kilograms, and the grip fatigue as the percentage difference between the maximum voluntary contraction and the force of contraction at the end of the trial. The electronic dynamometer records the force of the contraction per second in real time, with the maximum voluntary contraction per trial and the grip fatigue. The manual dynamometer has a peak-hold needle retaining the highest force exerted during the trial (the maximum voluntary contraction). A stopwatch was used to time the 10 seconds. At the end of the 10 seconds the examiner observed the current force exerted, then asked the participant to stop. If the participant was unable to continue grasping the dynamometer it was recorded as 100% fatigue for both dynamometer.

The electronic dynamometer was automatically calibrated before the start of each use. The manual dynamometer was calibrated by baseline prior to commencing the measurements, however, it was not repeated during the testing sessions.

Lateral pinch strength

The lateral pinch represents one of the precision grips of the upper limb. It is formed by opposition of the lateral aspect of the index finger with the pulp of the thumb and is used when grasping a key(335). Hence, it is commonly referred to as the key pinch. In order to maintain participant motivation when testing, only the lateral pinch, as the most commonly assessed precision grip, was measured.

Lateral pinch strength varies with the position of the participant and upper limb, in much the same way that grip strength varies. A significant difference has been shown between pinch strength measured with forearm neutrally rotated as opposed to supination (336). Woody et al found neutral rotation to provide the optimal pinch strength(337). Deviation, flexion and extension of the wrist have also been shown to alter pinch strength, with 33 percent difference in strength when the wrist is palmar flexed in comparison to a neutral position (335, 338). Participants were therefore, seated with the shoulder adducted and neutrally rotated, the elbow flexed at 90 degrees, the forearm and wrist neutrally positioned (330, 335, 339).

The maximal voluntary pinch strength was recorded in kilograms. The participant was asked to grip the pinch gauge as firm as possible and then release. The test was performed 3 times, alternating between hands after each grip to prevent fatigue and recorded in kilograms(119, 330, 336).

Range of movement

Range of movement of the wrist and forearm was measured in three planes; flexion/ extension, ulnar/radial deviation and supination/pronation. Participants were asked to perform each movement three times before repeating on the second wrist. Measurements in each plane of movement were completed before the participant was asked to continue onto the 2nd plane of movement.

Participants were seated in an upright standard chair, with the shoulder adducted and neutrally rotated and the elbow flexed at 90 degrees in accordance with guidance from the American society of hand therapists.

Flexion/ extension

Participants were positioned with the forearm fully pronated and the wrist in neutral deviation. There are three possible techniques for measuring flexion/extension that have been shown to be reliable; the radial, ulnar and the dorsal technique. All show a high intra-tester reliability, the dorsal technique however has a higher inter-tester reliability(122, 324). The dorsal technique was therefore used. The distal arm of the goniometer was aligned with the third metacarpal and the proximal arm centrally over the forearm(122). The goniometer was placed on the dorsal aspect of the wrist and the patient asked to bend the wrist up and down (122).

Ulnar/radial deviation

Participants were positioned with the forearm in full pronation and asked to move the hand from neutral either towards the thumb (radius) or the little finger (ulnar)(340). The goniometer was placed on the dorsal surface of the wrist, with the distal arm aligned with the third metacarpal and the proximal arm centrally on the forearm as for flexion and extension (122).

Supination/ pronation

Participants were asked to start each movement with the forearm in a neutral position, with the forearm horizontal to the floor and palmar aspect of the hand facing medially(326). To pronate and supinate the forearm, the participant was asked to turn the palm of the test hand to the floor and ceiling respectively as far as possible. The distal forearm method is considered the gold standard technique for measuring rotation of the forearm and can be performed with both the electronic and manual goniometers(325). The stationary arm of the goniometer was aligned parallel to the humerus anterior midline and the movable arm placed on the volar or dorsal aspect of the forearm(341).

Statistical analysis

Data from all test measurements were summarized using descriptive statistics; means and standard deviations using Excel 2011. The intra-rater, inter-rater and inter-instrument reliability were assessed using an interclass correlation coefficient (ICC) for absolute agreement for the two-way random effects model in SPSS 21.0, with 95% confidence intervals presented to assess the precision of the estimates(342). An ICC value of 0.70 and greater was deemed to signify an acceptable reliability(343).

Results

Participant Recruitment and demographics

Wrist fracture patient group

During the study 7 male and 43 female patients aged 26 to 85 years old (mean age = 57 years old) were recruited (Table 21); the uneven split between males and females reflected the characteristics of the wider study population. Eighty-nine patients were assessed for their eligibility to enter the study, 38 declined to enter and 1 patient was ineligible due to non-operative management. There were 3 patients unable to complete the testing sessions, see figure 9. The patient group consisted of predominately female patients aged 50 years and older with low impact injuries, managed with approximately equal numbers of each fixation device. All the patients had sustained a closed dorsally displaced distal radius fracture, with a marginally greater number of extra-articular fractures (Table 21).

Table 21 - Participant demographics

		No. Wrist fracture patients (n=50)	**No. Healthy Participants (n=25)**
Gender	**Male**	7 (14%)	10 (40%)
	Female	43 (86%)	15 (60%)
Age	**18 - 30 years**	2 (4%)	8 (32%)
	31 - 50 years	12 (24%)	10 (40%)
	> 50 years	36 (72%)	7 (28%)
Hand Dominance	**Right**	46 (92%)	24 (96%)
	Left	4 (8%)	1 (4%)
Injury Wrist	**Dominant**	31 (62%)	
	Non-dominant	19 (38%)	
Injury Impact	**High Impact**	7 (14%)	
	Low impact	43 (86%)	
Articular involvement	**Extra-articular**	31 (62%)	
	Intra-articular	19 (38%)	
Fixation	**Kirschner wires**	21 (42%)	
	Volar Locking Plate	29 (58%)	

Healthy volunteer group

Ten male and fifteen female adult volunteers aged 23 to 67 years old (mean age= 40 years) were recruited from Warwick medical school employees and the general public (Table 21). 26 employees were approached to enter the study, 1 was ineligible due to a prior distal radius fracture and none declined to enter, see figure 11-12. All participants completed the testing sessions.

Figure 11- Patient flow (OST = Orthopaedic Specialist Trainee, PH1=Physiotherapist 1)

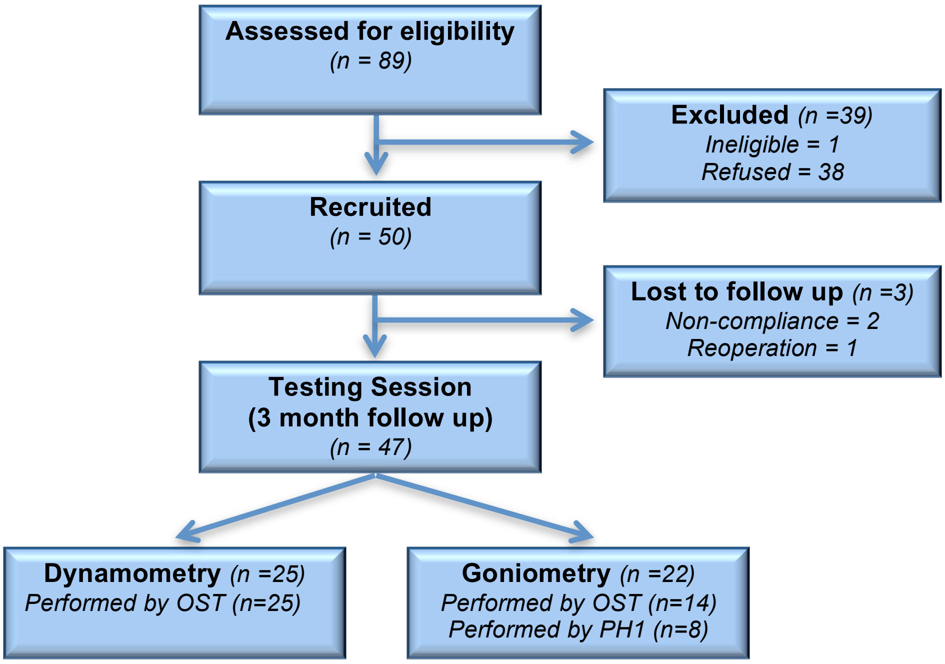
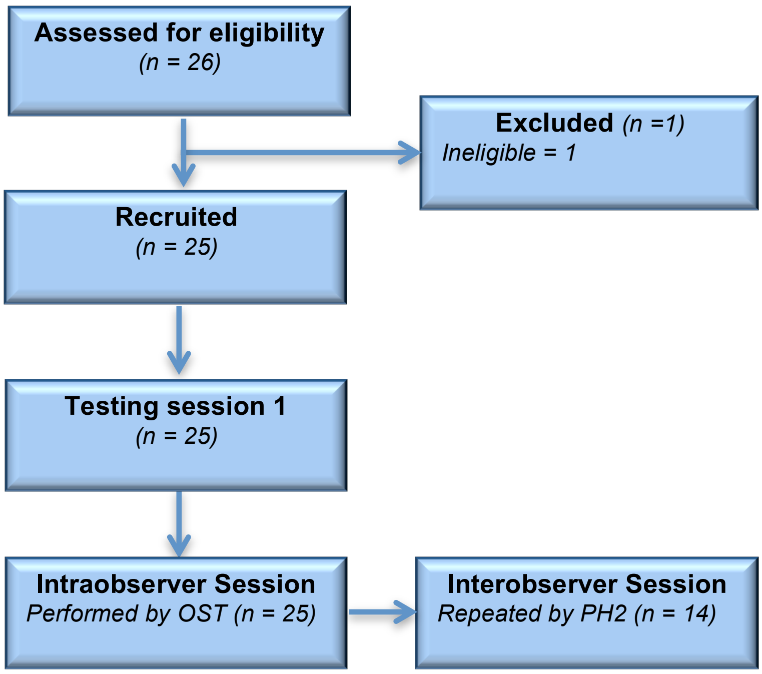


Figure 12 - Healthy volunteer Flow (OST = Orthopaedic Specialist Trainee, PH1=Physiotherapist 1 and PH2 = Physiotherapist 2)



Dynamometry measures

The healthy volunteer group demonstrated higher mean grip maximal voluntary contractions (MVC) ranging from 23.0 to 28.4kg in comparison to the impaired group ranging from 11.8 to 21.3kg for both the injured and uninjured wrists. A similar trend was noted for the maximal pinch strength with a 1 to 2kg difference between the healthy volunteers and the patients' uninjured wrist and a 3kg difference in comparison to the patient's injured wrists (Tables 22-24).

The mean grip strengths were also shown to deteriorate over the three successive measurements, with the first measurement tending to be highest, then decreasing in magnitude by 2-6kg with the final measurement demonstrating the lowest strength. The mean pinch strength however did not show this trend, with the highest value equally distributed amongst the three measurements.

These findings do not consider the effect of hand dominance. The healthy volunteer group consisted of an equal number of dominant and non-dominant wrist measurements, whilst the patients group was mainly dominant injuries. Analysis of the healthy participant group based upon hand dominance found a 1kg difference between the dominant and non-dominant MVC and a 0.5kg difference for the pinch strength, an insufficient difference to account for the low MVC grip and pinch strength values of the patient groups' uninjured wrists.

The mean grip fatigue was also found to be marginally higher for the healthy participants, in comparison to the uninjured and injured wrists of the patient group (Tables 22-24). The grip fatigue is based upon the grip strength MVC and final value at the 10-second time point. The mean grip strength MVCs have been shown to differ greatly, the final grip strength in comparison varied by only 1kg to 5kg.

Goniometry measures

The healthy volunteer group demonstrated a greater range of motion in comparison to the injured wrists of the patient group, with the exception of radial deviation and pronation, which were found to be equivalent (Tables 22-24). The greatest difference occurred for flexion and extension, with a 15 to 20 degree difference. This trend remained regardless of the participants' age and gender (Tables 22-23). In comparison to the measurements for the patient's uninjured wrists, the healthy volunteers demonstrated only a marginally increased range of movement of 5 to 10 degrees, with the exception of pronation and radial deviation. Analysis based upon the age and gender of the participants, again did not alter this trend.

Table 22 - Age specific dynamometry and goniometry measurements of the healthy volunteer and patient groups

		Age								
		18 - 30 years			31-50 years			≥ 51 years		
		Healthy	Impaired		Healthy	Impaired		Healthy	Impaired	
			Uninjured	Injured		Uninjured	Injured		Uninjured	Injured
Grip Strength (kg)	**Electronic**	30.3 (11.8)	16.6	14.2	27.7 (10.4)	21.0 (2.7)	19.5 (5.0)	28.1 (10.6)	20.4 (7.1)	10.1 (5.5)
	Manual	29.1 (11.3)			26.5 (9.6)	19.4 (3.7)	17.9 (3.7)	27.8 (9.3)	13.7 (5.7)	11.1 (6.3)
Grip Fatigue (%)	**Electronic**	31.5 (6.7)	37.7	38.0	28.5 (9.2)	30.6 (11.5)	31.0 (8.3)	30.5 (10.6)	31.7 (12.0)	31.6 (15.1)
	Manual	35.2 (12.4)			31.4 (5.6)	26.7 (6.9)	25.9 (6.4)	27.8 (6.1)	23.3 (7.4)	21.4 (21.6)
Pinch Strength (kg)	**Electronic**	7.8 (1.9)	5.0	5.1	7.7 (2.3)	7.8 (0.9)	6.9 (1.4)	7.9 (1.2)	5.8 (1.8)	3.9 (1.2)
	Manual	7.7 (2.2)	5.4	6.0	6.6 (3.2)	7.3 (1.2)	7.4 (1.6)	7.5 (1.3)	4.5 (1.2)	3.9 (1.2)
Extension (°)	**Electronic**	71.3 (11.8)			73.6 (6.1)	67.7 (8.2)	48.2 (11.6)	66.7 (7.7)	63.4 (18.9)	49.6 (20.6)
	Manual	68.8 (8.8)			69.1 (6.7)	64.9 (9.4)	49.5 (12.9)	67.3 (6.5)	58.4 (17.6)	44.9 (19.7)
Flexion (°)	**Electronic**	74.6 (13.5)			65.7 (9.3)	67.8 (9.4)	47.3 (15.4)	63.7 (4.0)	57.5 (10.1)	46.1 (11.6)
	Manual	70.4 (12.0)			63.1 (10.1)	68.5 (8.1)	51.1 (12.1)	62.6 (1.9)	58.4 (10.9)	44.9 (9.2)
Pronation (°)	**Electronic**	79.2 (3.0)			79.4 (3.2)	80.7 (5.2)	75.7 (5.6)	81.5 (2.5)	82.8 (3.0)	79.2 (6.4)
	Manual	80.8 (3.8)			80.0 (3.3)	80.9 (4.8)	76.7 (6.1)	82.6 (3.3)	82.9 (2.1)	79.2 (6.0)
Supination (°)	**Electronic**	78.9 (4.8)			77.4 (3.3)	76.2 (9.5)	66.7 (13.4)	75.9 (3.2)	71.0 (7.9)	64.5 (6.4)
	Manual	80.0 (4.5)			77.1 (6.3)	75.5 (6.5)	68.3 (14.0)	76.4 (6.1)	71.7 (7.9)	63.9 (8.3)
Radial Deviation (°)	**Electronic**	23.7 (7.3)			24.7 (5.7)	30.1 (11.9)	25.6 (10.1)	24.2 (5.6)	25.7 (5.1)	21.7 (7.7)
	Manual	21.6 (6.8)			22.2 (6.7)	25.5 (11.0)	23.1 (9.5)	24.6 (5.1)	26.3 (5.4)	22.1 (8.4)
Ulnar Deviation (°)	**Electronic**	47.3 (10.5)			45.3 (5.5)	36.7 (11.4)	26.9 (7.3)	38.6 (6.3)	37.2 (8.9)	28.2 (6.4)
	Manual	46.0			44.4	35.3	28.0	41.0	32.4	26.6

		(8.0)			(6.3)	(9.1)	(9.2)	(5.5)	(10.0)	(8.9)

Table 23 - Gender specific dynamometry and goniometry measurements for the healthy volunteer and patient groups

		Gender					
		Male			Female		
		Healthy	Impaired		Healthy	Impaired	
			Uninjured	Injured		Uninjured	Injured
Grip Strength (kg)	**Electronic**	38.7 (7.8)	29.3 (6.6)	16.1 (10.0)	22.0 (5.6)	18.9 (5.4)	10.9 (5.4)
	Manual	37.0 (7.6)	20.3 (4.0)	15.7 (8.5)	21.5 (4.9)	13.6 (5.4)	11.4 (6.1)
Grip Fatigue (%)	**Electronic**	32.4 (8.9)	30.0 (16.8)	31.6 (5.9)	26.4 (7.1)	32.1 (11.0)	31.8 (14.9)
	Manual	32.9 (7.3)	27.4 (5.1)	19.7 (6.0)	29.7 (10.4)	23.2 (7.5)	22.5 (21.6)
Pinch Strength (kg)	**Electronic**	9.5 (1.5)	8.3 (2.0)	6.3 (2.3)	6.7 (1.0)	5.7 (1.5)	4.1 (1.2)
	Manual	9.2 (1.6)	7.0 (2.1)	6.4 (2.6)	5.8 (1.9)	4.6 (1.2)	4.1 (1.4)
Extension (°)	**Electronic**	70.0 (7.3)	68.4 (10.2)	44.9 (9.9)	71.5 (9.9)	64.5 (16.4)	49.7 (18.5)
	Manual	68.5 (5.7)	57.8 (9.7)	40.4 (8.0)	68.5 (8.1)	61.3 (16.1)	47.8 (18.4)
Flexion (°)	**Electronic**	66.5 (14.0)	46.6 (10.2)	35.1 (14.9)	69.0 (7.9)	65.1 (10.2)	48.4 (11.9)
	Manual	65.0 (12.9)	50.3 (5.7)	37.2 (7.2)	65.5 (7.4)	63.9 (9.0)	49.1 (10.1)
Pronation (°)	**Electronic**	79.7 (3.5)	81.0 (6.2)	79.0 (8.4)	80.0 (2.7)	82.4 (2.6)	77.5 (6.1)
	Manual	80.2 (4.0)	80.0 (7.2)	76.4 (8.3)	81.5 (3.2)	82.1 (3.9)	78.5 (5.8)
Supination (°)	**Electronic**	78.7 (3.0)	72.4 (12.2)	67.0 (5.8)	76.7 (4.2)	73.2 (8.5)	65.1 (10.2)
	Manual	78.6 (5.2)	75.1 (8.8)	69.7 (4.9)	77.3 (6.2)	72.9 (7.4)	64.9 (11.5)
Radial Deviation (°)	**Electronic**	27.0 (6.4)	20.8 (7.9)	22.7 (5.5)	22.4 (5.2)	28.6 (8.4)	23.4 (9.2)
	Manual	26.2 (7.1)	18.9 (8.5)	15.9 (2.2)	20.3 (4.4)	27.2 (7.3)	23.7 (8.8)
Ulnar	**Electronic**	45.0	33.3	26.7	43.4	37.6	27.8

Deviation (°)		(9.7)	(4.7)	(6.1)	(7.2)	(10.3)	(6.9)
	Manual	45.7 (6.6)	26.2 (8.8)	32.0 (11.1)	42.8 (6.7)	34.9 (9.3)	26.3 (8.5)

Dynamometry Reliability

Substantial reliability was achieved for all domains of reliability assessed for the grip and pinch strength of both healthy volunteers and patients. The intra-rater, inter-rater and inter-instrument (manual versus electronic instruments) reliability for the grip strength expressed as the intra-class correlation coefficient (ICC) ranged from 0.95 and 0.99 for both the manual and electronic instruments, with the inter-rater comparison demonstrating the highest ICC value (Tables 22-24). No difference was found between reliability for the manual and electronic instruments.

The ICC values ranged from 0.86 to 0.98 for the inter-rater, intra-rater and inter-instrument reliability for the electronic and manual pinch strength, with the inter-rater reliability demonstrating the highest ICC values. Overall the reliability was marginally higher for the pinch strength when performed with the electronic instruments in comparison to the manual instruments.

Acceptable intra-rater reliability was achieved for grip fatigue with both the manual and electronic equipment. The inter-rate reliability however, was lower for the electronic equipment than for the manual equipment. The interclass correlation coefficient values were lower than those of either the grip strength or pinch strength, ranging from 0.60 to 0.86 with wide confidence intervals (Tables 22-24). Although small variations in the grip strength MVC confer a high degree of reliability, when combined with variations in the final grip strength, this can translate to a larger variation in the grip fatigue. The inter-instrument reliability was poor regardless of whether the injured or uninjured wrist was assessed with ICC values of 0.47 and 0.38 respectively (Tables 22-24). However, when the inter-instrument reliability was determined from the 1st and 2nd testing sessions for the healthy group, higher ICC values of 0.56 and 0.72 were demonstrated.

Goniometry Reliability

The goniometry measurements demonstrated variable inter- and intra-rater reliability. Wrist extension was the only parameter to demonstrate an acceptable intra-rater and inter-rater reliability (ICC; 0.72 to 0.91) with both the manual and electronic goniometers. Conversely, flexion was the only parameter found to demonstrate unacceptable intra- and inter-rater reliability regardless of the goniometer used, with ICC values ranging from 0.60 to 0.69 (Tables 22-24).

Overall, the electronic goniometer was found to have acceptable intra-rater reliability when assessed in extension and radial deviation, and inter-rater reliability with extension and pronation (Tables 22-24). Despite demonstrating acceptable intra-rater reliability in radial deviation, the inter-rater reliability was extremely poor with an ICC value of -0.06. Exclusion of an outlier reading, however, results in an increased ICC value of 0.53, within a similar range to the other electronic goniometry measurements.

The manual goniometer demonstrated high ICC values ranging from 0.71 to 0.94 with extension, radial deviation and ulnar deviation, conferring substantial intra-rater and inter-rater reliability (Tables 22-24). The inter-rater comparison for pronation was the only measurement with an ICC value below 0.50, again exclusion of an erroneous measurement resulted in a substantial increase in the ICC from 0.31 to 0.84.

All parameters of wrist motion were found to have acceptable inter-instrument reliability, with ICC values ranging from 0.71 to 0.99 regardless of whether the injured or uninjured wrist was tested.

Table 24 – Inter-rater reliability for the healthy volunteer group (n = 12 participants). (*ICC values > 0.70 deemed to be acceptable are highlighted).*

Test	**Manual**			**Electronic**		
	1st tester mean (SD)	**2nd tester mean (SD)**	**ICC (95% CI)**	**1st tester mean (SD)**	**2nd tester mean (SD)**	**ICC (95% CI)**
Grip strength (kg)	23.2(9.2)	23 (8.9)	***0.99 (0.97:1.0)***	24 (9.0)	23.3 (8.7)	***0.99 (0.97:1.0)***
Grip Fatigue (%)	32 (9.8)	34.9 (9.9)	***0.76 (0.29:0.92)***	33.1(7.8)	34.3 (9.9)	0.60 (-0.30:0.87)
Pinch strength (kg)	7.4(2.0)	7.4(2.2)	***0.98(0.95:1.0)***	7.7(2.2)	7.5(2.5)	***0.98 (0.94:0.99)***
Flexion (°)	64.4(6.0)	68.1 (5.3)	0.69 (0.03:0.90)	66.9(6.0)	69.3 (8.2)	0.69 (0.02:0.90)
Extension (°)	66.7(8.3)	66.1(11.2)	***0.91 (0.72:0.97)***	71.1(7.0)	69.8(12.4)	***0.72 (0.04:0.91)***
Pronation (°)	80.8(2.8)	81.0(2.9)	0.31(-1.4:0.78)	74.9(6.7)	76.3(5.5)	***0.73(0.09:0.92)***
Supination (°)	77.3(5.6)	78.7(3.7)	0.69 (0.06:0.90)	73.0(5.4)	79.6(5.1)	0.54 (-0.27:0.86)
Ulnar deviation (°)	40.5(8.0)	40.2(9.0)	***0.94 (0.81:0.98)***	37 (5.4)	37.1(9.5)	0.69 (-0.10:0.91)
Radial Deviation (°)	22.3(5.9)	19.8(6.2)	***0.90 (0.55:0.97)***	23.3(4.7)	20.7(3.9)	-0.06 (-2.0:0.66)

Table 25 – Intra-rater reliability for the healthy volunteer group (n = 14 participants). (*ICC values > 0.70 deemed to be acceptable are highlighted).*

Test	Manual			Electronic		
	Mean observations (SD)		ICC (95% CI)	Mean observations (SD)		ICC (95% CI)
	1st	2nd		1st	2nd	
Grip strength (kg)	27.5 (9.6)	26.7 (8.9)	***0.96 (0.91:0.98)***	28.4(10.2)	27.9(9.4)	***0.96 (0.91:0.98)***
Grip Fatigue (%)	31.1 (8.4)	30.2(10.9)	***0.86 (0.68:0.94)***	31.1 (8.8)	31.5(10.7)	***0.80 (0.53:0.91)***
Pinch strength (kg)	7.4 (1.90)	7.5 (1.72)	***0.86 (0.69:0.94)***	7.9 (1.78)	7.63 (1.86)	***0.93 (0.83:0.97)***
Flexion (°)	65.4(9.6)	65.5(5.4)	0.60 (0.10:0.83)	67.8 (10.2)	67.3(6.5)	0.65 (0.18:0.85)
Extension (°)	68.4 (7.1)	67.7 (8.2)	***0.83 (0.63:0.93)***	70.8 (8.8)	72.4 (7.9)	***0.75 (0.44:0.89)***
Pronation (°)	81.2 (3.1)	82.6 (2.9)	0.54 (0.15: 0.80)	80.2 (3.3)	78.9(5.8)	0.65 (0.18:0.85)
Supination(°)	77.9(5.6)	79.8(4.5)	0.61 (0.14:0.82)	77.5(3.6)	76.7(5.1)	0.58 (0.04:0.81)
Ulnar deviation (°)	43 (6.7)	42.8 (8.1)	***0.71 (0.33:0.87)***	44.0(8.2)	39.9 (7.3)	0.57 (0.09:0.81)
Radial Deviation (°)	22.6 (6.2)	23.8(6.5)	***0.80 (0.56:0.91)***	24.5 (6.4)	25.4 (5.2)	***0.88 (0.72:0.95)***

Table 26 – Inter-instrument reliability in the patient group (n = 50 patients). (*ICC values > 0.70 deemed to be acceptable are highlighted).*

Test	Injured Wrist			Uninjured Wrist		
	Electronic Mean (SD)	Manual Mean (SD)	ICC (95% CI)	Electronic Mean (SD)	Manual Mean (SD)	ICC (95% CI)
Grip strength (kg)	11.8 (6.2)	12.3 (5.4)	***0.98 (0.94-0.99)***	20.7 (6.9)	21.3(6.1)	***0.95 (0.88-0.98)***
Grip Fatigue (%)	29.4(11.8)	23.3 (11.3)	0.47 (-0.30-0.80)	32.1 (12.4)	30.4(9.0)	0.38 (-0.78-0.78)
Pinch strength (kg)	4.4 (1.5)	4.4 (1.7)	***0.96 (0.90-0.98)***	6.0 (1.8)	6.0 (1.8)	***0.96 (0.91-0.99)***
Flexion (°)	47.3(12.1)	47.2 (10.2)	***0.95 (0.87-0.98)***	60.9 (11.1)	62.1(10.6)	***0.93 (0.82-0.97)***
Extension	48.4(16.6)	46.6	***0.99***	65.0 (15.6)	60.8	***0.93***

(°)		(16.8)	***(0.96-1.00)***		(14.7)	***(0.77-0.97)***
Pronation (°)	78.5 (5.9)	78.2 (5.9)	***0.94 (0.84-0.98)***	82.6(3.4)	82.1 (3.4)	***0.78 (0.44-0.91)***
Supination (°)	65.3 (9.8)	65.6 (10.6)	***0.97 (0.92-0.99)***	72.3 (8.4)	73.2 (7.2)	***0.95 (0.87-0.98)***
Ulnar deviation (°)	27.0 (6.5)	27.1 (8.6)	***0.71 (0.25-0.89)***	35.6 (8.7)	33.6 (9.3)	***0.89 (0.69-0.95)***
Radial Deviation (°)	23.7 (8.8)	22.5 (8.4)	***0.87 (0.67-0.95)***	27.4 (8.8)	26 (7.7)	***0.71 (0.27-0.89)***

Participant instrument evaluation

During the testing sessions, participants made several observations about their experiences of the instruments used. These are summarised as follows:

- *Dynamometer*
  - The electronic dynamometer tended to be stiffer in comparison to the manual dynamometer, which allowed a slight movement giving participants the sense of feedback during the contraction
  - The bar of the electronic dynamometer was also considered to be smoother, hindering the participants' ability to grip. Several complaints were made regarding slipping during the later contractions. The manual dynamometer in comparison has a slightly rougher surface affording an improved grip.
- *Pinch gauge*
  - The manual pinch gauge again showed a greater degree of movement and hence participants found it a more satisfactory instrument
  - A slight deviation in the grip applied was found to result in a difference of 2-3kg during maximal contractions, meaning the observer needed to be diligent to the participant positioning during testing

No observations were generated with either the manual or electronic goniometers.

DISCUSSION

The electronic dynamometer and pinch gauge have been shown to provide a reliable evaluation of grip and pinch strength, equivalent to their manual counterparts in both the healthy and impaired participants. The electronic and manual goniometers in comparison, demonstrated a variable reliability, despite an acceptable inter-instrument reliability.

The comparison of electronic and manual dynamometers and pinch gauges has had sparse consideration, with reliability studies predominately assessing inter-instrument reliability for maximal grip and pinch strength. Svens *et al.* for example, compared the manual and electronic dynamometers, demonstrating both intra- and inter-instrument reliability with interclass correlation coefficients equivalent to this study(344). King *et al.* conversely demonstrated only poor to moderate inter-instrument reliability between the electronic and manual dynamometers and pinch gauges (345). Neither study assessed the test retest or inter-rater reliability. Schectman and Shin however addressed the test-retest reliability of maximal grip and pinch strength respectively with alternating electronic and manual equipment(346, 347). Both demonstrated good reliability, ICC values were only available for the maximal pinch strength and found to be lower than those demonstrated in this study(346). In comparison to reliability studies for manual dynamometers and pinch gauges, the results of this study are comparable for both healthy volunteers and patients with ICC values ranging from 0.90 to 0.98(118-120). The focus in these previous studies has been upon the assessment of short maximal isometric contractions, failing to consider the assessment of sustained contractions measured as a determination of muscle fatigue.

Grip fatigue represents the exercise-induced reduction in the muscles ability to produce force(348). Lagerstrom *et al.* suggests it is an important facet of hand function that is often overlooked in patients with an injury or disorder of the upper limb, despite offering the potential for detecting impairment of the hand and wrist(177, 179, 349, 350). In this study, fatigue measured over a 10 second period was found to have good inter and intra-rater reliability with both manual and electronic dynamometers. The ICC values, however, were lower than for the grip strength MVC, most likely due to the cumulative effect of small variations in both the MVC and the end grip strength conferring a greater variation for the fatigue. Comparable findings have been shown with an electronic system similar to the one used here, with ICC values ranging from 0.87 to 0.93(179). No study has been performed to provide a comparison of manual and electronic dynamometers for the assessment of grip fatigue. The inter-instrument reliability, however, was found to be poor between the electronic and manual dynamometers used in this study, suggesting that these instruments are not interchangeable. When assessed in the healthy volunteer group, the reliability improved with ICC values conferring substantial and near substantial reliability. These findings suggest that the poor reliability was partly due to the patient group demonstrating a variable fatigue pattern secondary to discomfort caused by their injury. A poor inter-instrument reliability could be indicative of the instruments measuring different characteristics of fatigue. However, that is unlikely in this study, since the fatigue is determined by only two measures; the highest and last grip strength, for which only the recording of the result differs.

The reliability of goniometry measurements of the wrist has similarly been scarcely considered in either manual or electronic equipment. In this study the inter-rater and intra-rater reliability for both the manual and electronic equipment was found to be variable, with, ICC values for ranging from -0.06 to 0.81. These values were shown to vary within measures of the same arc, for example, ulnar deviation was shown to have an ICC value of -0.06 for the inter-rater reliability, whilst there was a value of 0.90 for radial deviation. Considering the method for measuring the radial and ulnar deviation is the same, it is possible that these variable measurements may be due to chance associated with multiple testing.

In contrast, Armstrong *et al* found forearm rotation to be reliable for both the inter-rater and intra-rater reliability when measured with an electronic goniometer and manual goniometer (351). A standardised testing protocol was used with each participant undergoing 30 measurements per movement, in comparison to a maximum of 12 per session in this study(351). In addition only two planes of movement were measured per participant and measures were taken to enthuse the participants throughout the testing sessions, which has been shown in wrist dynamometry to alter participants' effort during testing(351, 352). It is therefore possible that participants may have become 'experts' in performing the movements, focusing to a greater extent upon maintaining their maximal range of motion than might be seen in normal clinical practice. No comparisons however have been undertaken for wrist goniometry between manual and electronic goniometers.

Reliability studies have instead focused predominately upon the introduction and comparison of measurement techniques using manual goniometers in healthy participants under controlled conditions and cadaveric models(122, 324). LaStayo and Carter for example demonstrated high ICC values for the measurement of passive flexion/ extension using the dorsal volar technique (122, 324). The intra-rater reliability was found to be higher and less variable than the inter-rater reliability in both studies(122, 324). Similarly findings have been mirrored in several upper limb goniometry studies performed under controlled conditions, with the impractical use of a single therapist to monitor patient's progression advocated in the clinical setting(351, 353, 354). In this study both the inter-rater and intra-rater reliability were found to be variable, preventing such a distinction. A similarly variable inter-rater and intra-rater reliability, however, has been demonstrated by Bovens with reliability coefficient variables ranging from 0.04 to 0.89 for flexion/ extension and pronation/supination(121). Despite the disagreement between these studies, all have shown a 5-10° variance with the intra-rater and inter-rater reliability for all planes of movement(121, 324, 354). A similar finding has been demonstrated here with a mean SD of 5.9°(2.8° to 9.5°) for the manual and 6.3°(3° to 10.3°) for the electronic intra-rater reliability, and 6.2°(2.8° to 11.2°) for the manual and 6.7°(3.9° to 12.4°) for the electronic inter-rater reliability. These findings suggest that an increase or decrease of 10° is required to demonstrate a clinical change in joint motion(121).

Strengths and limitations

Numerous factors may account for the variation in the dynamometry and goniometry measures presented in this study: those, which are inherent to either the trial protocol, the selection of participants or to the testers. If we first consider the testing protocol, both the dynamometry and goniometry measures were performed during each testing session for the healthy participants. The extensive testing may have resulted in fatigue and a lack of motivation when performing the tests. Participants were provided with a resting period of 15 seconds between dynamometry testing in order to reduce the effects of fatigue. However, this may have been insufficient, as this was based upon resting periods suggested by Harkonen *et al.* for repetitive maximal voluntary contractions of shorter duration. Kamimura in contrast allowed a 1minute rest between contractions lasting 6 and 10 seconds, displaying differences of 1-2kg between subsequent observations in comparison to 1-5kg differences in the mean MVC strengths. Allowing a rest period of a minute between repetitions would, however, significantly increase the duration of the testing sessions, and burden for the participant. In addition to fatigue, the repeated wrist movement may also have resulted in muscle tightness and increased joint resistance effecting the range of motion performed(351). To some extent, however, the effects of fatigue and poor motivation were unavoidable, since the participants' comfort will always take precedence during testing. Another factor inherent to the trial protocol that might account for the differences in the measurements demonstrated in this study, was the order of testing. Although the order of tests was randomly allocated, neither the instruments nor testers were randomised, potentially resulting in artificially elevated values for one of the instruments and testers.

The lack of age and gender matching in the selection of the participants may provide a further limitation of this study. The patient group was predominately women over 50 years of age, whilst the participant group was younger and involved both male and female participants. This may account for the differences in the mean strength values between the two groups, as both age and gender have been shown to be factors that effect patients' grip and pinch strength(355).

The testers themselves may provide a further source of error. During the placement of the goniometer, variability may arise from differences in the identification of the joint axis and the landmarks to locate the goniometer arms(318). Testers may also differ in the force they exert on the goniometer when using goniometers that differ in their stiffness(351). In addition, previous studies have shown that testers can be influenced by the purpose of the study and have a tendency to record or fail to record certain numbers(351). Lastly, in this study the observations were only undertaken by three testers with the majority performed by the chief investigator, which may reduce the applicability of these findings. A number of measures were undertaken in this study to mitigate the risk of these errors. These included training and practice sessions to ensure testers were able to perform the observations using the same technique prior to undertaking testing on participants. The same goniometers were also used for all observations to reduce variation due to differences in equipment stiffness. Whilst recording the observations, testers ensured they took due care when documenting observations. The accuracy of the database was also checked several times against the data entry forms and the data recorded on the electronic equipment to ensure the integrity of the main database. Finally, in regards to the testers, all were health care professionals experienced in assessing patients with musculoskeletal injuries and healthy volunteers in an outpatient and academic setting.

This study was also limited by assessing only the active range of motion, instead of also including the passive range of motion. Although the passive motion may provide a better assessment of the peri-articular structures, it may not reflect the participants actual function(324). In addition, other facets of hand function such as fine and gross dexterity, coordination and sensibility could not be measured with the equipment used in this study, hence preventing a thorough assessment of hand function from being undertaken. However, the addition of these tests could have increased the burden upon the participants during testing, introducing error and reducing participant retention during the study.

Recommendations for future studies

In consideration of the knowledge that has been gained from undertaking this study, future studies could be improved with a number of enhancements to the selection of the participants, observers and instruments used during each testing session. Healthy volunteers for example, could be recruited from either relatives or other patients with non-upper limb trauma attending fracture clinic alongside the patient group. This might provide a more diverse selection of participants, allowing better age and gender matching with the patient group.

Testing sessions could be performed by a broader cohort of testers with respect to the level of seniority and profession, allowing a greater applicability of the results to other health care professionals. Randomising the order of testers during testing sessions would further improve the inter-rater reliability, by preventing artificially high or low readings with certain testers. The intra-rater reliability could also be improved by increasing the number of testing sessions to a minimum of three sessions per participant. This would ensure the intra-rater readings could always be taken from the first tests performed during each session, hence the effects of fatigue from subsequent sessions could be reduced. However, this may not be practical for either the participants or testers.

The testing sessions could also have been simplified by testing either solely the dynamometry or the goniometry. Shortening the number of tests performed in each session may improve both the concentration of the participants and reduce the effects of fatigue and joint stiffness. Although, this would mean either participants would need to attend more sessions, which would be time-consuming for them and possible affect their ability to participate in the study, or a larger number of participants would need to be recruited.

Lastly, a biomechanical study could have been performed using cadavers, however, only the goniometry measurements could be performed(122). In some respects the biomechanical study would be similar to perform, as there is no participant recruitment, nor any requirement for rest periods. However, only the passive range of motion could be measured, and it would not be able to simulate the effects of patient lethargy, poor concentration, or the interaction with the tester upon the measurements. However, as this study is primarily interested in the practical use of these instruments in a clinical setting, an in vivo observational study is appropriate.

Conclusions

The Tracker Freedom wireless dynamometer and pinch gauge (JTECH Medical, Salt Lake City, USA) has been found to exhibit excellent reliability equivalent to the BASELINE hydraulic hand dynamometer and pinch gauge (Fabrication enterprises Incorporated, Elmsford, USA) in the assessment of healthy participants and patients recovering from an acute distal radius fracture. In contrast, the reliability for the goniometry measures ranged from poor to acceptable with both the electronic and manual goniometers used.

The findings of this study support the continued use of dynamometry in the clinical and academic setting, and highlight concerns regarding the use of goniometry. Although, a number of areas have been highlighted for where improvements can be made for future studies, given the resources and knowledge available at the conception of this study, and the careful balance between participant fatigue (physical and psychological) and extracting the maximum data. These findings are likely to be unbiased and reasonably representative of both healthy volunteer participants and patients with a distal radius fracture.

5. A correlation of radiological parameters with physical and patient-reported functional outcomes in patients with a fracture of the distal radius

Sponsorship

This study was jointly sponsored by the University of Warwick and University Hospitals Coventry and Warwickshire NHS trust.

Declarations

The patient reported outcome measure scores were collected on behalf of the DRAFFT trial, and Miss Kate Denninson assisted in the collection of the physical outcome data.

Ethical approval

Ethical approval was granted on 7th January 2011 under reference no. 10/H1210/10

In chapter 4, dynamometry of the wrist was shown to have excellent reliability, whilst goniometry was conversely poor to acceptable regardless of the equipment used. With the reliability of these measures established, the electronic equipment has been used to further consider the outcomes of patients with a distal radius fracture. These patients can be assessed post-operatively either radiologically or by using physical and patient reported measures of function. In this chapter, the association between the functional outcome and radiological appearance of the fracture have been assessed.

Background

Dorsally displaced fractures of the distal radius can have profound implications for the patient. Accordingly, the successful surgical management of such fractures is of great importance(184). Emphasis on the anatomical reduction of the fracture through the use of locking plate fixation, increasingly dominates surgical fixation of these fractures, away from traditional methods of fixation such as percutaneous wires(184, 185, 356). This premise was derived from earlier observational studies such as McQueen *et al.* which detected a worse functional outcome in patients with a malunited fracture (dorsal angulation>10° and radial shift>2mm) in comparison to those with a united fracture. The correlation between the radiographic and functional outcome of the fracture is however controversial, with subsequent studies suggesting there is no association, in particular with the elderly population(50, 357).

The majority of these prior studies have tended to focus solely upon physical measures of function. Only a minority have also assessed whether the radiological outcome correlates with patient reported outcome measures, despite a combined use of both measures of function advocated to provide a complete assessment of the patient(117, 124, 175, 176). Patient reported outcome measures (PROMs) identify the presence of an impairment, by providing an assessment of the patient's perceptions of their recovery, encompassing their ability to perform their daily tasks and the presence of persistent symptoms(117, 124, 172). Physical measures complement the information gleaned from the PROMs, by providing details of the deficiency, typically assessing three facets of impairment; (i) gross motor power, (ii) precision grip and (ii) articular motion(117, 174).

Therefore, this study will assess whether the radiological outcome of patients with an operatively managed acute fracture of the distal radius, correlates with both patient reported and physical measures of wrist function over the 12-month post-operative period.

Methods

Objectives and research questions

The primary objectives of this study were:

6. To assess the strength of association (correlation) between radiological parameters and patient reported outcome measures in patients with an operatively managed fracture of the distal radius
6. To assess the strength of association (correlation) between radiological parameters and physical measures of function in patients with an operatively managed fracture of the distal radius

The secondary objective of this study was:

6. To assess the strength of association (correlation) between physical measures of function and validated patient reported outcome measures in patients with an operatively managed fracture of the distal radius

The following research questions were addressed

6. Do radiological parameters (dorsal angulation and ulnar variance) correlate with validated patient reported outcome measures (DASH, PRWE and EQ5D) in patients with a fracture of the distal radius treated with K-wire and locking plate fixation, determined by a correlation coefficient > 0.7?
7. Do radiological parameters (dorsal angulation and ulnar variance) correlate with physical outcome measures (grip strength, pinch strength and range of motion) in patients with a fracture of the distal radius treated with K-wire and locking plate fixation, determined by a correlation coefficient > 0.7?
8. Do physical outcome measures (grip strength, pinch strength and range of motion) correlate with validated patient reported outcome measures (DASH, PRWE and EQ5D) in patients with a fracture of the distal radius treated with K-wire and locking plate fixation, determined by a correlation coefficient > 0.7?

Trial summary

The study recruited patients participating in the DRAFFT trial, whilst attending the University Hospital Coventry follow-up fracture clinic. Potentially eligible patients were approached and invited to participate in the study, with their consent sought at either their 6-week follow up appointment or when they attended their 3-month appointment.

Baseline demographic data, presenting radiographs and pre-injury functional data from the patient reported outcome measures were extracted from the DRAFFT trial notes obtained at recruitment to the DRAFFT trial.

Electronic dynamometry and goniometry measures were performed at 3-months, 6-months and 12-months post operatively by either an orthopaedic specialist trainee (CP) or a research physiotherapist (KD). The PRWE, DASH and EuroQol questionnaires were posted to patients by the DRAFFT team at the corresponding times; 3-months, 6-months and 12-months post-operatively. Radiographs were performed at the final 12-month appointment (Table 27).

Table 27 – Time points for data collection

Time point	Data collection
Baseline	Baseline demographic data Pre-injury PRWE, DASH, EQ-5D Presenting radiographs
3 months	Physical measures of function PRWE, DASH and EQ-5D
6 months	Physical measures of function PRWE, DASH and EQ-5D
12 months	Physical measures of function PRWE, DASH and EQ-5D Radiographs

Sample size

Based on previous work, I estimated that the correlation coefficients between pairs of variables (PRWE and physical outcome measures) were likely to be approximately 0.7. In order to ascertain whether the correlation was within 0.2 units either way (between 0.5 and 0.9), the methods of Bland (*An Introduction to Medical Statistics*, 3rd Edition, Martin Bland, OUP: Oxford, *Section 18.6*) were used and z statistics calculated for each pair of comparisons, between 0.9 and 0.7 and between 0.7 and 0.5, and selecting the smallest. An approximate sample size of 46 was calculated, which was rounded-up to 50 to provide a convenient and feasible recruitment target for this study.

Eligibility criteria

Adult patients participating in the reliability study (chapter 4) also underwent measurements as part of this study, therefore the same eligibility criteria was applied. Patients were considered eligible if:

- They had sustained a closed dorsally displaced fracture of the distal radius
- They had entered the DRAFFT trial and undergone surgical fixation with either Kirschner wires or a volar locking plate.
- They attended the University Hospital Coventry and Warwickshire NHS trust for their postoperative care

Patients were considered ineligible if:

- They had received non-operative management
- They were unable to adhere to the trial demands

Recruitment and consent

Adult patients were recruited from patients entered into the Distal Radius Fracture Fixation Trial (DRAFFT) between January 2011 and July 2012. Patients were recruited into the DRAFFT trial at presentation, and were identified from either the daily fracture clinic or the daily trauma meeting and subsequently approached to enter the trial. In order to prevent participants from feeling overly burdened by the trial procedures involved in the DRAFFT trial, and potentially dissuading them from participating in either study, they were instead approached regarding this study at their six-week post-operative appointment. An appointment was made for 3 months post-operatively for those willing to participate, and they were given the option to sign the consent form at that time or at the 3-month appointment after greater consideration of the study commitments.

Instruments

The Tracker Freedom wireless dynamometer, pinch gauge and goniometer (JTECH Medical, Salt Lake City, USA), using the version 5 software were used in this study.

Outcome measures

The following outcome measures were assessed in all patients for this study:

- Physical measures of function
- Patient Reported Outcome measures
- Radiographic parameters

Physical Outcome Measures

Dynamometry, pinch strength and goniometry were performed in accordance with the American Society for Hand therapists. Patients were sat upright, with the shoulder adducted and neutrally rotated, and the elbow flexed at 90 degrees(358). Full descriptions of the measures are detailed in chapter 4.

Grip Strength

The maximum voluntary contraction and grip fatigue were recorded for each trial. The maximum voluntary contraction was defined as the maximum force exerted over the 10-second grip measured in kilograms, and the grip fatigue as the percentage difference between the maximum voluntary contraction and the force of contraction at the end of the trial.

Patients were asked to perform the test 3 times, alternating between wrists providing a minimum of a 15-second rest between trials to prevent fatigue(330, 331). The patient was asked to grasp the dynamometer and squeeze as hard as they can, avoiding a sudden application of force for a total of 10 seconds. The patient was instructed when to start, the midway point and the end of the trial with the following instructions: 'Start to squeeze now'; 'you have reached half way' and 'you can now stop'.

Key Pinch Strength

The maximum voluntary contraction was recorded for the lateral key pinch for each trial. The gauge was placed between the thumb pad and the radial side of the middle phalanx of the index finger(182). The thumb interphalangeal joint position was self-selected(359). The patient was asked to pinch as hard as they can onto the pinch groove as a single maximal exertion, alternating between each hand three times to prevent fatigue. The measurements were recorded in kilograms.

Range of movement

The range of movement was measured in three planes: flexion-extension; radioulnar deviation; and supination-pronation. Each plane of movement was performed three times before repeating with the second wrist. Measurements in each plane of movement were completed before the participant was asked to continue onto the 2nd plane of movement.

Patient reported outcome measures

Patient reported outcome measures (PROMs) provide a subjective account of the patient's perceptions of their symptoms, functional ability, quality of life and utility usage (172). There are two main types of patient reported outcome measures; generic measures of health, and measures specific to disease or anatomical site. MacDermid *et al.* suggests a combination of generic, extremity-specific and joint-specific measures should be used to evaluate recovery after a fracture of the distal radius(117, 124). The Disability of the Arm, Shoulder and Hand questionnaire (DASH), the Patient Rated Wrist Evaluation (PRWE), EQ-5d-3L and EQ-VAS measures were therefore chosen for this study and sent to patients via post to complete at their leisure.

Patient Rated Wrist Evaluation (PRWE).

The PRWE provides a wrist specific outcome measure, designed to quantify patient rated pain and disability of the wrist(131). It is a reliable and valid measure, shown to be more responsive to clinical change following fractures of the distal radius than the DASH questionnaire or SF-36(117). The PRWE consists of 15-items, of which 5 are dedicated to pain and the remaining 10 to function of the wrist. The total score is calculated from the sum of the pain and function scores, to give a score out of 100(186, 360). Both subscale scores are given an equal weighting of 50(186, 360). Any missing data is assigned the mean score of the subscale(360). A score of 0 is interpreted as no pain and disability, and an increase in the score indicates an increase in either pain or disability.

Validity

The convergent and divergent construct validity has been established against constructs of the SF-36 and the visual analogue score (VAS) for pain. The pain items of the PRWE correlates well with the VAS for pain at rest and exertion, with pearson correlation coefficients ranging from 0.654 to 0.872(361). Similarly, the pain and function constructs of the PRWE and SF-36 correlated well with Pearson correlation coefficients of -0.73 and -0.63 respectively(133, 361). Divergent validity has been demonstrated with a poor correlation to the mental constructs of the SF-36 with a Pearson correlation coefficient of -0.33(133). Criterion validity cannot be established as there is no comparative gold standard wrist specific outcome measure.

Reliability

Excellent test-retest reliability has been demonstrated in patients recovering from a distal radius fracture and patients with distal upper extremity musculoskeletal problems, with interclass coefficients of 0.90and 0.91 respectively(133, 362). Internal consistency has been demonstrated for the German, Swedish and Hong Kong versions of the PRWE with Cronbach alpha coefficients ranging from 0.7805 to 0.9502(361, 363, 364). The internal consistency has not however been established for the English version of the PRWE.

Responsiveness

The PRWE is responsive to clinical change in patients with distal upper extremity musculoskeletal problems and specifically in patients recovering after a distal radius fracture, with standardized response means (the ratio of the mean change and variability of the score) of 1.94 and 2.27 respectively(117, 362).

Disabilities of Arm, Shoulder and Hand score (DASH)

The DASH questionnaire is a regional upper extremity self-administered questionnaire formulated on the premise that the upper extremity acts as a single unit. The American Academy of Orthopaedic Surgeons advocate its use for the evaluation of upper extremity disability(365). It encompasses 30 items on disability and symptoms, with two further optional sections addressing impairment at work and participation in sports or performing arts(366). It is the most widely tested measure of the upper extremity, shown to be a valid and reliable measure, responsive to clinical change following fractures of the distal radius(367). In order to calculate the score, 90% of the items must be completed(368). The sum of the assigned values to the responses are averaged to give a score out of five, and transformed to a score out of 100 by subtracting one and multiplying by 25(368). A score of 0 indicates the least disability and 100 the most disability that can be recorded with the score(368).

Validity

Construct validity has been assessed through correlation of the DASH questionnaire with the function and mental constructs of the SF-36(369, 370). In a study of rheumatoid arthritis affecting the upper extremity, convergent and divergent validity has been demonstrated with a strong correlation to the physical components of the SF-36 and poor correlation to the mental components (pearson correlation coefficients of -0.7 and -0.27 respectively)(370).

Content validity has been examined against the three health outcomes depicted as essential by the World Health Organisation in the International Classification of Functioning, Disability and Health: impairment, activity limitations and participation restrictions(371). All three health outcomes are measured by the DASH score, with 27 of the 30 items dedicated to one of the three outcomes individually(371).

Despite the large number of outcome measures available to assess the upper limb there is not an agreed 'gold standard'. Criterion validity therefore could not be assessed.

Reliability

Excellent test-retest reliability and internal consistency has been demonstrated in patients with rheumatoid arthritis, distal radius fractures and work-related musculoskeletal symptoms(370, 372, 373). In a sample of industrial workers with symptoms in the upper extremity, a high interclass coefficient value of 0.92 (95% CI 0.88-0.95) and Cronbach angle of 0.91 has been demonstrated for the test-retest reliability and internal consistency respectively(372).

Responsiveness

In the evaluation of recovery following fractures of the distal radius, the DASH questionnaire is able to detect clinical change within the first three months after the patient sustained their injury with no floor or ceiling effects and a standardized response mean of 2.01 (117, 362, 370, 374).

EQ-5D

The Euro-Qol is a generic assessment of health-related quality of life, comprising of a self-reported questionnaire, the EQ-5D and a visual analogue scale, the EQ-VAS (375-378). The self-reported questionnaire measures five dimensions of health: mobility, self-care, usual activities, pain and anxiety/depression, with each assigned one of three levels of health ranging from 1 no problem to 3 inability/ extreme pain or distress (376, 377). The EQ-VAS is a visual analogue scale designed to rate ones current health state from 0 to 100, whereby 100 is the best possible state of health(375, 377). The EQ-5D generates a descriptive health state based upon the responses to the five domains, for example: a health state of 11111 would indicate the patient has no problem in all five domains(379). Any missing or ambiguous responses are assigned a value of 9(379). The EQ-VAS is assigned a value from 0-100, if the scale has not been marked a value of 999 is assigned instead(379). The National Institute of Clinical Excellence (NICE) has issued guidance recommending the specific use of the EQ-5D above other generic health outcome measures.

Validity

The EQ-5D has been shown to demonstrate construct and criterion validity(380-382). Construct validity was assessed against socio-demographic and clinical variables when assessed in a Greek population(380). Participants expected to report health problems such as the elderly, those with chronic illness and frequent utilizers of health services all demonstrated worse EQ-5D scores in comparison to those unlikely to report health problems(380). In addition, the EQ-5D has been shown to correlate with physical component summary of the SF-12, with a spearman's correlation coefficient of 0.73(382).

In comparison with the SF-36, a 'Gold standard' for generic health outcome measures, the EQ-5D has demonstrated convergent and divergent criterion validity(380). Convergent validity was demonstrated between similar constructs of the SF-36 and the EQ-5D, for example, the SF-36 physical functioning and EQ-5D mobility, and divergent validity between differing constructs e.g. the SF-36 mental health and the EQ-5D mobility constructs, with spearman rank correlation coefficients of 0.65 and -0.29 respectively(380).

Reliability

The EQ-5D is a reliable measure with good internal consistency(375, 380, 383, 384). Test-retest reliability has been demonstrated in numerous studies with interclass correlation coefficients ranging from 0.77 - 0.83 (382-384). Similarly, good Internal consistency has been shown, with a Cronbach's angle ranging from 0.74 – 0.89, derived from studies of a Greek population and patients with idiopathic adolescent scoliosis(380).

Responsiveness

The EQ-5D has been shown to be responsive to clinical changes in patients with a variety of musculoskeletal disorders, but has not been directly assessed in patients with fractures of the distal radius(377). For example, in a study of operatively managed elderly patients with displaced femoral neck fractures, the EQ-5D was highly responsive to clinical change with a standardised response mean of 0.90(377). Floor and ceiling effects have been assessed in a variety of groups of patients. Ceiling effects have been demonstrated for individual constructs of the EQ-5D e.g. usual activities, but not for the total score(381-383).

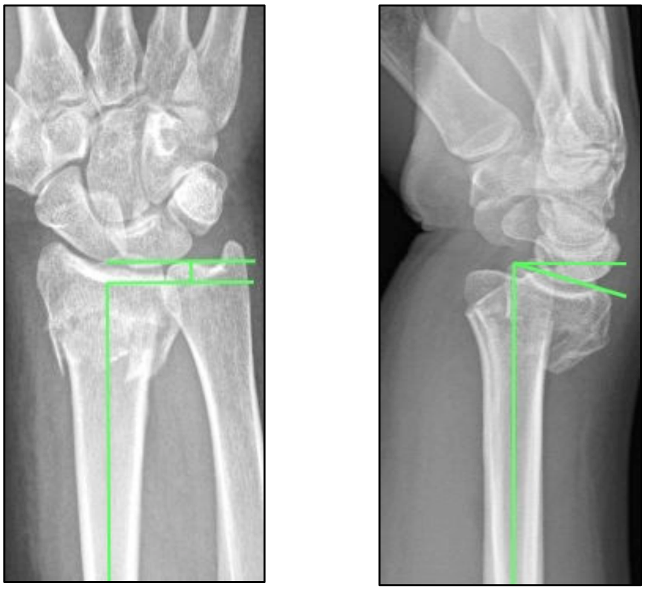
Radiographic evaluation

The degree of palmar tilt and ulnar variance were assessed at both time points from the posterior-anterior and lateral calibrated digital images, using the OsiriX DICOM viewer. The presence of metaphyseal comminution was assessed from the presenting images.

DICOM images were used as opposed to common image formats such as JPEG images, as they provide a scale modality to allow the measurement of length for the ulnar variance; a modality that is not possible with a JPEG format.

Figure 13 – Radiographic parameters (Source: Costa *et al.(278))*

(a) Ulnar variance **(b) Palmar tilt**



Ulnar Variance

The ulnar variance was assessed on the posterior-anterior image, as the distance between lines drawn along the distal ulnar aspect of the radius and the distal cortical rim of the ulnar parallel to the perpendicular of the long axis of the radius (Fig. 13a) (288, 385, 386).

Palmar tilt

The palmar tilt was assessed on the lateral image as the angle between lines drawn perpendicular to the long axis and along the distal joint surface of the radius (Fig.13b) (387, 388). The dorsal angulation represents a positive angle and volar angulation a negative angle(123).

Intra-rater reliability

The intra-rater reliability was determined from a random selection of 50 radiographs for patients from the DRAFFT trial. The radiographic parameters were measured for each radiograph twice by one observer (CP) with a minimum of one week between measurements. The intra-rater reliability was defined as the reproducibility of the measurement when performed by a single observer on separate occasions.

Statistical Analysis

All measurements were summarized using descriptive statistics; means and standard deviations, and correlations presented with graphical plots using IBM SPSS statistics (version 21).

A correlation analysis was performed using Pearson's product moment in IBM SPSS statistics (version 21) to determine firstly, if the radiographic parameters correlate with the functional outcome measures, and secondly if the physical measures of function correlate with the patient reported outcome measures. Correlations with the radiographic parameters were considered between the 6-week post-operative radiographs and the 3-month, 6-month and 12-month functional measures, and between the 12-month radiographs and the 12 months functional measures. For the second correlation analysis, each of the physical measures were considered independently with respect to each of the patient reported outcome measures, for the 3-month, 6-month and 12-month data collection time points. All correlations were also performed separately using the DRAFFT trial stratification factor for age (patients over and under 50 years old) in order to reflect the main demographic groups presenting with a fracture of the distal radius, and to assess for potential differences in the relationship between function and impairment that may result from differences in the biomechanics of the wrist with age. Approximate normality was presumed for the data variables based upon the precedent established in the DRAFFT trial for the patient reported outcome measures e.g. DASH, PRWE and Euro-Qol, from which this subsample of patients was derived(278). The normality of the data was confirmed for the maximal grip and pinch strengths using Shapiro-wilk's test for normality in IBM SPSS statistics (version 21). The data for both strength measures were found to be approximately normally distributed at all the data collection time points. A pre-determined correlation coefficient of 0.70, was considered to represent a reasonable correlation between the measures. In order to account for the increased risk of type I errors associated with an analysis of multiple pair-wise comparisons, Bonferroni's correction was used to adjust the significance level to $p>0.004$ for the comparison of the radiological parameters and functional outcome measures, and to $p<0.005$ for the comparison of the patient reported and physical outcome measures(389). Bonferroni's correction is known to be conservative, therefore we would expect that statistically significant associations from this analysis will represent important (and strong) associations between outcomes.

The intra-rater reliability for the assessment of the radiological parameters was determined using an interclass correlation coefficient (ICC) for absolute agreement for the two-way random effects model in SPSS 21.0, with 95% confidence intervals presented to assess the precision of the estimates(342). An ICC value of 0.70 and greater was deemed to signify an acceptable reliability(343).

Lastly, the responsiveness of the functional outcome measures was assessed by determining the standardized response mean (SRM) using IBM SPSS statistics (version 21)(138). The Standardized response mean was calculated as the mean difference of the scores divided by the standard deviation of the change in the scores, and was interpreted as follows: an SRM of 0.20 was considered as small, 0.50 as medium and 0.80 as large(390, 391). A number of alternatives have been proposed for the assessment of the responsiveness, such as the effect size and the receiver operating characteristics(327). The SRM was chosen as it considers the variability of the change in scores and allows the direct comparison of different variables by standardising the units of those variables(138).

Results

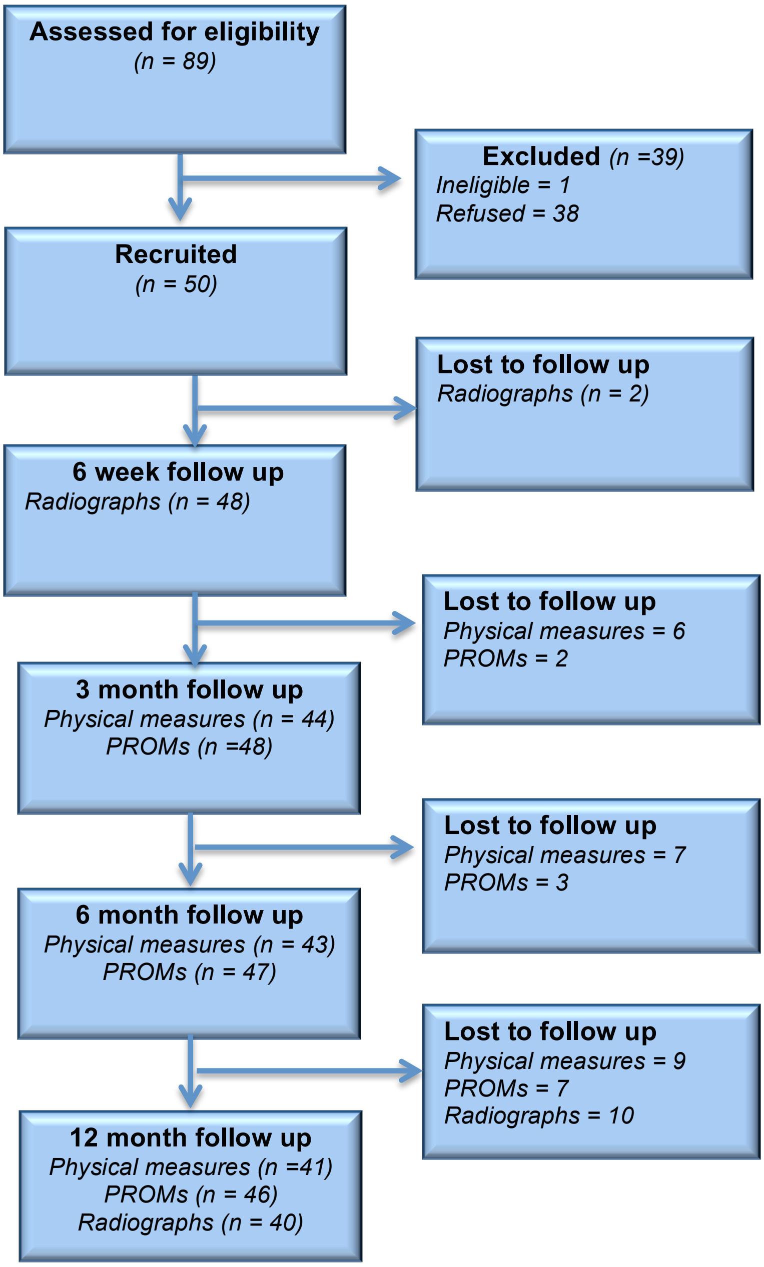
Participant recruitment and demographics

During the recruitment period 89 patients were approached to enter the study, 38 patients declined to enter and 1 patient was ineligible due to receiving non-operative management (Figure 14). The 50 patients entered into the study comprised of 7 men and 43 women, aged 26 to 85 years old (mean age = 57 years old). A larger proportion of the group were randomly allocated to receive a volar locking plate (29:21), however the groups were evenly distributed with regards to age, gender, hand dominance and injury impact (Table 28).

Table 28 - Patient demographic details

		Fixation Device		**Age**	
		Kirschner Wire (n=21)	**Volar locking plate (n=29)**	**<50 years**	**≥50 years**
Gender	**Male**	4 (19%)	3 (10%)	2 (14%)	5 (14%)
	Female	17 (81%)	26 (90%)	12 (86%)	31 (86%)
Age	**Mean (SD)**	57.6 (16.2)	57.1 (13.2)	38.4 (6.9)	64.7 (8.4)
Hand Dominance	**Right**	19 (90%)	26 (90%)	14 (100%)	31 (86%)
	Left	2 (10%)	3 (10%)	0 (0%)	5 (14%)
Injury Wrist	**Dominant**	12 (57%)	19 (66%)	9 (64%)	22 (61%)
	Non-dominant	9 (43%)	10 (34%)	5 (36%)	14 (39%)
Injury Impact	**High Impact**	4 (19%)	3 (10%)	3 (21%)	4 (11%)
	Low impact	17 (81%)	26 (90%)	11 (79%)	32 (89%)

Figure 14- Patient flow



Radiological Parameters

A minimal change in the radiographic parameters between the 6-week and 12-month radiographs was detected for all the patients (Table 29). A difference however, was noted in the radiological parameters between the age and fixation groups; with the under 50 year old and volar locking plate groups fixed in slight volar tilt, whilst the older and Kirschner wire groups were fixated in a more neutral position.

Table 29 - Age and fixation specific radiographic parameters; mean (standard deviation, SD)

	6 week				12 month			
	<50	≥50	Kirschner wire	Volar locking plate	<50	≥50	Kirschner wire	Volar locking plate
Dorsal Angulation	-7.9 (5.9)	-1.7 (7.3)	-1.4 (9.0)	-4.6 (5.6)	-8.6 (6.4)	-1.3 (8.1)	-0.8 (10.2)	-5.0 (5.8)
Ulnar Variance	0.2 (1.6)	1.5 (2.0)	1.4 (2.5)	0.8 (1.5)	0.3 (1.6)	1.7 (2.2)	1.8 (2.6)	0.9 (1.6)

Intra-rater reliability of the radiographic measurements

The interclass correlation coefficient for the dorsal angulation ranged from 0.59 to 0.90, and from 0.47 to 0.55 for the ulnar variance (Table 30). A substantial reliability was achieved with the measurement of the dorsal angulation on the pre-operative and 12 month radiographs. Substantial reliability could not be demonstrated however for the measurement of the ulnar variance at any time points.

Table 30 - Intra-rater reliability for the radiographic parameters (n = 50)

Radiographic parameter	Radiograph	1st Observation mean (SD)	2nd Observation mean (SD)	ICC (95% CI)
Dorsal Angulation	Pre-operative	21.8 (11.4)	23.8 (12.1)	0.90 (0.81:0.94)
	6 week	-3.5 (7.4)	-4.1 (6.9)	0.59 (0.37:0.74)
	12 month	-4.1 (8.3)	-4.8 (7.8)	0.73 (0.55:0.85)
Ulnar Variance	Pre-operative	3.3 (1.9)	3.4 (2.7)	0.54 (0.30:0.71)
	6 week	1.6 (1.4)	1.2 (1.7)	0.55 (0.33:0.72)
	12 month	1.7 (1.2)	1.3 (1.8)	0.47 (0.20:0.68)

Functional outcome measures

Patient reported outcome measures

The under 50 year old patient group demonstrated lower DASH and PRWE scores at all time points in comparison to the older group, with the greatest difference for the DASH score at the 3 and 6 month data collection time points. The DASH and PRWE scores were found to improve for both age groups. The EQ5D score in contrast, was found to only marginally improve over the 12-month follow-up period, with a minimal difference in the scores demonstrated between the two age groups (Table 31).

Table 31 – Age specific functional measurements; mean values (SD)

	3 month		6 month		12 month	
	<50	≥50	<50	≥50	<50	≥50
DASH	20.2 (13.3)	31.2 (20.0)	11.8 (10.4)	21.0 (17.0)	8.8 (10.6)	11.3 (15.6)
EQ5D	0.8 (0.1)	0.7 (0.1)	0.9 (0.1)	0.8 (0.1)	0.9 (0.1)	0.9 (0.1)
PRWE	28.1 (17.6)	32.8 (21.5)	14.9 (11.0)	18.7 (17.2)	11.4 (13.4)	11.7 (15.0)
Grip MVC (kg)	17.8 (4.8)	11.7 (6.3)	21.7 (5.9)	15.0 (5.2)	25.4 (4.0)	17.2 (6.2)
Grip Fatigue (%)	25.8 (9.5)	31.1 (13.3)	31.1 (8.9)	26.1 (13.0)	32.9 (9.1)	29.6(11.9)
Pinch Strength (kg)	6.7 (1.5)	4.1 (1.5)	7.4 (1.1)	4.9 (1.6)	7.7 (1.7)	5.2 (1.4)
Extension °	48.7 (10.8)	45.2 (18.4)	57.1 (11.2)	56.7 (11.2)	58.6 (6.0)	56.2 (15.5)
Flexion°	47.2 (13.8)	43.6 (11.9)	58.8 (8.1)	49.5 (10.4)	63.4 (8.1)	56.2 (7.5)
Pronation °	77.5 (6.4)	77.9 (8.3)	81.4 (2.7)	80.0 (6.3)	79.9 (6.2)	83.0 (3.1)
Supination°	63.4 (16.2)	63.9 (16.4)	66.8 (16.9)	71.2 (9.3)	67.2 (8.8)	69.4 (10.0)
Ulnar Deviation°	29.6 (7.3)	30.1 (8.7)	31.5 (8.8)	32.4 (8.9)	33.3 (6.6)	30.8 (7.8)
Radial Deviation°	25.5 (10.7)	20.2 (8.4)	24.3 (5.4)	25.0 (7.5)	24.2 (5.7)	25.5 (6.6)

Table 32 - Fixation specific functional measurements; mean (SD)

	3 month		6 month		12 month	
	Kirschner wire	Volar locking plate	Kirschner wire	Volar locking plate	Kirschner wire	Volar locking plate
DASH	31.0 (22.2)	26.3 (16.1)	20.8 (18.5)	16.7 (13.7)	13.7 (17.1)	8.2 (11.5)
EQ5D	0.8 (0.1)	0.7 (0.2)	0.9 (0.1)	0.9 (0.1)	0.9 (0.1)	0.9 (0.1)
PRWE	36.4 (22.9)	27.8 (17.8)	19.2 (15.6)	16.6(16.0)	13.7 (15.6)	9.9(13.5)
Grip MVC (kg)	11.9 (7.2)	14.3 (5.8)	15.5 (6.3)	17.8 (6.0)	18.7 (7.6)	19.9 (6.2)
Grip Fatigue (%)	28.3 (14.4)	31.0 (11.1)	27.0 (13.9)	27.8 (10.9)	28.7 (11.3)	31.9 (11.2)
Pinch Strength (kg)	4.3 (2.1)	5.0 (1.7)	5.5 (1.9)	5.5 (1.8)	5.3 (1.8)	6.2 (1.8)
Extension °	42.7 (18.2)	48.4 (15.8)	56.3 (10.8)	57.2 (11.5)	57.2 (10.5)	56.4 (15.9)
Flexion°	44.7 (14.6)	44.3 (10.7)	50.7 (12.5)	52.8 (9.0)	56.4 (8.3)	59.4 (8.1)
Pronation °	78.5 (5.1)	77.2 (9.4)	80.3 (5.7)	80.3 (5.7)	81.2 (4.9)	83.0 (3.6)
Supination°	62.4 (11.1)	64.9 (19.4)	68.1 (12.4)	71.7 (11.1)	68.4 (10.7)	69.2 (8.9)
Ulnar Deviation°	28.0 (6.0)	31.5 (9.6)	28.1 (8.3)	35.4 (8.0)	30.1 (6.6)	32.5 (8.1)
Radial Deviation°	18.2 (8.2)	24.3 (9.2)	23.6 (7.7)	25.8 (6.4)	23.1 (6.5)	26.8 (5.8)

An improvement in the PRWE and DASH scores was detected for both fixation groups over the 12-month post-operative period (Table 32). The Volar locking plate fixation group consistently demonstrated lower scores than the Kirschner wire group at all the times points, with differences in the scores between the groups ranging from 3.7 to 5.5 for the DASH score and from 2.6 to 8.6 for the PRWE score.

Physical measures of function

The under 50 year old patient group demonstrated a greater grip and pinch strength for all time points. However, the older patient group had the greater increase in grip and pinch strength of 47.0% and 26.8%, in comparison with a 42.7% and 14.9% increase in grip and pinch strength for the under 50 year old group (Table 31).

An increase in the grip and pinch strength was also demonstrated regardless of the method of fixation, although, the volar locking plate group had a marginally higher grip and pinch strength at all time points (Table 32). No trend was found for grip fatigue with either age or method of fixation (Table 31 and 32).

An increase in range of movement was also demonstrated regardless of the patients' age or method of surgical fixation, with a minimal difference in the range of movement exhibited between all patient groups. The greatest increase in movement was demonstrated for flexion and extension between 3 and 6-months post-operatively (Tables 31 and 32).

Responsiveness

The PRWE, maximal grip strength, pinch strength and wrist extension were all found to be responsive to a clinical change in the patients with a fracture of the distal radius between the 3 and 6 month data collection time points, with large standardized response means (SRM). Both the DASH and EQ5D scores demonstrated medium SRMs at this time point, whilst the remaining goniometry measures in contrast conferred only small SRMs.

During the 6 to 12 month post-operative period, only the maximal grip strength was responsive to a clinical change with a large SRM of 0.8. The PRWE, DASH score and wrist flexion demonstrated a medium SRMs, whilst the remaining EQ5D, pinch strength and goniometry measures were found to be poorly responsive with SRMs ranging from 0.1 to 0.4 (Table 33).

Table 33 - Responsiveness of the functional outcome measures at 3 to 6 months and 6 to 12 months

	3-6 months		6-12 months	
	Mean difference (SD)	**Standardised Response Mean**	**Mean difference (SD)**	**Standardised Response Mean**
DASH	8.7 (15.3)	0.6	7.4 (12.0)	0.6
EQ5D	0.1 (0.2)	-0.5	0.1 (0.2)	-0.4
PRWE	12.7 (13.7)	0.9	5.1 (11.3)	0.5
Grip MVC (kg)	3.6 (3.9)	-0.9	2.1 (2.6)	-0.8
Grip Fatigue (%)	4.0 (14.2)	0.3	2.2 (10.9)	-0.2
Pinch Strength (kg)	0.8 (0.9)	-0.9	0.3 (0.9)	-0.3
Extension	9.4 (11.0)	-0.9	0.2 (13.6)	0.0
Flexion	6.2 (14.0)	-0.4	6.4 (9.5)	-0.7
Pronation	1.7 (7.9)	-0.2	1.7 (6.5)	-0.3
Supination	2.8 (12.4)	-0.2	1.3 (14.7)	0.1
Ulnar Deviation	1.7 (9.9)	-0.2	0.6 (11.4)	0.1
Radial Deviation	3.2 (10.4)	-0.3	0.4 (6.4)	-0.1

Correlation of radiographic parameters with patient reported and physical measures of function

The radiographic parameters were found to correlate poorly with both the physical and patient reported functional outcome measures at all time points. Weak correlations were detected between the palmar tilt at 6 weeks and 12 months and the pinch strength and wrist flexion at 12 months, and the PRWE score at 3 months (Table 34). At 6 months, only wrist flexion for the patients under 50 years old was found to correlate with the palmar tilt (Appendix 7).

Only wrist flexion was found to correlate with the ulnar variance at 12 months. In comparison, no correlations were detected between the functional outcome measures at any time point and the ulnar variance at 6 weeks (Table 34).

Table 34- Correlation of 6 week and 12 month radiological parameters with the patient reported and physical outcome measures at 3, 6 and 12 months; *significant values (p<0.004) are highlighted.*

		Palmar tilt (Sig. 2-tailed)		Ulnar variance (Sig. 2-tailed)	
		6 weeks	**12 months**	**6 weeks**	**12 months**
DASH	**3 months**	0.42		0.05	
	6 months	0.31		0.10	
	12 months	0.21	0.26	0.00	0.16
EQ5D	**3 months**	-0.06		0.12	
	6 months	-0.17		-0.15	
	12 months	-0.11	-0.11	-0.09	-0.15
PRWE	**3 months**	**0.47***		0.08	
	6 months	0.37		0.15	
	12 months	0.20	0.21	0.03	0.12
Grip Strength (kg)	**3 months**	-0.26		0.09	
	6 months	-0.30		-0.05	
	12 months	-0.28	-0.32	0.01	-0.34
Grip Fatigue (%)	**3 months**	0.05		-0.21	
	6 months	0.08		-0.20	
	12 months	0.00	-0.04	-0.18	-0.08
Pinch (kg)	**3 months**	-0.41		0.05	
	6 months	-0.27		0.04	
	12 months	**-0.51***	**-0.57***	-0.05	-0.18
Supination	**3 months**	-0.05		-0.01	
	6 months	0.14		-0.09	
	12 months	0.10	0.09	0.06	-0.16
Pronation	**3 months**	0.13		-0.02	
	6 months	0.26		-0.03	
	12 months	-0.03	-0.10	-0.06	-0.10
Flexion	**3 months**	0.32		0.15	
	6 months	-0.24		-0.32	
	12 months	**-0.48***	**-0.46***	-0.42	**-0.49***
Extension	**3 months**	0.24		0.09	
	6 months	0.02		-0.27	
	12 months	-0.20	-0.18	-0.13	-0.29
Ulnar Deviation	**3 months**	-0.30		-0.26	
	6 months	-0.06		-0.35	
	12 months	-0.18	-0.21	-0.06	-0.13
Radial Deviation	**3 months**	-0.16		-0.09	
	6 months	-0.16		-0.23	
	12 months	-0.18	-0.30	-0.21	-0.13

0, 0.25
0.25, 0.5
0.5, 0.75
0.75, 1
-0.75, -1
-0.5, -0.75
-0.25, -0.5
0, -0.25

Correlation of patient reported and physical measures of function

DASH score

A weak correlation was demonstrated between the DASH score and the grip strength at all time points, and remained significant for the older patient group when analysed by age (Appendix 8). At 3 months, the maximal grip strength weakly correlated with 16 of the 30 individual questions from the DASH score, and 8 of the questions at 12 months (Appendix 9). However, no correlation was detected between the grip strength and any of the individual questions at 6 months (Table 35).

Table 35 – Correlation of the DASH score and physical measures of function at 3, 6 and 12-months. Significant correlations ($p<0.005$) are in bold, denoted with an asterix.

	3 months	6 months	12 months
Grip strength	**-0.58***	**-0.46***	**-0.50***
Grip fatigue	0.15	-0.35	0.15
Pinch strength	-0.38	**-0.44***	**-0.55***
Extension	-0.29	-0.20	-0.18
Flexion	0.00	-0.34	-0.26
Pronation	-0.32	0.08	-0.21
Supination	-0.27	-0.11	0.05
Ulnar deviation	-0.23	-0.01	0.06
Radial deviation	-0.33	-0.31	-0.01

0, 0.25
0.25, 0.5
0.5, 0.75
0.75, 1
-0.75, -1
-0.5, -0.75
-0.25, -0.5
0, -0.25

Maximal pinch strength was also shown to weakly correlate with the DASH score at 6 and 12-months (Table 33). Correlation with the individual questions occurred at 3 and 12 months, with a weak correlation with 7 of the questions at 3 months and 15 at 12 months. Only 1 question correlated with the pinch strength at 6 months (Appendix 9).

The only correlation with range of movement and the DASH score occurred at 12 months, with a moderate correlation with wrist flexion and pronation for the under 50-year old group (Appendix 8). Radial deviation was the only plane of movement to weakly correlate with 3 of the individual questions at 3 months (Appendix 9). At 6 and 12 months, only 3 questions correlated with wrist motion (Appendix 9).

EQ5D score

The EQ5D score correlated poorly with the physical measures at all time points, with only a weak correlation detected at 6 months with radial deviation (table 36). A ceiling effect was also detected at 12 months, with 29 patients demonstrating an EQ5D score of 1.0 despite a wide variety in their strengths and range of motions, for example a difference of 20kg in grip strength was exhibited between these patients. The ceiling effect was defined as more than 15% of data in the upper extreme of the scale, in this study 59.2% of the data was in the upper extreme of the scale.

Table 36 – Correlation of the EQ5D score and physical measures of function at 3, 6 and 12 months. Significant correlations (p<0.005) are in bold with asterix

	3 months	**6 months**	**12 months**
Grip strength	0.27	-0.36	0.31
Grip fatigue	-0.15	-0.24	-0.09
Pinch strength	0.22	0.41	0.30
Extension	0.10	0.12	0.01
Flexion	0.08	0.34	0.01
Pronation	0.23	-0.03	0.27
Supination	-0.07	0.11	0.25
Ulnar deviation	-0.07	-0.08	-0.09
Radial deviation	0.14	**0.44***	0.11

0, 0.25
0.25, 0.5
0.5, 0.75
0.75, 1
-0.75, -1
-0.5, -0.75
-0.25, -0.5
0, -0.25

Correlation with the separate questions revealed a weak correlation between the pain question and radial deviation at 3 months, and wrist flexion at 6 months (Appendix 9). None of the measures correlated with the individual questions at 12 months.

PRWE score

The PRWE score correlated weakly with the maximal grip strength at 3 and 12 months, and with the pinch strength at 3 months (Table 37). None of the measures correlated with the score at 6 months. Analysis of the subgroups, revealed moderate to strong correlations with wrist extension and radial deviation in patients under 50 years old at 3 months, and weak correlations with the grip and pinch strength in the older patient group (Appendix 8).

Analysis of the individual components of the score revealed only weak correlations between the functional component of the score, grip strength and supination at 3 months, and with the grip and pinch strengths at 12 months (appendix 9). None of the measures correlated separately with the individual components at 6 months.

Table 37 – Correlation of the PRWE score and physical measures of function at 3, 6 and 12 months. Significant correlations (p<0.005) are in bold with an asterix.

	3 months	6 months	12 months
Grip strength	**-0.49***	-0.35	**-0.46***
Grip fatigue	0.04	0.28	0.19
Pinch strength	-0.37	-0.25	**-0.45***
Extension	-0.31	-0.15	-0.17
Flexion	-0.16	-0.27	-0.23
Pronation	-0.43	0.03	-0.31
Supination	-0.44	-0.06	-0.18
Ulnar deviation	-0.25	0.04	0.07
Radial deviation	-0.37	-0.27	-0.01

0, 0.25
0.25, 0.5
0.5, 0.75
0.75, 1
-0.75, -1
-0.5, -0.75
-0.25, -0.5
0, -0.25

Discussion

In this study, the radiographic outcome measures were found to correlate poorly with both the patient reported and physical outcome measures. A limited number of weak correlations were detected between the 6-week and 12-month radiographic measures and the 3 and 12-month functional measures. Weak correlations were similarly demonstrated between the patient reported and physical outcome measures. These correlations predominately arose between the DASH and PRWE scores and the grip and pinch strength, and were also found to be the most responsive measures to clinical change over the 12-month period. Wrist motion in contrast, correlated poorly with the patient reported outcome measures and was found to be inadequate at detecting a clinical change in this group of patients.

Correlation of Radiological Parameters and Functional Outcome Measures

The radiographic appearance of the distal radius at presentation and following either conservative or operative management has traditionally been a key determinant in the assessment of these patients. Correlation between the functional outcome and the radiographic appearance of the wrist however remains controversial(65, 66, 392). Previous studies have suggested that a greater degree of dorsal angulation and radial shortening is associated with a poor functional outcome(393). In this study, the dorsal angulation at 6 weeks was found to weakly correlate with the PRWE scores at 3 months, and the wrist flexion and pinch strength at 12 months. In addition, weak correlations were also detected between the long-term radiographic outcome and the wrist flexion and pinch strength at 12 months. Villiars *et al*. similarly demonstrated only weak correlations between the early radiographic outcome and the long-term physical measures of function(394). These included correlations between the radial shortening and dorsal angulation at 1 week, and the grip strength ($p<0.001$), wrist flexion, forearm pronation and supination ($p<0.01$) at 3 years(394). Tsukazaki *et al.* also found the long term radiographic outcome to correlate poorly with the functional outcome, demonstrating only a correlation between the final dorsal angulation and wrist flexion(392).

In comparison to the patient reported outcome measures, several studies have similarly found there to be no correlation between either the early or late radiographic appearance and the long term DASH score(66, 68, 395, 396). Karnezis *et al*., in contrast to this study, found the PRWE score to moderately correlate with the long-term radiographic appearance at 12 months(397). Synn *et al.* however detected no correlation with the PRWE score at 6 months post-injury in keeping with the findings from this study(66). Correlation of radiographic indices and the EQ5D has not been considered previously in the literature, this is the only study to date that has therefore shown there to be no correlation between the EQ5D and radiographic indices of dorsally displaced distal radius fractures.

This limited correlation between function and the radiological outcome may be attributed to the preservation of the dart thrower's motion (DTM), an oblique plane of motion from radial extension to ulnar flexion(398, 399). The DTM has been shown to be the plane of global wrist motion used for most activities of daily living, arising predominately from midcarpal movement(398). Therefore, incongruity of the fracture affecting mainly the radiocarpal joint with minimal disruption of the midcarpal joint, may have little effect upon the overall functional outcome of the patient, hence explaining the lack of a substantial correlation with the functional outcome measures.

Correlation of Patient Reported and Physical Outcome Measures

The correlation of patient reported and physical outcome measures has been scarcely considered in the literature for fractures of the distal radius or for other impairments of the upper limb. In this study, the DASH and PRWE scores correlated with the grip and pinch strength to the greatest extent, with weak correlations detected at several time points. These findings are similar to those of Swart, Macdermd and Karnezis, who detected correlations between the DASH and PRWE scores and grip strength(175, 176, 400). In contrast, the EQ5D score did not correlate with any of the strength measures. This lack of a correlation most likely reflects the difference between these outcome measures. The EQ5D score is a generic measure, whilst both the PRWE and DASH scores are specific to the upper limb. Therefore, they are more likely to contain questions with a greater degree of crossover with the physical measures e.g. opening a jar asked in the DASH score requires grip strength.

Correlation with wrist motion was poor for all the PROMs, with a weak correlation detected between the EQ5D score and radial deviation at 6 months. The PRWE and DASH scores were found to only correlate with wrist motion for patients under 50 years old. Only one prior study has also detected a correlation between the DASH score and wrist motion(400). There are several possible explanations for the poor correlation with wrist motion. Firstly, in this study and prior studies, functional scores have been correlated with each individual plane of movement, and instead it may be a combined threshold of movement in several planes of motion that confers a difference in the functional outcome of the patient. Secondly, the majority of patients may have achieved the minimum threshold range of motion of 40° of flexion and extension, and 40° combined radio-ulnar deviation suggested by Ryu *et al*. that is required to achieve the majority of daily activities by the 3 month follow up appointment. Instead, impaired grip and pinch strength, may be responsible for hindering the patients' ability to perform their normal activities and hence resulting in differences in the scores between patients.

Responsiveness of the functional outcome measures

Although an improvement in the wrist function was detected for all patients, only the grip strength, PRWE and DASH score were consistently responsive to clinical change between the 3 to 6 month and the 6 to 12 month post-operative periods. In this study, grip strength was found to be the most responsive measure between both periods. These findings are similar to those of MacDermid *et al* who also found the PRWE, DASH score and grip strength to be responsive to a clinical change during the 3 to 6 month post-operative period, in contrast the PRWE was found to be the most responsive measure(117). MacDermid *et al.* however, only considered the responsiveness during the first 6 months of the post-operative recovery, with an additional assessment performed from 0 to 3 months post-operatively(117). This assessment was not performed in this study, as this would most likely confer an exaggerated responsiveness(132, 138). Kotsis *et al.* suggests that the reduction of the fracture and initial healing period would generate an immediate and large clinical improvement(138). Hence, Kotsis instead considered the responsiveness over a 12-month recovery period as patient's pain and function continues to improve during the 6 to 12 month period(138). Similar findings to Kotsis *et al* were demonstrated for grip strength over the 12-month period. The pinch strength in contrast was only responsive during the 3-6 months with a significant decrease in responsiveness from 6 months(138). In all the studies, range of motion was poorly responsive to clinical change(117, 132, 138). This could suggest that either wrist motion is predominately regained during the first 3 months of the patient's recovery, which was not assessed or conversely the wrist motion is regained gradually over a longer period of time resulting in only small clinical changes at the 3-6 month and 6-12 month periods. In addition, it could also be a reflection of the poor reliability of this measure hindering the detection of a clinical change.

Study limitations

The results of this study may have been limited by a few potential methodological weaknesses. The first of which is in regards to the reliability of the physical outcome measures and radiological parameters. For example, two observers performed the physical outcome measures during the patient's 12-month follow-up period, which may have resulted in differences in the measurement and recording of the data. In chapter 4, the intra-rater and inter-rater reliability for the measurement of grip and pinch strength was shown to be almost perfect. However, this was determined in healthy volunteers and with observers CP and HR instead of comparing observers CP and KD. The reliability of the goniometry measurements in comparison was inconsistent, with interclass correlation coefficients ranging from -0.06 to 0.73 for the inter-rater reliability, and from 0.57 to 0.88 for the intra-rater reliability. Inconsistencies in the reliability of the goniometry measurements may account for a lack of responsiveness and correlation with the patient reported outcome measures. Similarly, the poor reliability of the ulnar variance measurement may also partly account for the reduced correlation coefficients for the correlation of the ulnar variance with the functional outcome measures in comparison to the dorsal angulation.

Systematic error may also have arisen from the patient group, due to the intensity of the trial procedures and the selection of patients. The use of multiple outcome measures may have become a burden to the patient, causing a reduction in their concentration and motivation whilst completing the tests, hence introducing error into the measurements. The risk of this error was mitigated as patients had rests of approximately 15 seconds between measurements. Bonferroni's adaption, was also used to further reduce the risk of type I errors that arise from multiple outcome testing. In regards to this study, an abundance of type I errors could have led to the incorrect detection of correlations between the radiological and functional outcome, and hence an undue importance placed upon the radiological outcome of this group of patients.
The patient group may provide a further source of error, as only patients who had undergone a surgical fixation, and hence may not necessarily offer a sufficient range of outcomes to extrapolate the results to non-operatively managed patients. However, it is reasonable to presume that patients treated with non-operative management would either have had a relatively undisplaced fracture at baseline or were manipulated into an 'acceptable' position, with the exception of those with a low functional demand in whom a displaced fracture may be accepted.

The patient group were also predominately elderly. Although, this reflects the typical demographic for this injury, and these findings are in keeping with prior studies for the correlation of radiographic and functional outcomes for the elderly(396). Correlations may have been missed for younger patients, for whom these outcomes have been shown to be more closely correlated(396). In addition, there was approximately a 20% loss to follow up by the 12-month time point for the physical outcome measures, with only 41 patients available to undertake the physical measures as opposed to the required minimum of 46 patients. This may result in the study being underpowered, with potential correlations missed.

Lastly, the inferences drawn from this study may be limited by the statistical analysis performed. Although the correlation analysis provides an important initial step in determining whether the radiological outcome may be associated with the functional outcome of the patient, it is not possible to determine the causality of the relationship. Therefore, inferences cannot be drawn on whether the radiological outcome of the patient is predictive of their long-term functional outcome. This study does, however, add to the increasing body of evidence regarding the association between radiological and functional outcomes, and indicates the need for further studies.

Lastly, the correlation analysis only assesses the strength of the association between variables instead of the causality. Therefore, inferences cannot be drawn on whether the radiological outcome of the patient is predictive of their long-term functional outcome. This analysis does, however, provide an important initial step in determining whether these outcomes are associated and hence whether further studies should be carried out.

Conclusions

The radiographic appearance of the wrist following operative management for a dorsally displaced fracture of the distal radius, has been shown to correlate poorly with both patient reported and physical measures of function during the 12-month post-operative period. This raises concern regarding the use of radiological parameters to determine the operative fixation of these patients. Further confirmatory work would need to be undertaken, to determine whether the attainment of an anatomical reduction of the fracture is necessary to restore function of the wrist.

6. An exploration of the long-term consequences of operatively managed dorsally displaced fractures of the distal radius

Sponsorship

This study was jointly sponsored by the University of Warwick and University Hospital Coventry and Warwickshire NHS Trust

Ethical Approval

The protocol for this study was given ethical approval by the Coventry & Warwickshire Research Ethics Committee in May 2013 as a major amendment to the Distal Radius Fracture Fixation Trial (DRAFFT) a UK based randomised controlled trial.

Patients' recoveries are often followed during the first year after undergoing an operation for their distal radius fractures. Measures of function assessed in previous chapters provide a useful assessment for patients during this period, where the change in their recovery is likely to be at its most noticeable. The consequences to the patient can continue beyond this time and can be too subtle and complex in their nature to be detected by these measures. Instead alternative methods are required to capture patients' perspectives. In depth interviews have been undertaken in this chapter to gain insights into patients' recoveries and the long-term consequences of their fractures beyond this initial 12-month period. This has allowed the detection of clinically relevant patterns in their recoveries, which could be used to improve patients' consultations and outcomes.

Introduction

The first 12 months of patients' recoveries are characterised by an initial period of severe pain and disability, followed by a rapid improvement in their symptoms, so that by 6 months the majority of patients will have mild symptoms(186, 187, 401, 402). A small proportion of patients with these fractures may still complain of severe symptoms at one year (165, 186, 187, 402). Cohort studies have shown that patients' initially experience severe pain with repeated movement of their wrists or when lifting heavy objects, and mild pain at rest(186, 402). This significantly improves by 3 months with the majority of patients experiencing mild pain with activity and minimal or no pain at rest, severe pain is rarely experienced(186, 402). Patients' function has a similar recovery pattern with most demonstrating severe or very severe difficulty initially, particularly for activities requiring strength and dexterity, which improves to mild problems by 3 months(186, 402). Lifting heavy objects and activities relating to work and recreation tend to be impaired to the greatest extent during this time(186). Macdermid *et al.* found that although the majority of patients' symptoms improve by 12 months, 21% experience some pain and disability at this time point, with 8% of all patients demonstrating moderate to very severe symptoms(186).

Patient reported outcome measures (PROMS) and physical measures of function have frequently been used to assess patients' pain and function in these studies, allowing this characterisation of patients' recoveries (117, 124, 131, 186, 187, 359, 366). However, these measures provide no opportunity for free expression and accordingly may not fully capture the patients' perspectives and experiences. For example, the DASH score asks patients about recreational activities involving taking force through the arm. This may be appropriate to a younger active patient, but not necessarily to an elderly patient with mobility difficulties. Additionally, only two of the PROMs responsive to clinical change in the wrist, were developed in consultation with patients with a wrist injury, and the exact involvement of patients in the development process is unclear(133, 139). The majority of PROMs, were instead developed from the opinions of expert clinicians and items extracted from prior questionnaires(134, 141). Qualitative research methods may instead be more appropriate for capturing this data. In-depth interviews allow patients to describe aspects of their recoveries important to them and in their own terms.

Therefore, a qualitative exploratory study of patients' perspectives of their recoveries and the long-term impact of their fractures has been explored to provide a greater depth of understanding that may not be captured sufficiently with patient reported and physical outcome measures.

Aim

The main aim of this study was to explore the long-term experiences of patients who have undergone operative management for a dorsally displaced fracture of the distal radius. During the study, patients' home lives, their occupation and hobbies were examined reflectively, in order to gain a full understanding of the impacts of their fracture from their own perspective.

Research Questions

In order to meet the aims of this study, I addressed the following broad research question:

What are patients' experiences of the long-term consequences of operatively managed dorsally displaced fractures of the distal radius?

And the following secondary questions:

- Do patient related factors impact upon their experience of their distal radius fracture?
- What compensatory mechanisms have patients developed as a result of their distal radius fracture to adapt to the long-term consequences of their injury?
- When do patients consider their wrist function to have returned to their pre-injury level?

Sample size

A purposive sample of 14 participants was recruited from the existing DRAFFT trial in a stratified manner as each patient passed the 1-year milestone following their injury. As part of the DRAFFT trial participants underwent volar locking plate or Kirschner wire fixation and completed the Patient Reported Wrist Evaluation (PRWE), Disabilities of the Arm, Shoulder and Hand (DASH) and Euro-qol outcome measures at regular intervals. I recruited participants from a subset of the University Hospital Coventry Cohort of DRAFFT participants, who had also undergone additional physical measures of function alongside the patient reported outcome measures. The selection of these particular participants allowed a secondary comparison to be made between these traditional measures of function and the information gained during the in-depth interviews. Sampling of these participants continued until data saturation was achieved, stratified by their age (<50yrs vs. ≥50yrs), gender, and duration since they sustained their fracture.

I had originally intended to stratify the participants according to their operative management, age, gender and PRWE score. However, once I commenced sampling I realised there were a number of flaws with this stratification. Firstly, there were only a limited number of patients with a PRWE score that suggested poor function that had also undergone the physical measures. Secondly, I was concerned that the PRWE score might not adequately reflect the aspects of the participants' hand and wrist function deemed important to them, for example, an individual with a high score might be highly displeased by a particular loss of function that constitutes only a minor component of the score or may be completely absent from the score. Similarly, although the type of operative management the patient received may be of interest to the surgeon, it is unlikely to hold the same importance to the patient. Therefore, I decided to remove these components of the stratification and instead included the duration since the patient sustained their fracture, stratifying patients according to whether they were 1-2 years or 2-3 years post-injury. The duration was included as it is possible that some patient's may not have recovered 1 year after their fracture, but may have done so by 2 years following their fracture.

A sampling frame with random number sequences assigned to each group was used to determine the order patients were recruited to the study (see table 38). I had intended to interview approximately 8 patients for both the under and over 50 year old patient groups. However, during the interviews I reached data saturation earlier for patients in the under 50 years old group. In the over 50 year old group different themes arose between older and younger patients, therefore I decided to purposefully sample patients both under and over 80 years old to capture their different perspectives.

Table 38 - Sampling frame - stratified by age of the participant under 50 years and over 50 years old, gender and duration since they sustained their injury.

		Intended No. Participants
Under 50 years	**Men**	2
	Women	2
	1-2yrs post injury	2
	2-3yrs post injury	2
Over 50 years	**Men**	2
	Women	2
	1-2yrs post injury	2
	2-3yrs post injury	2

Eligibility Criteria

Patients meeting the following eligibility criteria were approached to enter this study:

- Aged 18 years and older
- Dorsally displaced fracture of the distal radius within 3cm of the radio-carpal joint identified on the presenting radiograph
- Operatively managed with either a volar locking plate or K-wire fixation as part of the DRAFFT trial
- The patient was at least 12 months post-injury
- Able to give informed consent

Patients were excluded from participating in the study if:

- They were managed non-operatively
- They were unable to complete an individual interview spoken in the English language
- They had withdrawn from the DRAFFT trial or they had voiced a preference to no longer participate in additional long-term follow up as part of the DRAFFT trial

Functional outcome measures

The patient reported outcome measures were collected as part of the DRAFFT trial and the physical measures for the correlation study (chapter 5) with the relevant data extracted for the patients participating in the in-depth interviews. Two types of functional outcome measures were assessed; patient reported outcome measures and physical measures of function. The three patient report outcome measures assessed were the limb specific DASH and PRWE scores, and the EQ5D generic measure of quality of life. These were assessed at the presentation when patients were asked to complete them for the week prior to their fracture, then at 3, 6 and 12 months post-injury. The physical measures included the maximal grip strength, grip fatigue, pinch strength and range of movement of the wrist and forearm. These were taken at 3, 6 and 12 months to correspond with the patient reported outcome measures. Both wrists were assessed to provide a comparator for the patient's normal function and hence were presented as a percentage of the uninjured wrist.

Participant interviews

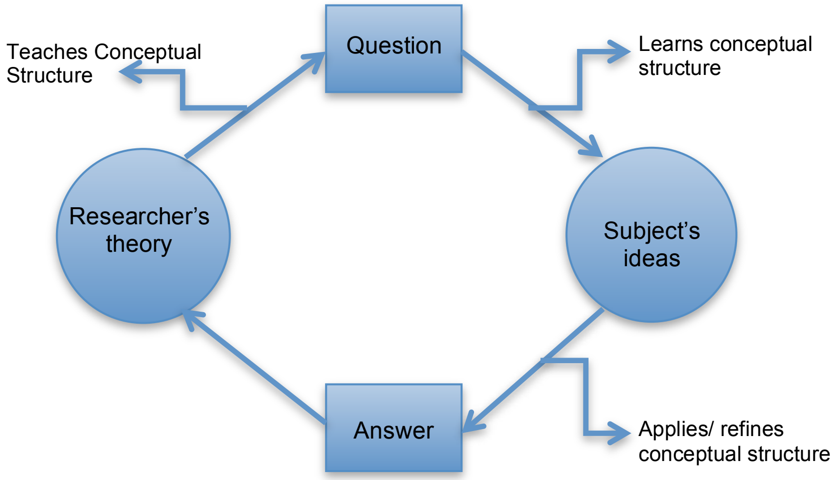
Theoretical approach

I adopted a realist approach for the interviews based upon Pawson and Tilley's model of theory driven evaluation 'Realistic evaluation'(403). Realism provides a middle ground between positivism and relativism. Wong *et al* suggest realism accepts the positivist stance that there is a real world that can be measured, however it also accepts there is an external social reality both influencing and offering a greater understanding of the real world(404). Pawson and Tilley's 'realist evaluation' provides a framework for constructing realist data, based upon the premise that an understanding of the context and mechanism by which an outcome arises are as important as the resultant outcome(403, 405). The context refers to the situation or factors that cannot be controlled by the program designers, and the mechanism, the processes that generate the outcome(404, 405). Therefore a realist evaluation intends to answer "what works for which individuals, under what circumstance and why does it work" instead of simply asking "what works best"(403, 406, 407).

In this study, the context referred to both the patients' home and work circumstances, and the treatment they received, for example, the patients' role within their family, or their occupation. The outcome was the patient's ability to use their wrist and the impact the fracture had upon their home, work life, and recreational activities. The mechanism, therefore, encompassed the processes involved in the patients' recovery leading to their resultant wrist function, whether it was good or poor. The interviews focused upon the context and the outcome of the patients' fracture through a series of comparisons made before the patients' fracture and at the time of the interview. Inferences were then drawn from these findings to hypothesise what mechanisms were involved in bringing about these changes. I decided prior to the interviews, not to pursue patients' references to the treatment they received, to ensure I did not distract them from discussing the long-term consequences of their injuries.

The realist interview therefore, differs from the conventional structured and unstructured approaches. During the realist interview, information is exchanged between participants of differing level of expertise, driven by the researchers theory(403). By leading with theory, Pawson and Tilley suggest two key processes arise, firstly the teacher-learner function and secondly the process of conceptual refinement (see figure 15)(403).
The teacher-learner function acknowledges that the respondent will often seek greater knowledge about the researcher and the theoretical basis of the interview than they are offered in conventional interviews(403). Pawson and Tilley suggest the researcher should "play a more active role in teaching the overall conceptual structure" by providing greater detail during the explanatory components of the interview such as the introduction and linking narratives(403). Conventional structured interviews in comparison have been criticised for relying too heavily upon precise questioning to guide the respondent and as a result may still fail to orientate the respondents to the interview concept considered(403).

Figure 15 - Structure of the realist interview, taken from Pawson & Tilley (2011)



The second phase of the realist interview involves the conceptual refinement function, during which the respondent delivers their response within the conceptual structure taught in the teacher-leaner phase(403). By providing the respondent with greater contextual knowledge they have a clearer comprehension of the researcher's goals and hence can either confirm or falsify the researcher's theory with ease(403). Unstructured interviews and attitude scales often lack this conceptual detail, leaving respondents with inner conflict and seeking further contextual information(403).

Interview implementation

A total of 14 participants were interviewed for this study, with interviews lasting on average 13 minutes with the longest lasting 30 minutes 31 seconds and the shortest 8 minutes and 22 seconds. All the interviews were performed face-to-face in either the participant's home or at the University Hospital. The dialogue was recorded using an electronic audio recorder with the patients' permission. During the interview, the participants were not referred to by their name to ensure anonymity of the audio-recordings.

At the start of each session I reiterated the purpose of the interview, thus providing the contextual basis of the study as suggested by Pawson and Tilley (2011). In addition I informed participants that I would be asking about both before and after their fracture in order to elicit the experiences that resulted from their fracture. I also explained my role as solely a researcher during the interview, as I had previously been in contact with many of the patients in a clinical setting. I then proceeded by asking the participants to tell me about themselves in the period just before they fractured their wrist, but did not attempt to limit the time period over which they considered their experiences. The interview was then directed towards the participants' home lives, occupations, hobbies and self-care just prior to and then following the fracture. An interview guide was developed including anticipated questions and prompts to ask during the interview (see appendix 10), as the interviews progressed the guide was refined following review of prior interviews.

The audio recordings of the interviews were transcribed verbatim using a professional transcription service, and later checked against the recording for accuracy. All transcripts were anonymised and assigned the participant's identification number. Patients had originially been informed on the patient information sheets that they would be sent copies of their transcripts to allow clarification of any unclear sections. At the time of the interviews, patients were informed only transcripts that were unclear would be sent, unless patients specifically requested their transcripts. No transcripts required clarification or were requested by any of the patients, hence none were sent. At the interviews, patients were also informed that they could contact myself via the trial telephone number if they had anything further to add to their interview. No patients chose to contribute any additional details.

Coding and analysis

The transcripts were analysed using a comparative analysis for changes in the individuals activities and for the meaning it held for them.

Table 39 - Coding Framework

Code	Description
Context	The participants surroundings and circumstances before, during and after their wrist fracture, that may or may not be related to their fracture
Before Fracture	Activities undertaken by the participant prior to their fracture, deemed to be related to the affected wrist by the researcher or the participant
After fracture	Activities undertaken by the participant after their fracture, deemed to be related to the affected wrist by the researcher or the participant

The process of analysis commenced with immersion into the data, involving listening to the audio-recordings, reading and re-reading the transcripts(250, 251). Preliminary interview transcripts were coded thematically using the NVIVO coding software. A broad coding framework was generated in conjunction with FG, from the first transcripts and applied to all the following transcripts (see Table 39).

Comparisons were then drawn between activities the participants previously undertook, with those they had either returned to or were no longer able to partake. At this stage, comparisons drawn up by the participants were excluded and introduced later in the analysis. Summaries of these comparisons were generated alongside a synopsis of the coded sections (Table 40). Additional synthesis notes were constructed separately detailing interesting comparisons and similarities with other participants.

The second stage of the analysis involved generating four common themes with several subthemes, which emerged from the coded summaries. Relevant data from all the patients was then amalgamated for each theme. All the themes and subthemes are detailed in table 40, with extracts from the patient coded summaries to illustrate each theme. Each theme was then embellished with data from the functional outcome measures to provide a greater understanding of the patient's perceptions.

The context mechanism outcome framework was then applied to the themes generated in this analysis, to determine whether any patterns could be detected in the recovery of this group of patients that might be clinically applicable. Themes and subthemes pertaining to the patients' activities, wrist demand, level of independence, and comorbidities before their fracture, as well as any concomitant injuries resulting from their accident were integrated into the context component of the framework. Similarly, themes relating to the consequences of the patients' fractures were separated according to those describing any processes involved in the patients' recovery, and those detailing the patients' resultant function and symptoms, and integrated into the mechanism and outcome components respectively. Broad groups were formed within each component of the framework, and patterns discerned from the interaction of those groups for each patient.

Table 40 - Example of summary comparison notes

Context
Can you tell me a bit about yourself? Yes, very busy. I'm a full-time riding instructor so my job is hands on. I work with horses so there is a lot of touchy feely work being done as well and also heavy work, you know, mucking out, things like that. So I'm also married with a daughter so again very busy all the time and very physical person. What is your role at home? Okay at home, cleaner, cooker, washer, everything, I do everything at home so yes, washing up, all the washing, cleaning, vacuuming, polishing, everything, it all comes to me because I like to have it right.
Before the fracture
What would happen on a typical day? Okay well nowadays I don't do so much physical because I'm mainly doing teaching and managing the riding school but for many years I've been mucking out, sweeping the yard and doing quite a lot of physical, strenuous work and obviously also handling the horses and a lot of riding. So quite a lot of physical work I do. Do you have any other hobbies at all?

I am kept busy. I am actually a musician. I can play the clarinet, piano, flute and saxophone so yes, I do, but I don't tend to do it very much anymore because I haven't got time, I'm very busy with work and everything else so I have sort of put that to a side line really
After the fracture
How have things changed? To be honest they haven't really changed very much. At the beginning just after I had the operation obviously my hand was still very sore and it took a few months to sort of get back to stuff but because I like my house right and because I like to be busy, I just get on with carrying on doing all my housework and things like that so to be honest nothing has really changed, I do everything myself. I do struggle to put pegs on the washing line, that is one of the things that that I sort of fumble around a bit and occasionally I find myself quite clumsy. In terms of housework, do you need any help now? Do your family help at all? No, no, everything – the only time my mum does bits is when I'm at work and I'm busy, I haven't got time. She will come in and get my washing off the line if it's raining and stuff like that but not because I can't do it physically.
Summary of comparisons
Before: Busy horse riding instructor "quite a lot of physical, strenuous work and obviously also handling the horses and a lot of riding", wife and mother. Physical and dexterous hobbies: "I am actually a musician. I can play the clarinet, piano, flute and saxophone". Independent of activities of daily living After: Wife and mother, remains a riding instructor but has had changes in her role at work, but still physical elements and continues with the clarinet. Remains independent Comparisons: • Dexterity - "I do struggle to put pegs on the washing line, that is one of the things that that I sort of fumble around a bit and occasionally I find myself quite clumsy" "Sometimes turning my hand, I know it sounds silly, but getting money out of my purse or putting money back in my purse, sort of....twisting movement, that's just slightly affected" • Adaption – "like putting heavy pots into the oven, that I did struggle with and sometimes I do still now. I sort of put more pressure into my left hand"

Study procedures

Recruitment

Potential participants were identified from the University Hospital Coventry cohort of DRAFFT participants that had either agreed to continue with long term follow up as part of the DRAFFT trial or had not been approached yet about further follow up. Participants were sent a letter of invitation and a participant information sheet, then contacted by myself via telephone to invite them to participate in the study and to discuss any issues related to the study. An interview date convenient to the participant was then arranged for those expressing an interest in the study either at the participant's home, place of work or at University Hospital Coventry. I limited the number of times contact was attempted to contact participants via telephone to three separate occasions. A total of 17 out of 74 potentially eligible participants were approached to enter the study, two could not be reached via telephone and two participants declined to enter the study. The remaining 57 participants were not approached as data saturation had been achieved.

Consent

At the start of the participant interviews I reiterated the purpose of the study and gave participants the opportunity to discuss any issues that may have arisen from the study material previously provided. All participants agreed to enter the study and informed verbal and written consent was obtained. As part of the consent process participants' freedom to withdraw from the study without prejudice was emphasised.

Ethical Considerations

No benefits in the form of incentives were offered to participants to encourage their participation, and no participants suffered any physical or psychological harm as part of the interview process.

It was considered that participants, who have experienced long-term difficulties with their wrist, might have become distressed during the interview. Therefore, participants found to have on-going problems with their wrist were informed that their difficulties could be discussed with the chief investigator of the DRAFFT trial and further follow up arranged if appropriate and consented to by the participant. Information for the Patient Advice and Liaison Service (PALS) and contacts within the NHS trust and University of Warwick were also provided on the participant information sheet in case participants' difficulties related to concerns regarding their management.

Date Management

All electronic participant-identifiable information was held on a secure, password-protected database accessible only to myself. Paper forms with participant-identifiable information were held in secure, locked filling cabinets within a restricted area of Warwick Medical School. Participants were identified by a code number only. All paper and electronic data will be retained for at least five years from the completion of the study.

Results

Participant characteristics

A total of 18 patients were invited to participate in interviews; 2 patients declined to participate in the study due to a recent deterioration in their health, and a further 2 could not be contacted on the follow up telephone call. After three attempts to contact them they were deemed to have declined to enter into the study. The remaining 14 patients participating in the study consisted of 8 women and 6 men of white British origin, with a mean age of 57.3 years (SD; 19.7). All of the patients lived independently, although 2 had assistance with their cleaning and food preparation, and one required a walking aid. The majority of patients in this sample had a high demand for their wrist function (n=9), but there was an equal number of patients who were employed either full time or part time in comparison to those unemployed, retired or acting as a full time carer. The main patient and injury characteristics are detailed in tables 41&42. The interviews were conducted at 2.4 years (SD; 0.6) post-injury.

Table 41 - Patient and injury characteristics

		No. Patients
Gender	Male	6
	Female	8
Mean age (SD)		57.3 (19.7)
Hand demand level	High demand	9
	Low demand	5
Dominant injury	Yes	9
	No	5
Injury impact	High energy	5
	Low energy	9
Fracture configuration	Extra-articular	11
	Intra-articular	3
Mean duration (years) since fracture (SD)		2.4 (0.6)
Fracture fixation	Kirschner wires	6
	Volar Locking Plate	8

Table 42 - Functional outcome measures at 3, 6 and 12 months post-injury

(a) Physical measures of function

	Mean values % of uninjured wrist (Standard deviation)		
	3 months	**6 months**	**12 months**
Grip strength (kg)	66.3 (20.2)	80.8 (16.1)	86.7 (15.2)
Grip Fatigue (%)	84.7 (28.3)	82.8 (39.4)	86.2 (25.9)
Pinch Strength (%)	80.5 (22.6)	90.9 (17.7)	97.3 (13.8)
Pronation (%)	95.4 (6.8)	96.4 (9.7)	98.4 (7.1)
Supination (%)	82.6 (18.7)	93.2 (18.6)	94.0 (9.1)
Flexion (%)	77.1 (20.1)	82.9 (11.2)	87.0 (13.2)
Extension (%)	66.2 (21.4)	81.6 (10.2)	77.4 (12.3)
Radial deviation (%)	68.3 (31.9)	85.5 (16.1)	101.2 (27.7)
Ulnar deviation (%)	83.2 (49.4)	93.5 (25.6)	78.2 (23.5)

(b) Patient reported outcome measures

	Mean values (Standard deviation)			
	Baseline	**3 months**	**6 months**	**12 months**
DASH score	3.9 (7.4)	26.0 (14.5)	17.5 (13.7)	13.8 (16.2)
PRWE score	2.3 (6.7)	29.4 (16.6)	15.3 (12.4)	14.0 (15.1)
EQ5D score	0.5 (0.3)	0.8 (0.1)	0.9 (0.1)	0.9 (0.1)

Interview analysis – Thematic analysis

Patients' descriptions of their recoveries and the current state of their wrists produced a number of commonalities allowing the creation of several themes. These themes broadly focus upon: how patients' perceptions of their recovery differ according to the demand upon their wrists; the consequences of their injury; adaptions to their recovery and the time taken to return to normality (Table 43).

Patients' perceptions of their recovery and current state of their wrist

The way in which patients perceived their recoveries and the functional measures, varied considerably with; the demands they place upon their wrists, the effects of deteriorating health with ageing, and any concomitant injuries they had sustained in addition to their distal radius fracture. Three subthemes were derived from these perceptions:

Wrist demand

The demands upon the patient's wrist function can be considered in terms of the activities they performed before their injury that relied upon a normal hand function. Based upon patients' descriptions of their pre-injury function and their baseline upper limb specific functional scores, they were found to exhibit either a high or low demand upon their wrist.

Patients in the high demand group were younger and independent in regards to their self-care and activities of daily living, demonstrating lower mean baseline DASH and PRWE scores of 0.3 (SD = 1.0) and 0.6 (SD= 1.7), typified by patient 006:

> I do everything at home, so yes washing up, all the washing, cleaning, vacuuming, polishing, everything it all comes to me.

This was characterised by their involvement in a variety of leisure and work-based activities requiring either intricate function of their hand or the ability to exert force through the wrist. Again patient 006, provides a rich example of requiring significant wrist strength in her role as a full time riding instructor "heavy work, you know, mucking out, things like that", as does patient 12:

> I was heavily into martial arts… at quite a high level, national level…. my wrist obviously was taking quite a pounding, punch bag work, very impact-related exercises.

Patients 1 and 4, instead undertook activities requiring intricate hand function such as painting and sewing:

> I'm very sort of hands on really, I do quite a bit of sewing, so we make most our own sort of stuff around the house.

Patients in the low demand group in contrast were older with a mean age of 78.2 years (SD=8.7) in comparison to the younger high demand group with a mean age of 46.9 years (SD= 14.4), and had slightly higher DASH and PRWE baseline scores of 10.2 (SD = 9.8) and 5.3 (11.0) respectively. Although the patients were independent with regards to their self-care, they had some assistance with activities of daily living, for example patient 7 "I do have a delivery of ready meals" and patient 10:

> Normally there is somebody who comes in and cooks and does a bit of cleaning around the house in the morning

This group can be characterised instead by no longer partaking in activities requiring a significant degree of hand function, for example patient 11 no longer took part in her regular hobbies at the time of her injury

> I stopped them years ago; I used to draw and I used to knit and I used to sew but my eyes wouldn't let me do that anymore, so I've stopped most of it. I don't do very much during the day at all. I just like sitting, well watching the television

Patient 3 similarly described her leisure activities as;

> I like to sit and watch, so I like to watch TV and I read a lot and I like to puzzles, I like Sudoku and crosswords and things like that.

None of the patients in this group engaged in any activities requiring either significant strength or dexterity of the hand and wrist.

The high and low demand groups differed in both their perceptions of their recovery and the current state of their wrist, and in the change in their functional scores during the first year post-injury. The low demand group considered their wrist function to have returned to ‘normality’ in a shorter duration and demonstrated a greater satisfaction with their current wrist function, despite the interviews being performed on average at 2 years post-injury for both groups. For example patient 11 describes her current wrist function as; “it does everything I want it to and it goes in all directions. I can’t believe how easily it’s gone”, and patient 7 as; “I’m very happy with my wrist”. Additionally patients in the low demand group articulated significantly fewer symptoms and adaptions to their wrist function either during the recovery or at the time of the interview. Patients often referred to these changes with terms such as “twinges” minimalizing the significance of any changes to their wrist function they had experienced.

The high demand group, despite initially suggesting they were satisfied with their current wrist function, on further probing reported more symptoms and adaptions they had made, including lifestyle changes. For example, patient 2 initially described her injured wrist as “it doesn’t impact I don’t think” but later divulges significant restrictions

> It’s not fully functioning. I’m restricted in stuff that I can do…I haven’t got the movement in my wrist….vacuuming the inside of the car is harder than it perhaps was cause my wrist doesn’t bend properly.

Patients 1,2, 6, 8, 9 and 12 all experienced lifestyle changes predominately affecting their recreational activities, such as changing the type of riding for patient 6 “since I’ve had my accident, I’ve been really throwing myself into dressage rather than the jumping” and patient 12 who no longer took part in martial arts training or competitions despite having reached a high level

> I changed all that after the injury and I do a lot of cycling now…a lot of hill work…..rather than a lot of impact type stuff, I don’t do any impact things now.

Patients in this group also demonstrated a greater awareness of their wrist function, with a better recollection of their previous function to provide a comparator to their current state allowing them to articulate intricate details about deficits in their hand and wrist function. For example with patient 2:

> Things like getting change out of my purse, trying to find the right change… I don’t seem to have the dexterity in my fingers to do it.

or with patient 12:

> If I was pushing myself up from a soft surface like a bed…… it's just a little tighter in that direction than it used to be.

These findings were supported by the DASH and PRWE scores. Although the DASH scores at 12 months were similar for both groups, the low demand group demonstrated a lower 12-month PRWE score and a smaller difference between the 12-month and baseline scores for both the DASH and PRWE scores in comparison to the high demand group.

Hand dominance

The dominance of the patient's wrist fracture, also contributed to a subtle difference in patients' perceptions of their wrist function. The importance of having a non-dominant injury was acknowledged in four of the five patients' interviews with a non-dominant wrist fracture, but conversely in none of the interviews of patients with a dominant fracture. These subtle differences arose between the types of difficulties patients experienced and their mechanisms for adapting to their fractures. Problems with strength of the wrist tended to be more apparent than those of dexterity, patient 8 for example describes difficulty with lifting heavy saucepans and maintaining his own weight

> If I'm boiling you know the rice….. it's not going in the left hand no way…. I can't even hold my own weight in a press up position.

Patient 9 also experienced difficulties with strength during gymnastic manoeuvres "I don't feel that it's as strong anymore to support my weight". These patients required fewer adaptions due to a prior tendency to use their dominant hand for the majority of tasks, such as patient 13 "I'm right handed anyway….I mostly use my right arm for lifting things" and patient 9 "My right hand is my hand of choice… I would always use my right anyway". Patients with a dominant wrist fracture in contrast experienced a greater range of problems, with restricted movement and dexterity, however the overall DASH and PRWE scores were similar for both groups.

<u>Deteriorating health due to the ageing process, concurrent illnesses and injuries</u>

Within the low demand group, several of the older patients experienced either a deterioration in their general health associated with their increasing age or had concurrent illnesses affecting their effected arm, that coincided with their wrist fracture recovery. The effects of these additional impairments meant that they often found it difficult to distinguish between these changes and those that had resulted from their fracture. Patient 10, explained his difficulties when discussing the presence of pain in his wrist as follows:

> The trouble I get is sort of old age pains, you know. They come and go….. what I do have is as much this one as that one.

Patient 7, similarly found difficulty in distinguishing between symptoms from her shoulder and wrist

> I think the trouble is that I've got torn muscles in my shoulder…..it's difficult to tell whether it's from my shoulder or my wrist.

As a result it is not possible to fully determine the extent to which their wrist fracture had impacted upon their lifestyles.

Similar to these effects of deteriorating health and concurrent illness, patient 8 had sustained several significant injuries at the time of his fracture, hindering his ability to disentangle the changes associated with his multiple injuries from his wrist fracture. The patient tended to find it difficult to focus upon the symptoms and problems associated with his wrist fracture and instead preferentially discussed the injuries troubling him to a greater extent. For example when discussing the presence of pain he instead focused upon his leg "it's nothing painful like how I've had with the legs", similarly with his return to his previous hobbies or working

> I've tried skateboarding, but I find it difficult with the left leg because of that being bowed out ……. It was harder than like trying to get a job before. Because obviously like I was ... I had a limp.

Consequences of the fracture

Patients' accounts of the consequences of their fracture focused upon the symptoms and functional limitations they had and continued to experience, including their increased sense of apprehension and any changes they had to make in their recreational activities.

Symptoms and functional limitations

Loss of dexterity, range of movement and difficulty with strength tended to dominate patients' accounts of their recoveries and current wrist status. Patients tended to describe these difficulties both in terms of the problems they had during their recovery and those that remained. The majority of patients did not consider themselves to be significantly limited and instead described these symptoms as occasional difficulties when probed during the interview.

Loss of dexterity

Several of the high demand patients mentioned difficulty with performing tasks that required movement of the fingers and a precision grip, such as patient 6

> I do struggle to put pegs on the washing line, that is one of the things that I sort of fumble around a bit and occasionally I find myself quite

> clumsy" and patient 2 "things like getting change out of my purse, trying to find the right change.. I don't seem to have the dexterity in my fingers to do it.

The range of movement of the fingers was not assessed, however the lateral pinch was over the first 12 months post-injury. The affected patients all had dominant injuries, therefore it could be expected that their pinch strength should equal if not exceed that of the uninjured wrist at 12 months post-injury. For patients 1 and 6, a minor deficit however remained at 12 months of 20% and 10% of the uninjured wrist. Patients 2 and 6 also scored 'mild to moderate difficulty' for the dexterity questions on the DASH and PRWE scores. The remainder of the patients without dexterity symptoms had a pinch strength equivalent to or greater than their uninjured wrist and reported no difficulty with the dexterity questions of the DASH and PRWE scores, with the exception of patients 10,12 and 13 who scored mild to moderate difficulty.

Restricted movement

Only high demand patients experienced restrictions in their range of movement. Restrictions were experienced in all planes of movement, although individually patients tended to be affected in one plane of movement to a greater extent. Patient 2 described the greatest degree of restriction:

> I don't have the movement in my wrist…..if you clean the glass on there, just getting into corners, having my wrist at the angle, things like that when it's the whole twisting movement …vacuuming the inside of the car is harder than perhaps it was, cause my wrist doesn't bend properly.

In relation to the range of movement at 12 months; the greatest restriction tended to arise in flexion and extension, despite patients tending to complain of rotational difficulties. Patient 2 regained the least movement in her wrist in comparison to her uninjured wrist, corresponding with the restrictions she articulates in the interview. The low demand patients, 11 and 13, also had a reduced range of movement at 12 months but at the time of the interview did not perceive themselves to experience any such problems. This may be because the interviews for 11 and 13 were conducted approximately 21 months later, and hence their restrictions had improved or they did not perceive them to be a problem as they were both low demand patients.

Strength

Reduced strength was common to both high and low demand patients. Typically, patients described difficulty with lifting heavy objects such as saucepans or their own bodyweight, or undoing tight jars and bottles. Patient 12, for example

> Open jars, things like that. They cause me a little bit of difficulty now depending on the jar type….my grip is obviously not as good as it was

Grip strength was the only measure of gross motor strength measured for the injured limb in this study, the remaining muscle groups were not included as they were not deemed specific to the recovery of patients with a wrist fracture. The majority of patients regained 80-105% of their non-injured grip strength at 12 months post-injury, again six of these patients had a dominant injury so a normal grip strength should be at least 100% of the uninjured wrist. Two patients only regained 60% of their strength, both patients had difficulty lifting heavy objects, but also had concurrent conditions affecting their injured arm that may account for their poor strength as opposed to their wrist fracture. Five patients also scored as having moderate difficulty with lifting heavy objects and activities requiring grip strength on the DASH and PRWE scores at 12 months, all of which also mentioned these problems persisting in the interviews at approximately 1-2 years later.

Pain

Patients rarely acknowledged pain in the wrist, instead, subtle symptoms such as aching and twinges or an awareness that the wrist was different were described. Patient 9, for example

> Sometimes when its cold, and I've been outside…sometimes I do feel that it's aching, or maybe if I've done too much it may ache.

This corresponds with the pain components of the DASH, PRWE and EQ5D scores, with the majority of patients scoring mild pain mainly with specific activities at 12 months. Patient 6, was the only patient to score moderate pain on both scores with specific activities, however her interview 11 months later, she describes her pain as having improved significantly.

Apprehension

Several of the female high demand patients admitted since their fracture they have become more apprehensive of partaking in activities that either originally resulted in their fracture or which they perceived to convey a greater risk of injury. Patient 4, for example described being tentative when walking on wet or slippery surfaces:

> I kind of put my feet down more carefully so that I don't slip… I'm very conscious in terms of I watch what I did.

Despite patient 6 experiencing the most traumatic injury she chose to modify her horse-riding instead of completely stopping unlike patient 2 and 4 who no longer skate after their accidents:

> Well that was because my accident was scary……I was a bit sort of hang on a minute, I've got to be careful not with my jumping….. I've really been throwing myself into dressage rather than that jumping, I sort

> of just took a bit of a side step from the jumping side and threw myself into something else.

Interestingly, none of the men or patients who had previously described prior falls mentioned any similar psychological effects or changes in their behaviour.

Changes in recreational activities

The majority of patients returned to their prior activities, a few however decided to opt for less physically demanding activities, such as bowls instead of golf. These changes however, were due to both the patients' limited wrist function hindering their performance, but also contextual changes. Patient 12 for example deciding to take up cycling instead of martial arts:

> I changed all that after the injury and I do a lot of cycling now…. A lot of hill work and that seems to have benefitted. Rather than a lot of impact type stuff. I don't do impact things now. ….. It wasn't something that was totally injury-related anyway. So that was something that was probably going to happen. I got as far as I could with that and I thought perhaps I just needed a change.

Two of the patients as previously discussed also chose to stop their recreational activity completely due to an increase in post-injury apprehension.

Adaptions to the fracture

Patients adapted to their injuries by either opting to use their non-injured wrist, using alternative movements to achieve the task or by adapting the task itself to their new capabilities. The majority of patients adapted by using their alternate wrist, either performing the task solely with the alternate wrist for tasks such as cleaning or bowls or by using both hands, often for strength related tasks such as patient 7

> I'm probably more careful how I lift saucepans…. I probably use two hands for larger ones.

Patient 2 described using the most adaptions to achieve her normal recreational and daily activities, some of these changes included using steps in the swimming pool instead of climbing out, using free weights instead of a bar and weights attached, or going onto her knees in the bath to then stand up instead of pulling herself up using rails in the bath.

Duration of their recovery

Nearly all of the patients considered themselves to have either fully recovered or recovered the majority of their wrist function by the time of their interview, despite later divulging they continued to experience some restrictions as a result of their fracture.. This was applicable regardless of whether the interviews were carried out after 18 months or 40 months. The first 6-12 months was considered the period during which they had the greatest improvement in their wrist function and symptoms. This corresponds with the patient reported and physical measures of function; over 70% of function had been recovered for the physical measures by 12 months post-injury and the PRWE and DASH scores improved by 50% between 3 and 12months (Table 43). In addition, five patients that reported having returned to the previous level of wrist function by the interview had returned to their baseline DASH PRWE scores by 12 months, but not to 100% for all of their physical measures.

Table 43 – Examples from patient interviews illustrating themes

Themes	**Examples from the patient interviews**
Patient's perceptions	**High Demand**
	I had a lot of interests; painting, golf and a few other things….. I was playing golf about once a week or once every two weeks…. Obviously Golf is quiet strenuous, you know it depended a lot on arm movement, wrist movement, and its the same with painting … the painting took a lot of my time. I was quite involved with the house …. I mean the jobs I did around the house… my job was washing up, a bit of a specific one is cutting the lawn….. I'd also have to make a meal about 3 nights a week *(Patient 1, male 71 years old)* Just getting on with jobs… you know normal cleaning, cooking, ironing, so routine stuff….. I would do the vacuuming and the dusting, Sainsbury's shop, that kind of thing A lot of cycling, I used to go to the gym and do a lot of aerobics and body pump classes, they were probably my regular activities *(Patient 2, female 42 years old)* I really enjoy gardening….I dig my allotment…I'm very sort of hands on really….I do quite a bit of sewing so we make most of our own sort of stuff around the house….doing lots of DIY at home….all the general sort of cleaning chores I would do" *(Patient 4, female 48 years old)* I was semi retired doing a bit of work, I'd just really sort of started semi retirement but I was doing a fair bit of driving, fair bit of surveying. Getting into lofts and such, really didn't have any great problems …. do some tidying up, washing up, cook for myself if I'm on my own…..photography, painting, I do do painting….go on walks, a walking holiday *(Patient 5, male 65 years old)* Very busy all the time and very physical person… Full-time riding instructor…. I'm doing a 50 or 60-hour week …..heavy work, you know, mucking out, things like that…...I do everything at home, so yes washing up, all the washing, cleaning, vacuuming, polishing,

	everything it all comes to me….I am actually a musician. I can play the clarinet, piano, flute and saxophone. *(Patient 6, female 40 years old)* Motor biking and skateboarding…..I'm into everything to be honest with you. If I get bored I go snow dome for the week you know….snowboarding and tobogganing…..Gym was another thing that I used to do as well *(Patient 8, male 22 years old)*
	Low demand
	I'm not a physical person. I like to sit and watch so I like to watch TV and I read a lot and I like to do puzzles, I like Sudoku and crosswords and things like that *(Patient 3, female 66 years old)* I stopped doing embroidery or knitting *(Patient 7, female 84 years old)* I had been having falls…I've fallen for some time due to these statins. So I did use a stick quite early on, just for balance really I don't do an awful lot of cooking I stopped them years ago; I used to draw and I used to knit and I used to sew but my eyes wouldn't let me do that anymore, so I've stopped most of it..I don't do very much during the day at all. I just like sitting – well watching the television *(Patient 11, female 83 years old)*
	Hand Dominance
	I'm very lucky it was my left one… I actually do the pushing with the right hand *(Patient 11, female 83 years old)* I'm right handed anyway….I mostly use my right arm for lifting things *(Patient 13, female 72 years old)*
	Deteriorating health, concurrent illnesses and concomitant injuries
	I think the trouble is that I've got torn muscles in my shoulder…..it's difficult to tell whether it's from my shoulder or my wrist. *(Patient 7, female 84 years old)* The trouble I get is sort of old age pains, you know. They come and go….. what I do have is as much this one as that one *(Patient 10, male 86 years old)* I've arthritis in my neck … spondylitis, so its always affected my arm, so I drop things if I don't remember to hold them tight…..I get up, there's never any pain in it … unless I do

	that with it or something like that, but I probably would have got that anyway, you know, with my neck *(Patient 13, female 72 years old)*
Consequences of the fracture	**Symptoms and functional limitations**
	Its not fully functioning…I am restricted in stuff that I can do…I haven't got the movement in my wrist...vacuuming the inside of the car is harder than it perhaps was… cause my wrist doesn't bend properly…. I can't move my wrists in the right way to push my body up…. I tend to be a lot more clumsy….I can't seem to grasp some a big box say with that hand….. Things like getting change out of my purse, trying to find the right change…… I don't seem to have the dexterity in my fingers to do it. *(Patient 002, female 42 years old)* I do struggle to put pegs on the washing line, that is one of the things that I sort of fumble around a bit and occasionally I find myself quite clumsy….sometimes turning my hand ……… getting money out of my purse or putting money back in my purse…. twisting movement, that's just slightly affected. *(Patient 006, female 40 years old)* I can't even hold my own weight in a press up position….it just being weak… anything that involves …pushing up, like just moving the back wrist, you know going against that, nothing, nothing at all…. there's just a horrible shooting pain. *(Patient 008, male 22 years old)* its just the movement is definitely not as fluid… I don't feel that it's as strong anymore to support my weight…sometimes when its cold, and I've been outside, or it might not even…I don't know, but sometimes I do feel that it's aching, or maybe if I've done too much it may ache…If I've been holding something then it might ache a bit. *(Patient 009, female 34 years old)* I did lose a little bit of the flexibility, flexing my wrist backwards. So if I was say pushing myself up from a soft surface like a bed, yes I might notice that a little bit. It's just a little tighter in that direction than it used to be, perhaps in the opposite direction as well….I have lost just a little of movement there…. just taking tops off bottles occasionally is a little more difficult than it used to be. *(Patient 012, male 56 years old)* Only thing you notice is if you do a press-up you see how straight one arm is as opposed to there's a little angle in the other *(Patient 014, male 49 years old)*
	Apprehension
	I'm too scared in case I break anything else (Patient referring to roller skating) *(Patient 002, female 42 years old)*

	I kind of put my feet down more carefully so that I don't slip…I certainly won't go ice skating again, that's for sure. *(Patient 4, female 48 years old)* Well that was because my accident was scary…. I was a bit sort of hang on a minute, I've got to be careful now with my jumping (patient stopped horse jumping due to the accident) *(Patient 006, female 40 year old)* They needed people to do hand springs and stuff, it was something I wasn't comfortable doing, because I didn't feel that my wrist would support doing that again….If I was going to do a handstand… I don't now feel as confident. *(Patient 009, female 34 year old)*
	Changes in recreational activities
	Since I've had my accident, I've been really throwing myself into dressage rather than the jumping…I sort of just took a bit of a sidestep from the jumping side and threw myself into something else. *(Patient 006, female 40 year old)* I've tried to go back to the gym as well and push…nothing. No I cannot do, there's nothing there *(Patient 008, male 22 year old)* I changed all that after the injury and I do a lot of cycling now…. A lot of hill work…. Rather than a lot of impact type stuff, I don't do any impact things now. *(Patient 012, male 56 year old)*
	Adaptions to the fracture
	For certain moves, I have to ditch the bar and just use free weights…I just have to differently…to get up..I tend to sort of use my elbow I look really clumsy….climbing on the board was hard cause I feel like I'm doing it one handed I probably tend to probably do it with my left now…I have to use my left hand for toilet tissue cause I just can not do it with my right. Climbing back onto things, even like climbing out of the edge of a pool Id use the steps cause I couldn't push up….getting out of the bath…I just do things differently because I turn over, I turn onto my knees now and stand up…I've got handles on the bath but I couldn't get out of the bath and I just automatically go on my knees now and do it that way. *(Patient 002, female 42 year old)*

	I tend to do quite a lot with my left hand *(Patient 006, female 40 year old)* Everything's always done separately….I do use my right hand more. *(Patient 008, male 22 years old)*
Duration of the recovery	I'd say the last 6 months or so there's been a great, final little bits come down you know got right. (3 years since fracture) *(Patient 001, male 71 years old)* Even by that sort of six month period I was sewing *(Patient 004, female 48 years old)* Six to twelve months afterwards" "at least six months before it was going back to normal. *(Patient 009, female 34 years old)*

Realist evaluation

In this section, I have applied the context, mechanism and outcome framework to the themes and subthemes generated in the thematic analysis in the previous section, to determine if patterns exist in the recovery of these patients that might assist surgeons' consultations. In table 44, I provide a summary of how these themes and subthemes are integrated into this framework.

Table 44 - A summary of the application of the context, mechanism and outcome framework to the themes and subthemes generated in the thematic analysis

	Context	Mechanism	Outcome
Theme	Patients perceptions of their recovery	Consequences of the fracture	Consequences of the fracture
Subthemes	Wrist demand Hand dominance Deteriorating health Concurrent illnesses Concomitant injuries	Changes in recreational activities Adaptions to the fracture	Functional limitations (reduced dexterity, strength and movement) Pain Apprehension

Context

The contexts within which patients sustained and recovered from their fractures were varied with respect to their home circumstances, occupation, and recreational activities. In regards to the patients' recovery, they are best considered in terms of their demand upon the patients' wrist, and the associated risk of repeat injury. They can be broadly grouped as follows:

- Low demand activities
- High demand activities
- High risk activities

Low demand activities

Patients described performing activities such as reading, working a television remote or washing, which didn't require the full recovery of their wrist function

High demand activities

These were activities patients described as requiring greater strength or dexterity to perform. Patients 1, 2, 4, 5, 6, 8, 9, 12 and 14 performed activities such as, painting, sewing, lifting weights, pegging washing on a line, and performing piercings.

High-risk activities

These included activities patients deemed to carry an inherent risk of re-injury that were unacceptable to them (patients 6, 8 and 12). For example, before their fractures, patients 6 and 12 competed in horse jumping and martial arts. Both of which carry a significant risk of injury from falls or from direct impact with other contestants.

Mechanism

In the previous section we have seen that patients in this study demonstrated two coping mechanisms during their recovery; adaption and avoidance of their tasks. These mechanisms were often engaged over a long duration, when patients were attempting to participate in high demand and high-risk activities. The low demand activities instead, tended to recover after the immediate post-operative period, and hence were not the focus of this study. For example, patient 1 was able to make their bed and wash their hair by 3 months following their operation without any difficulties.

Task adaption

Patients' adapted how they performed their tasks by either adopting a new technique or by using adjuncts to assist them in maintaining the function as before their fracture. These adaptive mechanisms were typically used in response to high-demand tasks. Patient 2 displayed many examples of adapting her tasks including; using single smaller weights instead of heavier weights on a larger bar to perform her exercises, or by using the steps in swimming pools, instead of climbing out by pushing up off the side. Similarly, patient 8 altered his body position to improve his ability to pierce the left side of his clients' bodies, and he was also learning a different technique to further account for his difficulties.

Activity avoidance

Patients tended to avoid mainly high-risk activities they deemed to have too great a risk of injury to themselves, such as patients 2 and 12 choosing to no longer go roller-skating or compete in martial arts practice and competitions. Patient 6 engaged both these recovery mechanisms, by choosing to avoid competing in horse jumping and instead adapting her horse riding, so she instead changed to dressage with a lower risk of sustaining a serious injury.

In some circumstances, however, patients avoided high-demand tasks they felt unable to perform, instead of using adaptive mechanisms. For example, patient 8 decided to cease all upper body exercise due to his problems with weakness, as opposed to altering the weight or his body position to reduce the force transmitted through his wrist.

Outcomes

Patients appeared to have three main outcomes following their fracture:

- Consciously deficient
- Unconsciously deficient
- Return to normal function

Consciously deficient

Patients described being aware that they were either unable to perform a task, or they could only partially perform the task with difficulty. For example, patient 8 described being unable to put weight through his wrist in a flexed position "I can't do nothing …..I can't even hold my own weight up in a press up position". In response to this deficiency patients either avoided the task altogether, as demonstrated by patient 8 who chose to avoid upper body exercises or adapted to these problems.

Unconsciously deficient

Patients transferred to this state as a progression from being consciously deficient. Patients were still either completely unable to perform a task, or unable to perform it in the same manner as before their fracture. However, through adapting their technique, using adjuncts, or exchanging the task for a similar task, patients developed a new sense of normal for their wrist function, whereby they are no longer aware of having a deficit. This was displayed by several patients who initially described their wrist function as normal following their fracture, however, upon prompting, several mentioned having a number of difficulties. Patient 4, initially described her wrist as "absolutely fine", but later mentioned no longer being able to hold heavy saucepans with her injured wrist, and instead preferentially using her normal arm. Patient 6, similarly continued to avoid performing tasks with her injured wrist at the time of the interview and opted for her alternate wrist instead.

Return to normal function

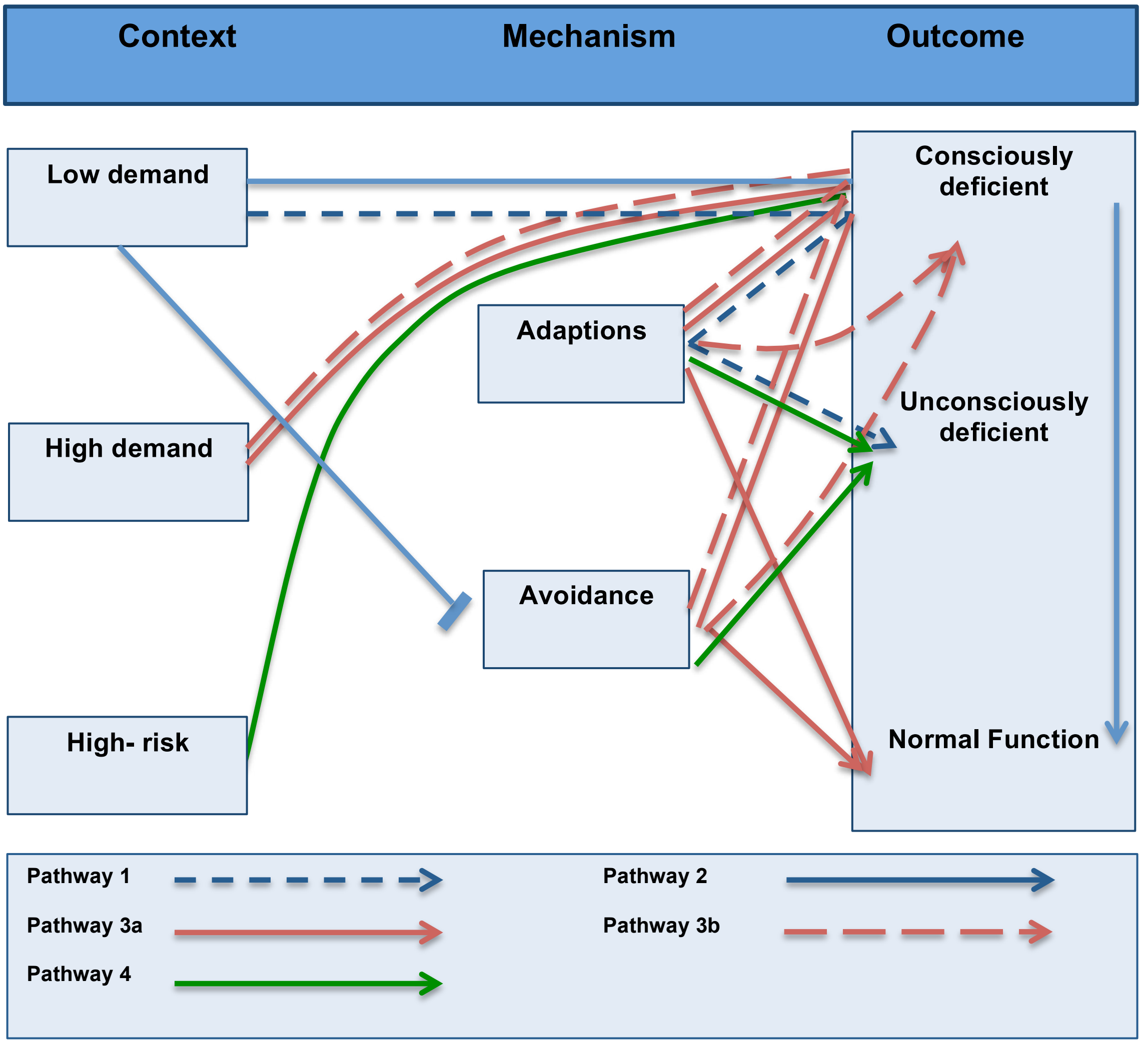
In addition to patients describing problems with their wrist function, most reported at the interview being able to perform some of the same tasks as before their fracture using the same technique, without the need for any adaptions or adjuncts. From the DASH scores, patients 1, 3, 4, 5, 9, 11 and 14, all regained their ability to perform tasks such as preparing meals, opening heavy doors, and turning keys by 12 months following their operative fixation. Patient 5, in particular, also described being symptom free “I don’t get any twinges, pains”. Again, some patients engaged these recovery mechanisms until their wrist was healed and their function had returned to normal.

It is important to appreciate that patients were not restricted to only one outcome. For example, most patients demonstrated normal function when performing self-care tasks, but were consciously deficient in tasks requiring fine motor skills or lifting. Patients also appear to proceed from one outcome to another during their recovery, typically from a conscious deficit to an unconscious deficit, and eventually to normal function.

Patterns derived from the context, mechanism and outcome framework

A number of patterns can be derived from the application of this framework to the themes and subthemes generated in the previous analysis section. These patterns are considered in terms of the categories of patients that would present to orthopaedic surgeons i.e. those performing low demand, high demand and high-risk activities. A schematic representation of these is presented in figures 16 to 19.

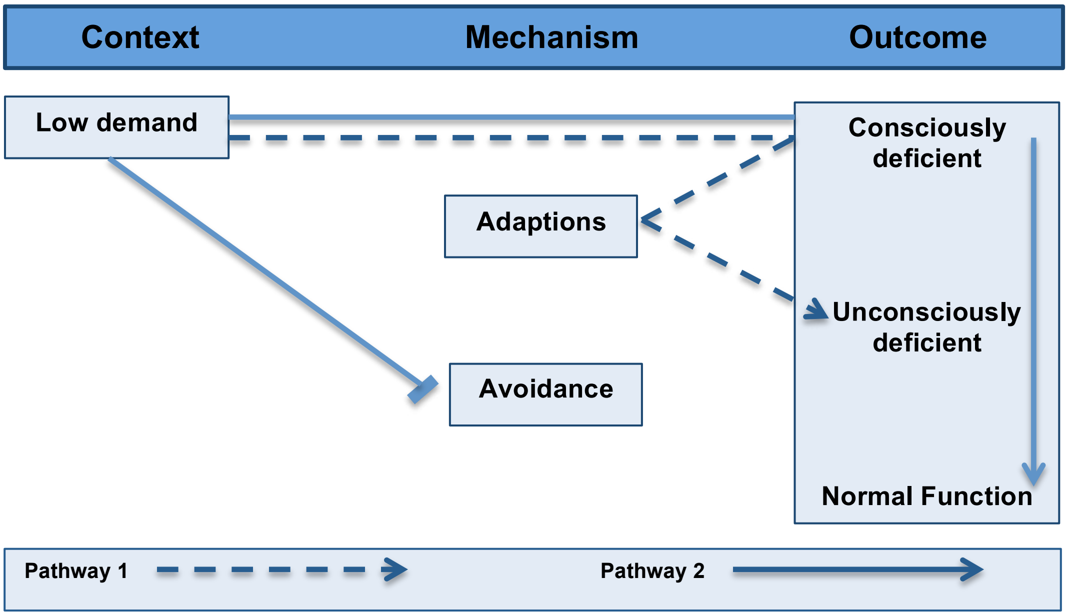
Figure 16 - Summary of all the patterns derived from the context, mechanism and outcome framework



Low demand patients

Patients engaging in low demand activities (n=5) followed two pathways during their recovery, resulting in one of two outcomes, with or without the use of adaptive mechanisms (See figure 17). Importantly, none of these pathways involved the adoption of avoidance mechanisms, which may be due to their lack of high risk and high demand activities in their daily lives. Patients' low expectations, increasing age and concurrent illnesses were all prominent factors affecting their recoveries.

Figure 17 – Recovery pathways of low demand patients recovering from a distal radius fracture



Pathway 1: Consciously deficient to unconsciously deficient using adaptive mechanisms

Patients 7 and 13 often described using adaptive mechanisms such as using their unbroken wrist to a greater extent, or adjuncts to improve their dexterity. Due to their concurrent illnesses and concomitant injuries, they weren't able to confidently decipher whether the limitations they experienced were due to their fracture or other medical problems. Typically, they attributed their limitations to these other problems and older age.

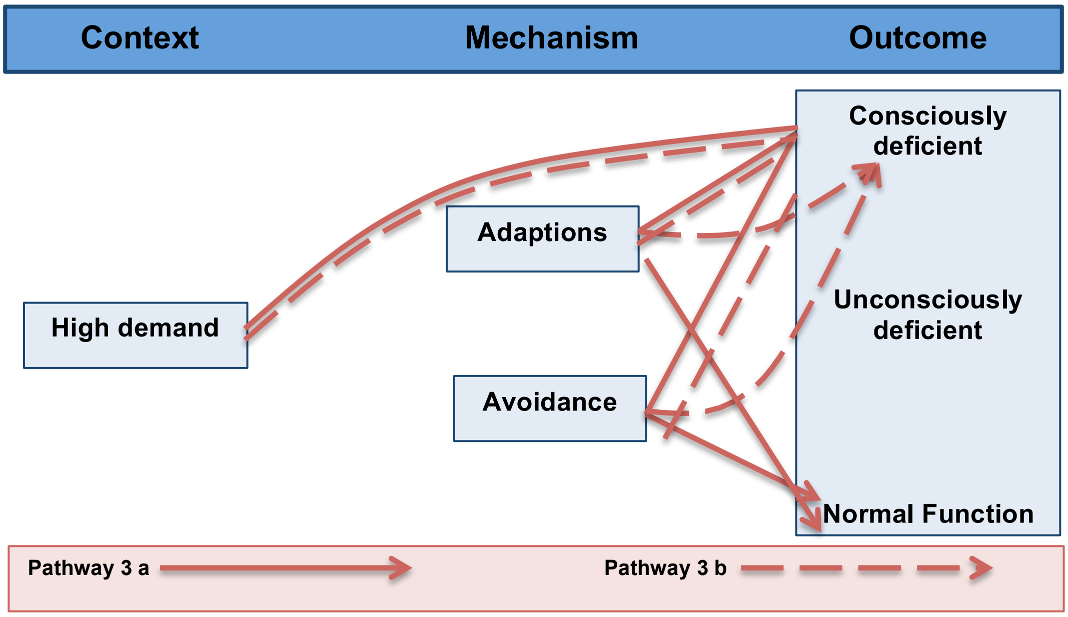
Pathway 2: Consciously deficient to normal function

Patients 3, 10 and 11, described progressing from being aware of their functional deficits to regaining their previous level of function without adopting any coping mechanisms. All of these patients had returned to their baseline PRWE and DASH scores by 12 months following their operations. Interestingly, these patients had either lower expectations for their wrist (patient 3), sustained non-dominant injuries (patient 11), or they had concurrent illnesses (patient 10 & 11), which have altered their perceptions of their function.

High demand patients

The high demand patients tended to adopt coping mechanisms during their recovery, in particular adaptive mechanisms, resulting in either a return to their normal function or plateauing to an improved but deficient state. Apprehension was a prominent feature amongst this group of patients. Their recoveries typically followed the same pathway, but resulted in different outcomes (see figure 18).

Figure 18 - Recovery pathway of high demand patients



Pathway 3: Consciously deficient to an improved consciously deficient state (a) or normal function (b) using adaptive mechanisms

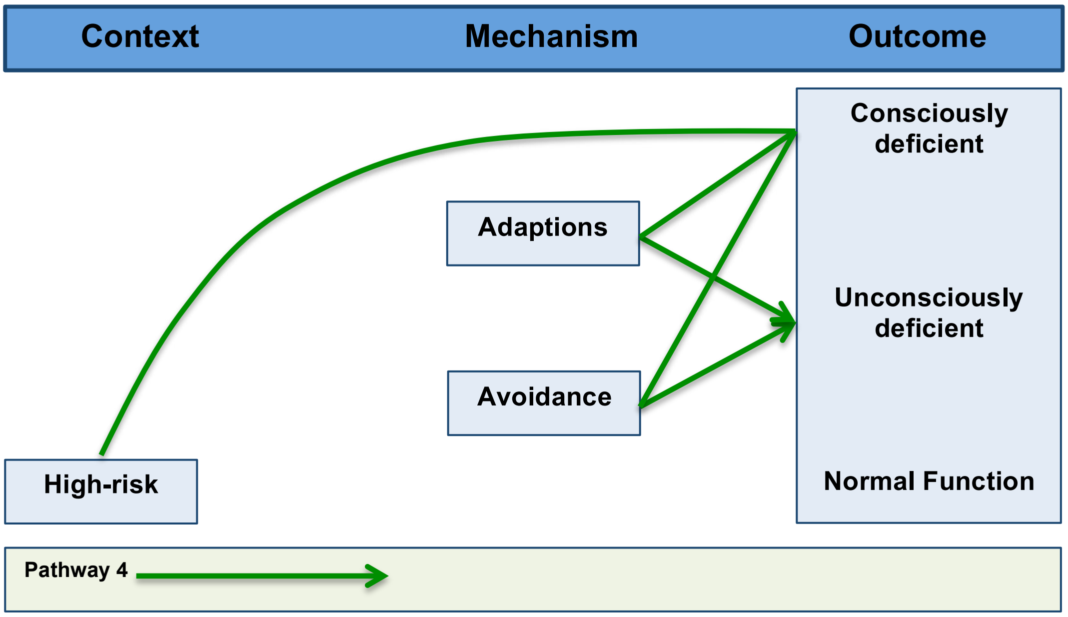
All of the high demand patients demonstrated an improvement in their wrist function, and used coping mechanisms similar to the low demand patients (patients 1,2,4,5,6 and 9), however, they did not all return to their pre-morbid state. Patients 2, 4, 6 and 9 did not achieve their full function, instead, plateaued to a state of improved conscious deficiency, remaining reliant upon mechanisms such as using their uninjured wrist. These patients were younger, female, with a greater level of education, more active and demonstrated a greater degree of apprehension. These patients also sustained their fractures as a result of a high-energy impact. The differences between these groups maybe partly due to a greater ability and willingness amongst the deficient group to articulate their concerns, but also due to differences in their expectations, which was also shown with the low demand group.

One patient (patient 14) in this high-demand group returned to normal function without adopting any coping mechanisms. Unlike the other high demand patients, this patient did not perceive himself to have any problems with his wrist during his recovery. However, based upon his functional outcome scores he had a reduced function in comparison to his premorbid state for the first 6 months, suggesting he was consciously deficient at that time. By 12 months his functional outcome scores had returned to normal. Inconsideration, that he had not mentioned his reduced function early in his recovery, it is possible that he may also have engaged in coping mechanism without necessarily being conscious of performing them.

High-risk patients

The three patients engaging in high-risk activities all adopted the same coping mechanisms, resulting in an improved but still deficient function (see figure 19). Avoidance of the original high-risk activity was particularly prominent in their recovery, either due to a functional deficit resulting from their fracture or as an attempt to avoid further injury.

Figure 19 - Recovery pathway of high-risk patients



Pathway 4: Consciously deficient to unconsciously deficient using adaptive and avoidance mechanisms.

These patients sustained their injuries, whilst pursuing high-risk activities. They progressed from a consciously deficient state, to an improved but unconsciously deficient state, adopting predominately adaptive mechanisms. The avoidance and adaptive mechanisms demonstrated by these patients differ slightly from those shown by other high demand patients. These patients avoided the high-risk activities associated with sustaining their fractures, mainly due to apprehension and their concerns regarding the risk of further injuries, but also due to a perceived inability (patients 6,8,12). As none of the patients attempted all the same high-risk activities following their fracture, it is difficult to ascertain whether their wrist function would have allowed them to participate. Similarly, as well as using adaptive mechanisms such as using their alternate hand to a greater extend, some of the patients chose to participate in high-risk sports, but adopted sports they perceived to carry a lower risk of injury and demand upon their wrist e.g. horse dressage instead of horse jumping (patient 6) or cycling (patient 12).

Multiple recovery pathways

The recovery of patients' wrist function does not necessarily follow a single recovery pathway. Instead it is more likely that patients demonstrate a number of pathways for different components of their wrist function. For example, patient 6 demonstrated several recovery pathways such as a high-risk pathway with coping mechanisms specific to her high-risk activities, and a high-demand pathway with adaptive mechanisms specific to daily tasks such as lifting pans when cooking. Patient 13 similarly followed a recovery pathway with adaptive mechanisms for the majority of her activities, as well as a pathway requiring no adaptions for personal care and low demand household activities.

Clinical application of the findings from the CMO framework

The evaluation of patients' perspectives has generated a number of important findings that can be applied to the practice of orthopaedic surgeons. In addition to demonstrating those patients have persistent symptoms longer than the typical duration of post-operative care. The application of the context, mechanism and outcome framework, has shown that groups of patients respond and perceive their injuries slightly differently, and hence they may benefit from different approaches during their consultations. For example, the low demand group were found to be less aware of problems with their wrists, due to their lower expectations and difficulty with distinguishing problems with their wrist from their old age trajectory and other comorbidities. In order to achieve a return to a pre-morbid level of function, these patients may benefit from a more inquisitive approach in their post-operative consultations to tease out whether their function has improved. Patient reported and physical measures of function may have a role in monitoring these patients in the clinical setting.

In comparison, the high demand and high-risk groups demonstrated a greater degree of apprehension and avoidance, which may hinder their willingness to use their wrists fully. These patients may instead, benefit from more informative and reassuring consultations, to encourage them to return to more of their pre-morbid activities. There may also be a role for specialised rehabilitation, which incorporates a cognitive component for patients who sustained their fracture due to a high impact mechanism. This approach would provide both exercises, as well as attempting to reduce any apprehension and anxiety, which may be acting as a barrier to further improvement in their function.

Discussion

The patients in this study have been shown to have some residual loss of function in their wrist, impacting upon several aspects of their lives for up to 3 years after sustaining their fracture. This loss of function can be broadly classified as either a conscious or an unconscious deficiency, based upon whether patients were aware of limitations in their function. The impact of this loss was found to vary with patients' wrist demand, their hand dominance, the presence of concomitant illnesses and injuries, and changes associated with the ageing process. Patients with a higher demand for their wrist function or a dominant injury tended to report more symptoms and lifestyle changes as a result of their fracture. The low demand group in comparison often reported a return to 'normality' with little alteration in their previous lives. This group, however, were subject to changes associated with the ageing process and concomitant illnesses hindering their ability to disentangle these changes from those that had resulted from their fracture.

Patients' accounts of the consequences of their fracture tended to focus upon their functional limitations, in particular difficulties with loss of dexterity, reduced strength and restricted movement. A number of patients also described increased apprehension both with activities that had resulted in their fracture and with those they considered may entail a risk of re-fracture e.g. uneven or slippery surfaces. Patients regularly engaged in avoidance and adaptive mechanisms during their recovery in order to cope with deficiencies in their function. Through the use of adaptive mechanisms, the majority of patients were able to return to their prior activities through adaptations of both their technique in performing the task or with the task itself. These adaptations had often become so engrained in patients lives that some developed a new sense of "normality' becoming unconsciously deficient to such an extent they often required prompting to recall their adaptions.

The CMO framework used in this analysis provides an important insight into not only what outcomes arise from an intervention, but provides some explanation for how that outcome comes about and for which patients(403). In contrast, standard tools for measuring function, such as patient reported and physical measures of function, only provide data about patient outcomes. This data might be misleading for patients displaying adaptive mechanisms, since they may develop alternative ways of performing tasks to compensate for their persistent impairment, resulting in falsely elevated scores. For example, a patient may report being able to get out of a bath, but they may only achieve this by getting into a kneeling position to stand instead of putting their weight through their wrist. However, it might be that the PROMs are identifying that patients' deficits are not important to them, and the CMO analysis provides an explanation for the lack of a greater correlation between physical and patient reported outcome measures.

In this study, the CMO framework, allowed the detection of clinical relevant patterns for the recoveries of these patients. Broadly, discernible patterns were detected between patients with a low functional demand, and those with a high functional demand who may also participate in high-risk activities. Clinicians have been shown to use pattern-recognition in the formulation of their decision(94, 107). Patients' signs and symptoms are perceived as cues, which the clinician compares against examples of this type of patient they have generated from their previous experience(94, 107). These patterns could, therefore, be used by orthopaedic surgeons to alter their approach in consultations towards specific groups of patients, to improve patients' engagement in their recovery, and hence drive clinical improvements. Overall, this analysis provided an understanding of how groups of patients regained their ability to perform specific tasks, and some of the reasons for differences between them. It did not, however, explain how patients regained specific aspects of their function such as strength and dexterity that could be beneficial to the rehabilitation of others. This was particularly noticeable for patients who had a return to their normal function, since the coping mechanisms allowed patients to carry out tasks but were not necessarily responsible for regaining specific aspects of the patients' function such as strength and dexterity.

Comparison with other studies

The functional outcome of patients following operative management for a dorsally displaced distal radius fracture with either a volar locking plate or Kirschner wire fixation, has been previously considered for up to 12 months following the injury(70, 207, 281). Few studies have included patients who were followed up after 12 months, however they have not specifically assessed patients at 2 years and beyond(70, 408). Patient reported and physical outcome measures have typically been used to capture the functional status of the patients, with only one study providing a qualitative assessment of patients with a variety of wrist disorders, of which a proportion of patients had sustained a distal radius fracture(70, 207, 281). The functional outcomes of patients were similarly found to improve over the course of the year with both interventions(70, 207, 281). These studies fail to specify what specific limitations patients have experienced, and whether there is a tendency towards certain limitations with particular groups of patients. Bialocerkowski's assessment of patients with a wrist disorder, provides the only account specifying patients' limitations with respect to their personal care, recreational activities, work and domestic duties(173). Similarities with this study were found with respect to wrist weakness and difficulty when performing activities requiring fine finger movements. However, Bialocerkowski reported pain significantly contributed to patients' difficulty when performing domestic and personal care activities(173). Additionally, a significant proportion of these patients experienced difficulties both in work activities and were unable to perform a greater range of activities in comparison to this group(173). Other than the role of hand dominance, which was found not to be significant, no distinction was made between the demand of the patients and their functional limitations nor the role of other concomitant injuries(173). The differences in comparison to this study are mostly likely due to the breadth of wrist disorders included in Bialocerkowski's study with no indication of the number, severity, duration of symptoms or management of the patients with a distal radius fracture(173).

The differences in the experiences and perceptions of patients, and the development of a new sense of 'normality' through acceptance and the use of compensatory mechanisms, although not present in orthopaedic literature has been widely considered in sociological studies for numerous chronic conditions such as stroke, rheumatoid arthritis and diabetes(409, 410). Parsons (1951) first introduced the concept that illness can be considered a socially and biologically altered state, suggesting patients take on a 'sick role'; a socially acceptable role where they are devoid of responsibility for their normal obligations and illness(411). This was further built upon by Mechanic and Volkart, who went on to suggest patients adopt 'illness behaviours' shaped by social factors such as their education, social class etc(412). These 'illness behaviours' were described as the ways in which patients perceive, evaluate and act upon their symptoms. For example, in a study of socioeconomic variations in the perceptions and behavioural responses to chest pain, patients from deprived areas considered themselves to be more vulnerable to cardiac disease yet tended to present less frequently with chest pain than those from affluent areas(413). Similarly gender was also found to be associated with variations in patients' illness behaviours in response to chest pain(414). In this study, gender differences arose in patients' willingness to discuss their apprehension when returning to their prior activities.

Ageing and concomitant illnesses may act as a further source of variation in patients' behaviours as seen in this study; through the acceptance of poor health as part of the ageing process and secondly by evoking difficulty in disentangling the impact of the illness under consideration with concomitant illnesses(415, 416). Faircloth *et al* supports this view, suggesting illness is experienced differently amongst patients, and may not necessarily be a 'biographical disruption' involving a catastrophic event as described by Bury(410, 415). Instead, the onset of an additional illness may form part of an ongoing 'biographic flow'(415). Osteoarthritic patients for example relate this disorder to being synonymous with increasing age, hence elderly patients affected by osteoarthritis accept their condition as part of their normal ageing trajectory(416). Ageing patients often have a number of comorbidities already impacting upon their lives to such a point that they are unable to distinguish from where their difficulties arise(415). Faircloth uses the example of a stroke patient who requires a wheel chair for the combined effects of their stroke, Parkinson's disease and visual impairment, to illustrate this difficulty with disentanglement(415). However, concomitant illnesses may not necessarily affect solely the elderly, Faircloth again provides an example of a younger stroke patient with diabetes and deteriorating vision(415). In this example, the stroke is seen as a secondary concern to the patient, that will 'unfold' in relation to the diabetes, and instead the diabetes and deteriorating vision are of greater importance(415).

Differences in the perceptions of patients in this study often corresponded to the adoption of compensatory mechanisms to maintain their prior quality of life and activities. Bialocerkowski similarly found patients with a disorder of the wrist adopted mechanisms such as opting to use their alternate wrist, or other parts of the body to perform the task or engaging those around them(173). These adaptive tendencies have also been shown with stroke patients, with the modification of their prior activities or the involvement of others such as health and social services to assist them in achieving their given task(417). Through the adoption of these mechanisms some patients in this study developed a new sense of 'normality.' Bury suggests patients with chronic illness adapt through three distinct mechanisms; coping, strategy and style(418). Coping refers to a cognitive change; patients learn to tolerate their illness or in this case their impairment, hence developing this new sense of 'normality'. Strategy encompasses the actions taken by individuals, such as opting to use the alternate wrist shown in patients with wrist disorders(173, 418). Lastly, style, the way in which patients present their illness or their perceptions, which we have seen can alter with various social factors(418). Patients' adaptions to their illnesses or injuries are not always useful for aiding their recovery. Mehta *et al* suggests that patients who go on to develop chronic pain and disability from their fracture, display negative cognitive behaviours and features of learned helplessness(419). Some of the patients in this study were also shown to adopt some of these behaviours described by Bury in their development of a new sense of normality(418).

Study strengths and limitations

This study provides the only account of patients' long-term functional status following a fracture of the distal radius, with the inclusion of both functional measures used in orthopaedic literature in conjunction with an exploratory assessment. Previous studies have tended to focus upon the use of functional measures and the radiological outcome typically up to 6 – 12 months post-injury, often to compare treatment effects. No consideration has been given previously to the role and extent of compensatory mechanisms used by patients during their recoveries to enable them to perform their usual activities. Through the use of the CMO framework, it has been possible to begin to discern some of patients' recovery pathways. However, due to the limited diversity and relatively small sample of patients, there may be other pathways that might have been apparent if a greater number and type of patients had been recruited. In addition, it is possible that alternative mechanisms might have been missed due to the timing of the data collection, the lack of further interviews, inexperience and a lack of guidance for the application of this framework. Data collection at multiple stages of patients' recoveries may have identified subtle mechanisms patients are unable to recall at 1-3 years after their injuries, as well as allowing the proposed CMO configurations to be refined. Additionally, the CMO framework remains a relatively new analysis for the assessment of complex interventions with limited guidance for its application(420). It is possible with increasing application of this framework greater guidance will be available for identifying alternative mechanisms.

The findings of this study may also be limited by the selection and recruitment of patients, with certain patient groups under-represented. The first of these groups is the elderly low demand patient group with mobility difficulties and multiple-comorbidities, requiring assistance with self-care and other activities of daily living. This patient group comprises of a significant proportion of individuals sustaining this type of fracture. Although, interviews were undertaken with low demand elderly patients, comparatively, they were still independent in regards to their self-care and were currently residing in their own homes with minimal assistance. The needs of these two elderly patient groups may differ with dependent elderly patients possibly under-represented in this sample.

Prior studies, of operatively and non-operatively managed elderly patients suggest that anatomical restoration of the distal radius does not result in a functional improvement for the patient(51). In this study, the elderly patients found it difficult to distinguish between changes resulting from old age and those relating to their fracture, which may explain why a difference in function could not be detected between operative and non-operative management in previous studies. It is possible that similar findings may also be demonstrated in a patient group with a lower degree of function with multiple comorbidities further 'clouding' their perception of their recovery.

The second patient group to be under-represented were the young men, who typically sustain high-energy injuries due to sporting and road traffic collisions. In the DRAFFT trial, only 4% of the patients presenting to University Hospital Coventry and Warwickshire, were male and under 50 years old. In this study, two men under 50 years old were recruited, of which only one was under 30 years old and hence representing younger men. Although proportionally this corresponds with the number of young men recruited to the DRAFFT trial. The perceptions of one patient cannot necessarily represent those of all young men, especially as this patient had sustained multiple-injuries and as a result was assessed separately from the other study patients. A sampling strategy instead based upon recruiting patients presenting to the University

Hospital Coventry and Warwickshire, but not as part of the main DRAFFT trial may have provided a greater representation of both these patient groups.

The entire patient group may also pose a threat to the external validity of this study, as all the patients in this study were recruited from the DRAFFT trial and had undergone operative fixation. Therefore, these patients may not be representative of those who chose not to participate in clinical trials or received non-operative treatment. Patients who choose to enter clinical trials have been found to display different traits and behaviours to those that have not. Several studies have investigated patients' motives for participating in clinical trials, and found they are motivated by a complex interplay of help-seeking, self-managing and altruistic behaviours(421-423). This help-seeking behaviour was seen in the United Kingdom prospective diabetes study (UKPDS), with patients found to participate in the study due to a desire for better care and a reduction in their risk of illness(424). This therapeutic misconception, whereby patients are under the mistaken belief that the treating clinician will always act in their best interest to their advantage, instead of also acting in the interest of the trial, has been described in numerous other trials(425, 426). Although, this has been described as a misconception, patients have been shown to receive better care as part of trial participation. Participants in the UKPDS, described how they received more personalised care and felt more reassured by the multiple appointments during the trial, in comparison to when they returned to normal care(424). Therefore, patients' perceptions to those treatments may not necessarily be the same as if they were part of normal care.

Conversely, patients who decline to participate in trials, do so either because they have strong views regarding their treatment, or they consider the practical inconvenience of participating in the trial outweighs the potential benefits. Patients declining to enter an exercise intervention trial for patients with breast cancer, were found to be older with multiple comorbidities, living alone, and have a long travel time to the research setting(427). For these patients, it is clear to see how participating in a trial would be difficult. This does, however, mean an important group of patients may be routinely missed from clinical trials, as well as explaining the under-representation of these patients in this study.

Patients' perceptions have also been shown to vary with the treatment modalities available to them(428, 429). A survey of patients suffering from neck and back pain in a US population demonstrated a greater preference and expectation of helpfulness for complementary treatments in comparison to conventional treatment(428). Similarly, Nyvang *et al* found patients with osteoarthritic knee pain perceived pharmacological treatments to be associated with a risk of side effects, whilst they expected total knee arthroplasty to restore their function as well as relieving their pain(429). These differences could mean that as patients in this study have only undergone operative management, their perceptions may differ in comparison to those undergoing non-operative management.

Limitations can also be detected within the patient interviews. A single interview was conducted with each patient, meaning that there was no opportunity to further probe patients about their meanings following analysis of the first interview or to check their responses. For example, when patient 004 describes how she has adapted to her injury she mentions: "you find interesting ways of holding things and opening jars", a follow on interview would have provided the opportunity to clarify what these other 'ways' are and how often she needs to use these adaptions in her daily life. A phone interview could have provided a simple and less intrusive method for allowing either further probing or cross-checking of responses to be undertaken that might also be agreeable to the patient. Additionally, a follow up interview could also be guided by interesting findings from the functional outcome measures; the DASH score for patient 007 for example was lower at 3 months than at 6 months, whilst for patient 013 the DASH score decreased from 3 to 6 months but increased significantly at 12 months. Another interview would therefore allow the patient to expand upon their answers from specific questions in the outcome measures. However, considering these interviews were performed at 1 to 3 years following their injury they may struggle to recall these subtle differences. Instead, interviews could have been conducted at time points corresponding to the collection of the outcome measures or the patients could have been asked to complete the patient reported outcome measures again in the month prior to these interviews to allow a direct comparison of the long term effects of the fracture. The decision not to send transcripts to patients, may also provide a further limitation of the interviews. Patients were provided with a contact telephone number to allow them to offer further information, either as an addition or a clarification to their original interviews. However, by not sending the transcripts their accuracy with regards to the patients' perceptions was not assessed.

Although the themes generated from these interviews were discussed with a senior researcher, a formal review process by an independent researcher was not undertaken. Therefore, the final themes generated were instead based upon my own interpretations. As an orthopaedic doctor with prior experience of patients with a fracture of the distal radius, it is likely that the generation of these themes may have been influenced by any preconceived ideas I had previously developed. Instead, an experienced researcher without either orthopaedic training or a prior interest in distal radius fractures might have checked these themes, hence avoiding this potential risk of bias. Additionally, these themes were not analysed with respect to social factors such as the patients' socioeconomic status, level of education or religious beliefs, which may have offered additional explanations for the differences in patients' perceptions and actions.

It is also possible that the patients' accounts of their fractures may have been influenced by my dual role as both a researcher and orthopaedic doctor. Earlier in the treatment of some of the patients, I was involved in the recruitment and follow up to the DRAFFT trial and functional outcomes study, often acting as a point of continuity during their first year post-injury. This may have prompted patients to respond by either divulging details about their wrist they had previously not mentioned to either the trial or medical team, or conversely prompted them to withhold the severity of their symptoms.

Implications for policy, practice and future research

Implication for policy

Although patients with a fracture of the distal radius have been shown to improve with orthopaedic intervention, full function is not necessarily regained by 3 years post-injury. Instead, some patients are hindered by a degree of functional limitation requiring the adoption of compensatory mechanisms to maintain their previous quality of life, or in extreme cases prompted the discontinuation of prior activities.

These findings suggest that there may be a role for further rehabilitation beyond the exercise sheets provided at the final 6-week post-operative appointment. A recent Cochrane review of rehabilitation of these patients, however, concluded there was insufficient evidence to determine the efficacy of various interventions for improving patients' outcomes(430). Therefore, in view of the limited evidence available, policy cannot be altered at present, with regards to recommending a specific post-operative rehabilitation regime.

Implications for practice

Even though policy cannot be altered, there are still implications for the practice of orthopaedic surgeons when consulting patients with a distal radius fracture. Patients' expectations have been shown to impact upon their level of satisfaction and functional outcome for a number of musculoskeletal procedures, including lumbar spine surgery(431, 432). It is important to address patients' expectations, not only to ensure informed consent is attained, but also to make sure those expectations are realistic with regards to the patients' prognosis. Therefore, patients should be advised that although the majority of patients see an improvement in their wrist function, some will continue to have problems with pain and functional deficit for up to 3 years following their operation. Patients may benefit from being given this information at their preoperative and 6-week post-operative consultations. In addition to addressing patients' expectations, this study suggests some patients may also benefit from a more inquisitive approach during post-operative consultations, such as elderly patients, to ensure they do not have a persistent impairment that might be amenable to further treatment.

Implications for future research

A number of potential research avenues have been highlighted as a result of this study. The most important of these avenues is to explore of the consequences of these fractures at 10 years or longer post-injury, in order to determine whether some patients' symptoms persist, and to detect the development of early osteoarthritis. Current literature has only considered patient outcomes up until 7 years post-injury, with the majority of clinical effectiveness data focused upon the outcome of patients at 6–12 months(278, 315). A larger study using both qualitative and quantitative research methods would allow the assessment of a larger group of patients, with a greater consideration of the specific implications to individual patients, and the potential detection of alternative recovery patterns.

Additional research avenues could include addressing patient-surgeon consultations pre- and post-operatively to ascertain whether patients' expectations of their fractures are addressed during consultations. This could be achieved through the observation of patient consultations, and by undertaking patient interviews. Further studies could then be undertaken to assess the impact of altering surgeon consultations so that patients' expectations are met, for example, by using decision-making tools, upon patients' short-term and long-term outcomes.

Conclusions

Declarations

None

In these final conclusions the aims of this thesis have been revisited. The main findings and the limitations upon those findings are summarised, allowing consideration of the patients' journey as a whole and how patients' care can be improved.

Review of the thesis aims

The overall aim of this thesis was to explore patients' care when undergoing operative management for a dorsally displaced fracture of the distal radius. Each stage of this journey has been considered, encompassing the patients' definitive surgical management, their post-operative assessment and finally their long-term recovery.

The first stage of patients' orthopaedic care typically commences in the fracture clinic, where the surgeon decides upon definitive treatment in consultation with the patient. Variation has been shown to exist in the management of these patients arising from this first stage of the patients' journey. In order to understand this variation in operative rates and to improve patient care, the processes involved in surgeons' decision-making when deciding upon operative management, and the factors influencing their decisions were explored in chapter 2 using a mixed methods approach. Variation was detected in the management of clinic patients and the clinical vignettes, with a number of potential influences upon their decisions identified, providing a basis for further studies. After the surgeon and patient decide upon operative management, the surgeon must then decide what operation to perform. In chapter 3, a systematic search and appraisal of the literature available to inform surgeons decisions was performed, assessing the functional outcome of two commonly performed operative procedures (volar plate fixation and percutaneous wire fixation) in the UK with validated patient reported outcome measures. Evidence was available from several randomised controlled trials of varying quality to make this assessment.

The next stage in the patients' journey is the assessment of their post-operative wrist function, in order to detect potential complications and to inform clinical trials assessing the efficacy of different operations. The radiological and functional outcome of the patient can be measured in the outpatient setting. The physical assessment of the patients' function can be assessed using both manual and electronic equipment. In chapter 4, a reliability study was performed to determine whether manual and electronic equipment are both able to reliably measure patients' physical outcome and hence whether electronic equipment, which displays greater modality, can be used in the research setting. An observational study was then performed in chapter 5, using the electronic equipment to assess the strength of association between the physical and patient reported measures of function, and the radiological outcome. This preliminary study is in agreement with other exploratory studies, indicating the need for resources to be allocated to perform a larger scale explanatory study.

Patients' recovery beyond 12 months after their operation is often poorly considered in the literature, despite the persistence of symptoms for some patients. This final stage of the patients' journey was considered in chapter 6, with an exploration of patients' perspectives of the long-term consequences of their fracture. Insights were gained into the impact of the fracture upon the patient and patterns were discerned for how these patients recovered, which may be clinically relevant to the practice of orthopaedic surgeons.

Limitations

Before considering the main findings of this thesis, it is important to address some of the potential limitations upon those findings. The use of patients from the DRAFFT trial was a common limitation for the studies performed in chapters 4,5 and 6. The Medical Research Council (MRC) has advocated the embedding of multiple studies within larger trials in order to allow the better use of resources(433). This thesis attempted to abide by the MRCs advice by inviting patients recruited into the DRAFFT trial to participate in the studies assessing patients' post-operative outcomes. Patients participating in trials can differ from those who choose not to participate, typically displaying less extreme views, a greater degree of altruism, and the belief that they will benefit from participating in the trial(421-423). Regardless of whether participants were recruited from the DRAFFT trial or from the general population, the risk of selecting atypical patients would remain a possible limitation as patients are still being recruited into a research study.

The small number of participants and the lack of diversity amongst them was another potential limitation common to several studies. Attempts were made to sample patients and healthy volunteers over a prolonged period of time and from a variety of settings. Time and resource constraints meant that recruitment could not be prolonged further, however, due to the exploratory nature of these studies they still provide useful preliminary data to base future studies upon.

The final significant limitation upon the findings of this thesis is with regards to the study procedures in particular for chapters 2 and 4. These studies were designed based upon the methods adopted in prior studies. Through the undertaking of these studies a number of improvements to future studies were detected, for example, reducing the number of tests performed, increasing the rest period between tests, and reducing the number of vignettes discussed in surgeon interviews.

Summary of thesis findings

The exploratory work undertaken as part of this thesis has led to a number of findings contributing to our current understanding of the management of distal radius fractures under the care of orthopaedic surgeons.

The processes involved in surgeons' decision-making when deciding upon the patients' definitive treatment were found to be complex, involving a series of key decisions based upon the patients' presenting radiographs, and refined in view of factors inherent to the patient and the surgeon, such as the patient's age, functional demand, anaesthetic risk and the surgeons' area of expertise. Variation was detected in surgeons' decisions when deciding upon the management of clinic patients and vignette cases, suggesting surgeons' have different thresholds for their decisions. These findings are in keeping with the information-processing and Bayes theorem decision-making models, and Wennbergs and Chasis's theories on the influence of surgeon factors upon their decision-making in the absence of sufficient clinical evidence(92, 94, 194, 221).

The review of the literature in chapter 3 comparing the functional outcome of patients treated with a volar locking plate fixation in comparison to percutaneous wire fixation, identified 812 studies of which 6 met the pre-specified eligibility criteria(70, 207, 278, 281, 311, 312). All of the studies were randomised controlled trials of varying size and quality. The patients' functional outcome was assessed with the DASH, PRWE, EQ5D, and Herzberg scores, the maximal grip strength and range of motion of the wrist and forearm(70, 207, 278, 281, 311, 312). A small treatment effect was detected in favour of plate fixation in patients with predominately A2, A3, C1 or C2 type (AO muller classification system) fractures(70, 207, 278, 281, 311, 312). However, this treatment effect is of insufficient magnitude to be likely to confer a clinically relevant difference to patients.

In chapter 4, as part of the assessment of patient monitoring, the reliability of the electronic and manual dynamometers and goniometers were compared. Both dynamometers demonstrated excellent inter and intra-rater reliability for patients and healthy participants, comparable with previous studies(346, 347). The inter-instrument reliability was excellent for the assessment of the maximal grip and pinch strength, but poor for the grip fatigue, suggesting these dynamometers may not be interchangeable for that modality. In contrast, the inter- and intra-rater reliability of the manual and electronic goniometers was only poor to acceptable. Prior studies using predominately healthy participants demonstrated greater ICC values conferring acceptable reliability with manual goniometers, except for one study showing a variable reliability(121, 122, 324). The inter-instrument reliability, however, was acceptable for all planes of motion.

On the basis of these findings the electronic equipment was used in the correlation study.

In chapter 5, the physical and patient reported measures of function were found to correlate poorly with the radiographic parameters, with only a limited number of weak correlations detected between the palmar tilt at 6 and 12 months, the PRWE score at 3 months and the pinch strength, and wrist flexion at 12 months. The ulnar variance was found to correlate with only wrist flexion at 12 months. Several studies have similarly found either no correlation or only weak correlations between the functional and radiological outcome in agreement with this study(66, 392). This study indicates there is minimal association between the patients radiological and functional outcome, however, it is not possible to determine the causality of the relationship, and instead a larger explanatory study would need to be performed.

Lastly, patients' long-term perspectives explored in chapter 6, demonstrated that although patients' function improved in the post-operative period, a number of patients continued to have some residual loss of function impacting upon their lives up to 3 years following their initial injury. Prior observational studies have also shown that a small number of patients have severe pain and impaired function at 1 year after their fracture(186, 402). A number of recovery patterns were detected through the application of the CMO framework. Patients were found to transfer from an awareness of limitations in their function, to an improved but still deficient state of which they were either aware or unaware, or they returned to their pre-morbid function. During this transition some patients adopted adaptive and avoidance mechanisms, allowing them to maintain their previous level of function. One prior study has also shown that patients adoption of adaptive but not avoidance mechanisms after an impairment to their wrist(173).

Implications for policy, practice and future studies

The findings of this thesis have several implications for the practice of orthopaedic surgeons and policy makers, and for the direction of future work. Disparity has been detected in the operative management of patients with a distal radius fracture in this thesis and prior studies, indicating the need to improve the uniformity of orthopaedic surgeons' decision-making. NICE guidance has been introduced since this variation was detected to assist surgeons in deciding which patients require an operation. This guidance is, however, limited in regards to which patients would specifically benefit from operative management. Good quality clinical trials assessing operative versus non-operative treatment options for these patients of sufficient size to allow a subgroup analysis is required to provide surgeons with stringent guidance to base this decision upon. In the presence of this guidance, surgeons' will be less likely to be influenced by factors that are not directly related to the patient or their fracture.

The synthesis of the evidence provided in the systematic review, is important for the refinement stage of the surgeons' decisions when they decide upon the specific type of operative management. Both the volar locking plate and percutaneous wire fixation were found to improve the functional outcome of patients, with only a small and clinically indiscernible difference in the treatment effects. In consideration of this evidence, the cost implications of each treatment and patients' preferences should contribute to surgeons' decision to a greater extent.

The findings in chapter 4,suggest both the electronic and manual dynamometry display equivalent reliability for the post-operative assessment of these patients, and highlights the need to be cautious when interpreting the assessment of the range of wrist motion using either goniometer. Further reliability studies would need to be performed assessing solely the range of motion during a testing session to either confirm or refute the findings in this thesis. Similarly, based upon the exploratory data from chapter 5, further explanatory work is also required to assess the causality of the relationship between the functional and radiological outcome. This could contribute to the evidence supporting surgeons' decisions regarding what type of operation to perform.

The persistence of symptoms beyond 12 months after the patients fracture, and the use of adaptive and avoidance mechanisms detected in the final chapter, has implications for the post-operative rehabilitation of these patients and for surgeons' decision-making. These findings are suggestive of a possible role for post-operative rehabilitation, which would need to be supported with clinical effectiveness data from future trials. In regard to surgeons' decision-making, improvements could be made, by addressing patients' expectations of their post-operative wrist function and by tailoring their consultations in consideration of the recovery patterns detected in this study. Further studies would need to be performed to identify the presence of other recovery pathways that may not have been detected in this study.

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Appendices

Appendix 1 – Patient interview schedules

Demographic information									
Participant Identification Number									
Date of Birth									
Gender	Male		Female						
Ethnic Background									
Asian		Black		Chinese		Mixed		White	
Occupation									
Association professional/ technical occupations		Professionals							
Administrative/ secretarial		Skilled trades							
Personal Services		Sales/ Customer services							
Process/ Plant/ Machine operatives		Elementary occupations							
Unemployed/ Retired/ Looking after home									
Further Details									

Fracture information				
Dominant hand	Right		Left	
Hand injured	Right		Left	
Date of injury				
Mechanism of injury				
Low impact injury (fall from standing height or walking)		High impact injury (fall from >2m high, sports injury or road traffic accident)		
Further Details:				

Medical History									
Comorbidities									
CVA		Heart failure		Angina		HTN		MI	
Renal failure		Liver failure		IDDM		NIDDM		Asthma	
Osteoporosis		COPD		RA					
Other:									
Smoking									
No		1-10 per day		11-20 per day		>21 per day			
Alcohol intake									
0-10 units per week		11-20 units per week		>21 units per week					

Level of Independence					
Mobility					
Walks unaided		Walks with walking aid (stick or frame)		Immobile	
Self care (washing, dressing, personal hygiene)					
Independent		Carers required for all self care activities		Requires some assistance	
Activities of Daily Living (Housework, hobbies, work)					
Able to perform ADLs		Requires some assistance		Unable to perform ADLs	
Further details:					

Appendix 2 – Anonymised observation schedule

Wrist Fracture Management Study – Observation Schedule
V 1.0 08/04/2013 1

Observation Schedule

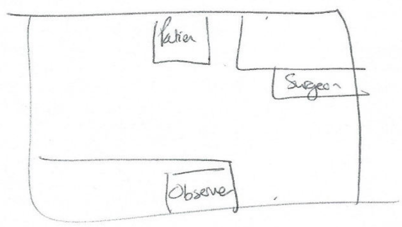
Participant information				
Patient details				
Patient identification number	002.			
Patient Consented	Yes	✓	No	
Surgeon details				
Surgeon identification number	003.			
Surgeon Consented	Yes	✓	No	
Gender	Male	✓	Female	
Seniority (years since qualified from medical school)	Under 20years		20 years and over	
Year of graduation				

Subspecialty							
Upper limb	✓	Lower limb		Pelvic		Spinal	
Trauma		Paediatrics		None – in training			

Observation details				
Date	16/01/14			
Time	Observation commenced	10 38	Observation completed	10:41
	Duration of observation		(Minutes)	
Location	UHCW	✓	Rugby St Cross	

Consultation room setting:

Please indicate the location of the patient, surgeon and observer in the consultation room.



Surgeon – patient relationship
Body Language. → Surgeon facing patient & making eye contact. → close proximity. Ensured patient understood the injury. Picked up on verbal cues Showed reassurance & empathy when patient describing themselves as "lucky"

Information sought by the surgeon and offered by the patient (denoted by S and P in text for surgeon and patient respectively)
How accident occurred? – fall Discussed fracture configuration & management of the patient. Sensation to hand. ~~Ab~~ Examined the patient Discussed sequelae of the fracture. S - Asked about ~~fall~~. wrist #. P – Informed surgeon - due to a fall - slipped over whilst shopping.

Sequence of events during the consultation
(1) Looked at Xray (2) History (3) Examination. (4) Discussed management of the case and potential problems.

Unexpected events during the observation
None.

Appendix 3 – Search Strategies

MEDLINE (OVID)

1. Colles' Fracture [Mh]
2. Radius Fractures [Mh]
3. Wrist injuries [Mh]
4. (distal adj radius$ adj fracture$).mp.
5. (wrist adj fracture$).mp.
6. (colles adj fracture$).mp.
7. Orthopedic Fixation Devices[Mh] or Fracture Fixation[Mh], Internal[Mh] or Fracture Fixation[Mh]
8. Internal Fixators[Mh] or External Fixators[Mh]
9. Bone Wires[Mh]
10. Bone Plates[Mh]
11. kirschner.mp.
12. wire fixation.mp.
13. volar locking.mp.
14. locking plate.mp.
15. 1 or 2 or 3 or 4 or 5 or 6
16. 7 or 8 or 9 or 10 or 11 or 12 or 13 or 14
17. 15 and 16
18. Randomized controlled trial.pt.
19. controlled clinical trial.pt.
20. randomi?ed.ab.
21. random$.ab.
22. trial$.ab.
23. placebo.ab.
24. drug therapy.fs.
25. groups.ab.
26. 18 or 19 or 20 or 21 or 22 or 23 or 24 or 25
27. exp animals/ not humans.sh.
28. 26 not 27
29. 17 and 28

MEDLINE - In-Process & Other Non-Indexed Citations (OVID)

1. (distal adj radius$ adj fracture$).ti,ab.
2. (wrist adj fracture$).ti,ab.
3. (colles adj fracture$).ti,ab.
4. (distal adj radial adj fracture).ti,ab.
5. ((bone or locking) adj plate).mp.

6. ((external or internal) adj fixat$3).mp.
7. (bone or kirschner or kapandji).mp.
8. wire$.mp.
9. 7 and 8
10. 1 or 2 or 3 or 4
11. 5 or 6 or 9
12. 10 and 11

EMBASE (OVID)

1. wrist fracture[Mh]
2. Colles fracture[Mh]
3. radius fracture[Mh]
4. (distal adj (radius or radial) adj fracture).ti,ab.
5. 1 or 2 or 3 or 4
6. fracture fixation[Mh] or fixation device[Mh] or fracture external fixation[Mh]
7. external fixator[Mh]
8. internal fixator[Mh]
9. internal fixation.mp.
10. bone plate[Mh]
11. volar plate fixation[Mh]
12. plate fixation[Mh]
13. wire fixation[Mh]
14. Kirschner wire[Mh]
15. bone wire[Mh]
16. volar locking plate.mp.
17. 6 or 7 or 8 or 9 or 10 or 11 or 12 or 13 or 14 or 15 or 16
18. 5 and 17
19. clinical trial[Mh]
20. randomized controlled trial[Mh]
21. randomization[Mh]
22. single blind procedure[Mh]
23. double blind procedure[Mh]
24. crossover procedure[Mh]
25. placebo[Mh]
26. randomi?ed controlled trial$.tw.
27. rct.tw.
28. random$.mp. and allocate$.tw.
29. (allocate$ adj2 random$).tw.
30. single blind$.tw.
31. double blind$.tw.

32. ((treble or triple) adj blind$).tw.
33. placebo$.tw.
34. prospective study[Mh]
35. or/19-34
36. case study[Mh]
37. case report.tw.
38. abstract report[Mh] or letter[Mh]
39. or/36-38
40. 35 not 39
41. 18 and 40

Cochrane Central Register of Controlled Trials

1. MeSH descriptor: [Radius Fractures] 1 tree(s) exploded
2. distal near (radius or radial)
3. colles
4. wrist
5. fracture
6. (#2 or #3 or #4) and #5
7. #1 or #6
8. MeSH descriptor: [Bone Plates] this term only
9. MeSH descriptor: [Bone Wires] this term only
10. MeSH descriptor: [Internal Fixators] this term only
11. MeSH descriptor: [External Fixators] this term only
12. kirschner wire or kapandji
13. locking plate
14. external fixation
15. internal fixation
16. #8 or #9 or #10 or #11 or #12 or #13 or #14 or #15
17. #7 and #16

Appendix 4 – Trial summaries

Record	Rozental 2009
Participants	Two tertiary care institutes, Massachusetts 45 patients participated Inclusion criteria: closed dorsally displaced distal radius fracture (dorsal angulation >20 degrees or 100% apposition or >5mm ulnar variance or both dorsal and volar comminution), isolated injury, independent function Exclusion criteria: complex articular fractures, neurovascular injury, multiple trauma or other injuries and inflammatory arthritis AO classification: 16 A type (6 A2, 10 A3), 29 C type Gender: 34/11 female/male Mean Age: 51 years (19 to 79) Assigned: 22/23 CRPP/ ORIF Assessed: 21/21 CRPP/ ORIF
Interventions	Timing of intervention: within two weeks of the injury Closed reduction and fixated with 1.6 mm Kirschner wires applied extra-focally (2 patients required additional external fixation). Immobilised, cast and pins removed at 6 weeks Volar locking plate fixation with either a VLS (wright medical) or a DVR plate (Hand innovations). Immobilised in a volar splint with an early range of motion protocol after 1 week
Outcomes	Length of follow up: 6,9, 12 weeks and 12 months Functional outcome: DASH score, grip strength, pinch strength and range of motion Clinical outcomes (complications): Major complications: 1/1 (CRPP/ORIF) Minor complications 6/1 (CRPP/ORIF) Radiological parameters: union, radial height, radial inclination and volar tilt

Record	Marcheix *et al.* 2010
Participants	Two district general hospitals 103 patients participated Inclusion criteria: patients > 50 years old with a dorsally displaced distal radius fracture Exclusion criteria: patients <50 years, open fractures, poly trauma patients or those not local to the study centre AO classification: 1 type A2, 39 type A3, 48 type C2, 14 type C3 Gender: 86/17 (Female/ Male) Median Age: 73/75 years (SD; 11) (CRPP/ ORIF) Assigned: 56 / 54 (CRPP/ORIF) Assessed: 53/ 50 (CRPP/ORIF), loss to follow up due to death or patient failed to appear at the first consultation
Interventions	Timing of intervention: not stated

	Closed reduction and mixed pinning (1.8 or 2.0mm wires), 3 wires placed intra-focally and 1 wire extra-focally – immobilised and wires removed at 6 weeks Volar fixed angle plate and immobilisation for 3 weeks in a below-elbow cast Both groups had 15 sessions of supervised physiotherapy
Outcomes	Length of follow up: 3, 6, 12 and 26 weeks after surgery Functional outcome – DASH and Herzberg scoring system (range of motion, grip strength and pain) Clinical outcomes CRPP – 5 complex regional pain syndrome, 3 infections and 1 hypoaesthesia in the territory of the radial nerve ORIF – 1 complex regional pain syndrome Radiological parameters – radial inclination, radial shortening, ulnar variance and palmar tilt

Record	**Costa *et al.* 2014**
Participants	UK based Multi centre trial – 18 centres 461 patients participated Inclusion criteria: dorsally displaced distal radius fractures (within 3cm radiocarpal joint) Exclusion criteria: open fractures with a gustillo grading greater than 1, inability to adhere to trial procedures AO classification: 144 type A2, 162 type A3, 5 type B1, 2 type B2, 1 type B3, 63 type C1, 60 type C2, 18 type C3, AO type not stated for 6 patients Gender: 385/86 (Female/ Male) Median Age (SD): 59.7(16.4)/58.3(14.9) years (CRPP/ ORIF) Assigned: 230/231 (CRPP/ORIF) Assessed at 12 months: 211/205 (CRPP/ORIF)
Interventions	Timing of intervention: within 2 weeks of the injury Closed reduction and Kirschner wire fixation, with cast immobilisation and wire removal at 6 weeks Volar fixed angle plate – both locking and unlocking screws, immobilisation decided by the surgeon All patients provided with written physiotherapy advice
Outcomes	Length of follow up: 3, 6 and 12 months after surgery Functional outcome – PRWE, DASH and EQ5D Clinical outcomes: complications CRPP – 2 re-fracture, 14 neurological injuries, 4 tendon injuries, 18 superficial wound infections, 1 deep wound infection ORIF – 2 re-fracture, 20 neurological injury, 6 tendon injury, 12 superficial wound infection and 1 deep wound infection Radiological parameters – ulnar variance, palmar tilt and dorsal comminution

Record	**Hollevoet *et al.* 2011**
Participants	Ghent University Hospital 42 patients participated Inclusion criteria: low impact dorsally displaced distal radius fractures in patients ≥50 years old Exclusion criteria: High impact or bilateral fractures, previous fracture, fractures associated with an ulnar head fracture or patients with a psychiatric condition Gender: 36/4 (Female/ Male) – gender of 2 patients excluded after randomisation not stated Median Age (SD): 66/67 years (CRPP/ ORIF) Assigned: 20/22 (CRPP/ORIF) Assessed at 12 months for DASH: 18/16 (CRPP/ORIF) – loss to follow up due to death, psychiatric condition, declined or loss of contact with the patient.
Interventions	Timing of intervention: not stated Closed reduction and Kirschner wire fixation – mixed or intrafocally applied 1.6mm wires – cast immobilisation and wire removal at 5 weeks Volar fixed angle plate – LCP 2.4mm distal radius plate (Synthes) applied with locking screws Both groups were immobilised with a cast for 5 weeks post-operatively
Outcomes	Length of follow up: 5 weeks, 3 months and ≥12 months Functional outcomes – DASH, grip strength and range of motion Clinical outcomes: complications CRPP – 3 pin tract infections (1 required a surgical procedure), 1 removal of k-wire under local anaesthesia ORIF – 1 deep wound infection, 3 removal of plate for pain, 1 CRPS with removal of plate Other complications not assigned to specific groups; trigger finger, carpal tunnel syndrome and rupture of extensor pollicis longus tendon Radiological parameters – ulnar variance, palmar tilt and radial inclination

Record	**McFadyen *et al.* 2011**
Participants	Two district general hospitals 56 patients participated Inclusion criteria: closed unilateral dorsally displaced unstable extra-articular distal radius fractures, AO class type A, dorsal angulation (>20 degrees), dorsal comminution, radial shortening (>4mm) Exclusion criteria: AO type B or C fractures, multiple injuries, bilateral fractures, pre-existing radiographic evident wrist arthritis, dementia and open fractures Gender: 33/23 (Female/ Male) Median Age: 65/61 years (18 to 80) (CRPP/ ORIF) Assigned: 29/ 27 (CRPP/ORIF)

	Assessed: 29/ 27 (CRPP/ORIF) – no loss to follow up
Interventions	Timing of intervention: All treated for: both groups immobilised for 6 weeks in a cast Closed reduction and extra-focally fixated with three 1.6mm Kirschner wires Volar locking plate fixation with either a DVR (Hand innovations) or a LCP T-plate (Synthes)
Outcomes	Length of follow up: 3 and 6 months Functional outcome – quick DASH and Gartland and Werley scoring system Clinical outcomes – ORIF – no complications recorded CRPP – 5 pin-site infections,1 superficial radial nerve palsy, 1 carpal tunnel syndrome, 1 painful migrated pin. Three patients required a second operation. Radiological parameters – radial inclination, shortening and dorsal tilt

Record	**Goehre *et al.* 2014**
Participants	Hospital not stated 40 patients participated Inclusion criteria: unstable dorsally displaced distal radius fractures in patients ≥65 years old, dorsal tilt > 20 degrees, radial shortening > 2mm, radioulnar joint instability or associated ulnar fracture Exclusion criteria: carpal injuries, multiple injuries, pre-existing functional deficit or severe comorbidity AO classification: 10 type A2, 23 type A3 and 7 type C1 Gender: 37/3 (Female/ Male) Median Age (SD): 73.8(8.9)/ 71.3(5.7) years (CRPP/ ORIF) Assigned: 19/21 (CRPP/ORIF) Assessed: not stated
Interventions	Timing of intervention: not stated Closed reduction and Kirschner wire fixation – extrafocally, intrafocally or mixed pinning with 1.6-2.0mm wires – cast immobilisation and wire removal at 6 weeks Volar fixed angle plate – LCP 2.4mm distal radius plate (Synthes) applied with locking screws with immobilisation for 1 week
Outcomes	Length of follow up: 3, 6 and 12 months Functional outcome – DASH, PRWE, Castaing score, range of motion and grip strength Clinical outcomes: complications CRPP – 2 carpal tunnel syndromes ORIF – 3 carpal tunnel syndromes (1 requiring a release) and1 malunion Radiological parameters – ulnar inclination, palmar inclination and ulnar variance – assessed 1st day and 6 months post-operatively

Appendix 5 – Risk of bias assessments

Rozental 2009		
Domain	**Support for judgement**	**Review authors' judgement**
Selection bias		
Random sequence generation	"Patients were randomized with the aid of a computer generated list"	Low risk
Allocation concealment	"Numbers were placed in sealed envelopes and were opened at the time of the intervention" Comment: although the envelopes were sealed, there is no mention whether the envelopes were opaque.	Unclear risk
Performance bias		
Blinding of participants and personnel	Insufficient information to determine whether blinding occurred or not.	Unclear
Detection bias		
Blinding of outcome assessment	Physical measures "A directed clinical examination was performed by an independent examiner who was a research assistant in the department of orthopaedic surgery……The independent examiner was not made aware of the treatment arm to which the patient had been randomized, but no masking was used to cover the patients' wounds" Patient reported measures The DASH questionnaire was assessed at the clinic appointments with the independent examiner. Comment: although complete blinding was not achieved, an independent examiner was used meaning it is unlikely that the outcome measurement would be influenced by the lack of blinding".	Low risk
Attrition bias		
Incomplete outcome data	There was a minimal loss to follow up, with similar numbers for both groups. Although the reasons differed between the groups, (olecranon fracture for the wire group and failure to present due to moving from the area for the plate group) the numbers were sufficiently small meaning it is unlikely that this difference would have affected the overall outcomes.	Low risk
Selective reporting	The primary and secondary outcomes were reported in concordance with the study protocol published on	Low risk

	the ClinicalTrial.gov website	
Other bias		
Other sources of bias	Participants were only operated on by 4 specialist hand and upper extremity surgeons, hence the results may not be applicable to the wider community of orthopaedic surgeons. No baseline functional scores provided	High risk

Marcheix 2010		
Domain	**Support for judgement**	**Review authors' judgement**
Selection bias		
Random sequence generation	"The computer assigned treatment, using blocked randomization"	Low risk
Allocation concealment	"Treatment allocation was performed by connection to a specifically designed secure password protected website"	Low risk
Performance bias		
Blinding of participants and personnel	No mention of whether the participants and key personnel were blinded.	Unclear risk
Detection bias		
Blinding of outcome assessment	No mention of whether the analysis was blinded	Unclear risk
Attrition bias		
Incomplete outcome data	Similar number of patients and reasons for lost to follow up in both groups.	Low risk
Selective reporting	Study outcomes reported in concordance with the trial protocol published on the www.controlled-trials.com website	Low
Other bias		
Other sources of bias	Demographic characteristics were the same for both groups. No preoperative functional data provided for the DASH score No information provided regarding the number, grade or specialism of the surgeons	**Unclear risk**

Costa 2014		
Domain	**Support for judgement**	**Review authors' judgement**
Selection bias		
Random sequence generation	"The randomisation sequence was generated and administered at an independent Clinical Trials Unit (York, UK) to ensure that allocation was concealed"	Low risk
Allocation concealment	**"**The method of fixation was allocated using a secure, centralised, telephone randomisation service"	Low risk
Performance bias		
Blinding of participants and personnel	"The operating surgeon could not be blinded in the trial and, since the K-wires protrude on the back of the wrist and the locking-plate require an incision, nor could the patient" Comment: Although participants were not blinded, the majority did not have a preference for either intervention. In addition, the operating surgeons were not responsible for collection of outcome data. Therefore, it is unlikely that the lack of blinding would have altered the trial outcomes.	Low risk
Detection bias		
Blinding of outcome assessment	"All staff involved in checking, entering and analysing questionnaire responses were blind to allocation".	Low risk
Attrition bias		
Incomplete outcome data	"There is no evidence that missingness patterns differed between treatment groups" Comment: there was both similar numbers and reasons for missing data between the groups.	Low risk
Selective reporting	All outcomes were reported that were detailed in the published study protocol	Low risk
Other bias		
Other sources of bias	No difference in baseline characteristics and functional scores between the two groups. "Treatments were undertaken by 244 different surgeons; the median number of operations per surgeon was 1 (IQR 1-2). As expected, any individual surgeon only operated on a small number of patients (2-3) enrolled in the study; 88% of surgeons (215 out of 244) treated less than 3 study participants." Comment: the trial outcomes were unlikely to be affect by surgeon bias	Low risk

Hollevoet 2011		
Domain	**Support for judgement**	**Review authors' judgement**
Selection bias		
Random sequence generation	A computer program (Microsoft Office Excel) had been used to randomize the procedures".	Low risk
Allocation concealment	"The sequence was not concealed" Patients were enrolled and assigned to their respective groups by the 1st author, with no attempts at concealment.	High risk
Performance bias		
Blinding of participants and personnel	"Blinding was not possible because of surgical scars and on the radiographs the type of treatment was visible" Comment: Participants and key personnel not blinded	High risk
Detection bias		
Blinding of outcome assessment	"The first two authors performed the clinical examination and obtained the DASH score' Authors were not blinded hence the have introduced bias.	High risk
Attrition bias		
Incomplete outcome data	*Patient reported outcome measures* Greater proportion of data missing for the plate fixation group in comparison to the wire group. *Physical measures* Greater proportion of data missing at 3 months for the plate fixation group. At 1 year although the missing data was balanced in numbers between the two groups, the reasons however differed between the groups.	High risk
Selective reporting	No study protocol available to determine whether the trial procedures were adhered to and hence which outcome measures were intended to be assessed.	Unclear risk
Other bias		
Other sources of bias	No difference in baseline characteristics between the two groups. Although baseline functional scores were not provided, both the age and occupation of the two groups were similar, indicating the patient's wrist function may also have been similar.	Low risk

	"Patient's were operative on by surgeons of our department, including the authors of the present study. Orthopaedic surgeons in training were supervised by senior surgeons." Comment: this suggests participants were operated on by a number of surgeons of varying experience reducing the risk of surgeon bias, however, the study was performed at a single site potentially reducing its applicability.	

McFadyen 2011		
Domain	**Support for judgement**	**Review authors' judgement**
Selection bias		
Random sequence generation	"Patient were randomised by computer-generated permuted block envelopes"	Low risk
Allocation concealment	"Permuted block envelopes" Comment: the authors do not mention whether the envelopes were opaque, sealed or sequentially numbered	Unclear risk
Performance bias		
Blinding of participants and personnel	Insufficient information to determine if the participants and key personnel were blinded	Unclear risk
Detection bias		
Blinding of outcome assessment	Physical measures "Clinical evaluation was performed by a senior physiotherapist, who was blinded to the treatment modality used." Patient reported measures No mention of whether the quick DASH administered by a blinded assessor.	Low risk Unclear risk
Attrition bias		
Incomplete outcome data	"No patients were lost to follow-up" Comment: no missing data	Low risk
Selective reporting	Although functional and radiographic outcomes were reported in concordance with the protocol details published on the www.controlled-trials.com website. The published protocol doesn't specify the exact outcomes or the timing of their administration	Unclear risk
Other bias		

Other sources of bias	There was no difference in the patient's demographic characteristics, however, no baseline functional scores were provided. The number, grade and specialism of the surgeons was also not provided.	Unclear risk

Goehre 2014		
Domain	**Support for judgement**	**Review authors' judgement**
Selection bias		
Random sequence generation	"A modified randomization method was used. With a random number generator, two permuted single blocks (K-wire fixation and plate fixation) of variable length were created. The total length of both blocks was set to 40 events."	Low risk
Allocation concealment	"Each of the 40 events was placed in a sealed non-translucent envelope stored in a box"	Low risk
Performance bias		
Blinding of participants and personnel	No mention of whether the participants and key personnel were blinded.	Unclear risk
Detection bias		
Blinding of outcome assessment	No mention of whether the analysis was blinded	Unclear risk
Attrition bias		
Incomplete outcome data	Insufficient reporting of attrition/ exclusions to allow a judgment of risk.	Unclear risk
Selective reporting	No study protocol available to determine whether the trial procedures were adhered to and hence which outcome measures were intended to be assessed.	Unclear risk
Other bias		
Other sources of bias	Both treatment groups had similar demographic characteristics and fracture configuration. No baseline functional outcome data was provided. "The operations were performed by only three experienced senior orthopaedic surgeons". Comment: the outcome data may not be applicable to a wider population and there have been biased by a surgeon effect. "No sample size calculation was performed and the number of patients actually recruited was small"	High risk

Appendix 6 – PRISMA checklist

Section/topic	#	Checklist item	Reported on page #	Description
TITLE				
Title	1	Identify the report as a systematic review, meta-analysis, or both.	98	
ABSTRACT				
Structured summary	2	Provide a structured summary including, as applicable: background; objectives; data sources; study eligibility criteria, participants, and interventions; study appraisal and synthesis methods; results; limitations; conclusions and implications of key findings; systematic review registration number.	X	Not included
INTRODUCTION				
Rationale	3	Describe the rationale for the review in the context of what is already known.	99-100	
Objectives	4	Provide an explicit statement of questions being addressed with reference to participants, interventions, comparisons, outcomes, and study design (PICOS).	100	
METHODS				
Protocol and registration	5	Indicate if a review protocol exists, if and where it can be accessed (e.g., Web address), and, if available, provide registration information including registration number.	X	The protocol was not published for this review
Eligibility criteria	6	Specify study characteristics (e.g., PICOS, length of follow-up) and report characteristics (e.g., years considered, language, publication status) used as criteria for eligibility, giving rationale.	100-101	
Information sources	7	Describe all information sources (e.g., databases with dates of coverage, contact with study authors to identify additional studies) in the search and date last searched.	101-103	
Search	8	Present full electronic search strategy for at least one database, including any limits used, such that it could be repeated.	Appendix 3	
Study selection	9	State the process for selecting studies (i.e., screening, eligibility, included in systematic review, and, if applicable, included in the meta-analysis).	103-104	Performed independently and in duplicate
Data collection process	10	Describe method of data extraction from reports (e.g., piloted forms, independently, in duplicate) and any processes for obtaining and confirming data from investigators.	104 – limited	Data extraction method detailed - Single data

				extractor
Data items	11	List and define all variables for which data were sought (e.g., PICOS, funding sources) and any assumptions and simplifications made.	104	
Risk of bias in individual studies	12	Describe methods used for assessing risk of bias of individual studies (including specification of whether this was done at the study or outcome level), and how this information is to be used in any data synthesis.	106	Risk of bias was assessed using the Cochrane risk of bias tool for randomised controlled trials
Summary measures	13	State the principal summary measures (e.g., risk ratio, difference in means).	105	
Synthesis of results	14	Describe the methods of handling data and combining results of studies, if done, including measures of consistency (e.g., I^2) for each meta-analysis.	X	Meta-analysis not performed, only a qualitative synthesis
Risk of bias across studies	15	Specify any assessment of risk of bias that may affect the cumulative evidence (e.g., publication bias, selective reporting within studies).	X	Not assessed as evidence not synthesised
Additional analyses	16	Describe methods of additional analyses (e.g., sensitivity or subgroup analyses, meta-regression), if done, indicating which were pre-specified.	X	Subgroup analysis could not be performed

RESULTS				
Study selection	17	Give numbers of studies screened, assessed for eligibility, and included in the review, with reasons for exclusions at each stage, ideally with a flow diagram.	107	Flow diagram and description presented
Study characteristics	18	For each study, present characteristics for which data were extracted (e.g., study size, PICOS, follow-up period) and provide the citations.	108 – 110	Trial summaries are provided in appendix 4
Risk of bias within studies	19	Present data on risk of bias of each study and, if available, any outcome level assessment (see item 12).	110-112	Detailed risk of bias assessments are provided in appendix 5
Results of individual studies	20	For all outcomes considered (benefits or harms), present, for each study: (a) simple summary data for each intervention group (b) effect estimates and confidence intervals, ideally with a forest plot.	113-120	

Synthesis of results	21	Present results of each meta-analysis done, including confidence intervals and measures of consistency.	X	Meta-analysis was not performed
Risk of bias across studies	22	Present results of any assessment of risk of bias across studies (see Item 15).	X	Not applicable
Additional analysis	23	Give results of additional analyses, if done (e.g., sensitivity or subgroup analyses, meta-regression [see Item 16]).	X	Not applicable
DISCUSSION				
Summary of evidence	24	Summarize the main findings including the strength of evidence for each main outcome; consider their relevance to key groups (e.g., healthcare providers, users, and policy makers).	121-122	
Limitations	25	Discuss limitations at study and outcome level (e.g., risk of bias), and at review-level (e.g., incomplete retrieval of identified research, reporting bias).	122-124	
Conclusions	26	Provide a general interpretation of the results in the context of other evidence, and implications for future research.	125	
FUNDING				
Funding	27	Describe sources of funding for the systematic review and other support (e.g., supply of data); role of funders for the systematic review.	98	No funding was received

Appendix 7 – Correlation coefficients for the correlation of the radiographic parameters with the physical and patient reported outcome measures

Table 45 - Correlation of 6-week radiographic parameters with 3-month patient reported and physical measures of function. (Sig. 2-tailed). Significant correlations (p<0.004) are highlighted.

	Dorsal Angulation		Ulnar Variance	
	≥50 yrs	<50 yrs	≥50 yrs	<50 yrs
DASH	0.44	-0.02	0.04	-0.38
EQ5D	-0.08	0.16	0.11	0.37
PRWE	**0.48***	0.37	0.11	-0.33
Grip Strength (kg)	-0.08	-0.35	0.22	0.03
Grip Fatigue (%)	-0.04	0.14	-0.25	-0.30
Pinch (kg)	-0.32	-0.09	0.29	-0.14
Supination	0.06	-0.41	0.08	-0.42
Pronation	0.12	0.17	-0.05	0.09
Flexion	0.22	-0.45	-0.19	0.37
Extension	0.06	-0.50	-0.18	0.27
Ulnar Deviation	-0.39	-0.17	-0.37	0.31
Radial Deviation	-0.02	-0.14	-0.03	-0.50

0, 0.25
0.25, 0.5
0.5, 0.75
0.75, 1
-0.75, -1
-0.5, -0.75
-0.25, -0.5
0, -0.25

Table 6 - Correlation of 6-week radiological parameters with 6-month patient reported and physical measures of function. (Sig. 2-tailed). Significant correlations (p<0.004) are highlighted

	Dorsal Angulation		Ulnar Variance	
	≥50 yrs.	<50 yrs.	≥50 yrs.	<50 yrs.
DASH	0.29	0.54	0.01	0.24
EQ5D	-0.11	0.01	-0.09	0.08
PRWE	0.41	0.28	0.11	0.23
Grip Strength (kg)	-0.29	0.14	0.24	-0.33
Grip Fatigue (%)	0.13	0.18	-0.14	-0.26
Pinch (kg)	-0.18	0.13	0.40	-0.26
Supination	0.19	-0.12	0.02	-0.53
Pronation	0.38	-0.41	0.01	-0.06
Flexion	-0.02	**-0.81***	-0.27	-0.05
Extension	0.10	-0.33	-0.36	0.05
Ulnar Deviation	-0.02	-0.35	-0.34	-0.58
Radial Deviation	-0.16	-0.32	-0.28	-0.07

0, 0.25
0.25, 0.5
0.5, 0.75
0.75, 1
-0.75, -1
-0.5, -0.75
-0.25, -0.5
0, -0.25

Table 47 - Correlation of 6-week radiological parameters with 12-month patient reported and physical measures of function. (Sig. 2-tailed). Significant correlations (p<0.004) are highlighted

	Dorsal Angulation		Ulnar Variance	
	≥50 yrs.	<50 yrs.	≥50 yrs.	<50 yrs.
DASH	0.18	0.49	-0.09	0.06
EQ5D	-0.07	0.11	0.00	-0.12
PRWE	0.23	0.37	0.01	-0.01
Grip Strength (kg)	-0.16	0.50	0.33	-0.46
Grip Fatigue (%)	0.08	-0.06	-0.14	-0.20
Pinch (kg)	-0.41	-0.14	0.24	-0.03
Supination	0.04	0.16	0.08	-0.18
Pronation	-0.13	-0.36	-0.11	-0.35
Flexion	-0.41	-0.31	-0.35	-0.35
Extension	-0.21	0.05	-0.08	-0.50
Ulnar Deviation	-0.20	0.19	-0.07	0.18
Radial Deviation	-0.23	-0.25	-0.30	-0.04

0, 0.25
0.25, 0.5
0.5, 0.75
0.75, 1
-0.75, -1
-0.5, -0.75
-0.25, -0.5
0, -0.25

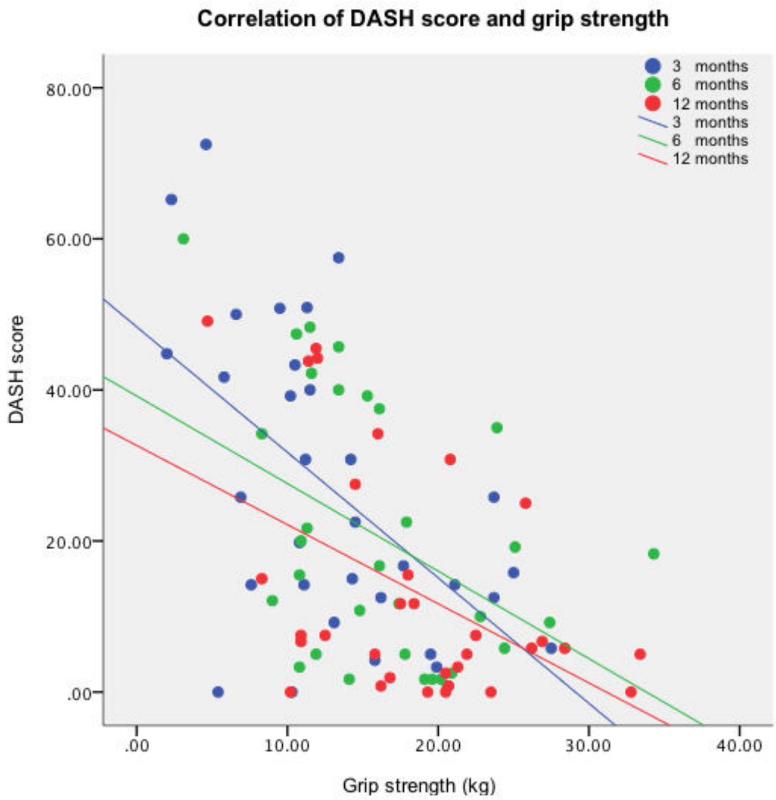
Table 35 - Correlation of 12-month radiographic parameters with patient reported and physical measures of function. (Sig. 2-tailed). Significant correlations (p<0.004) are highlighted

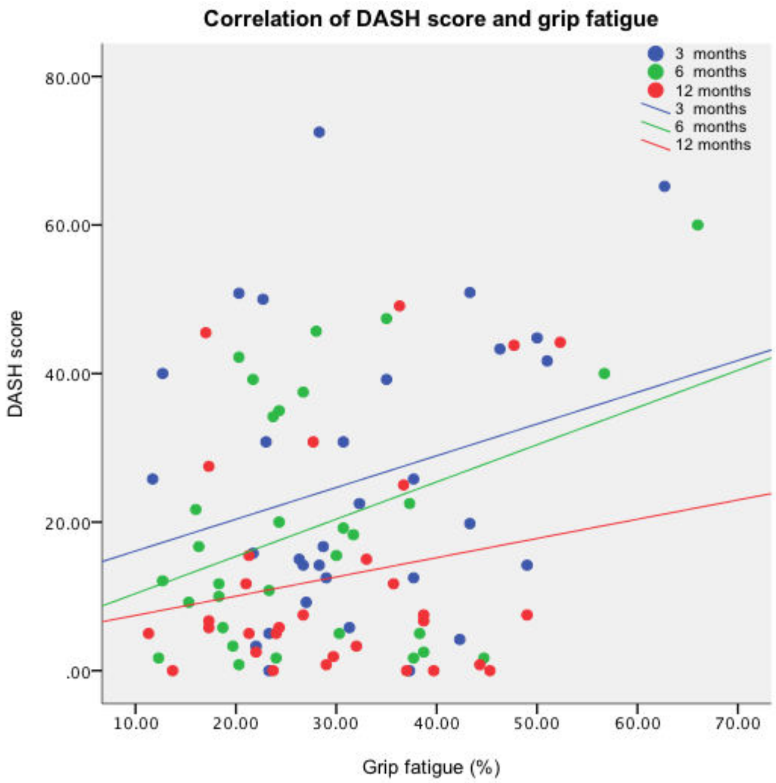
	Dorsal Angulation		Ulnar Variance	
	≥50 yrs.	<50 yrs.	≥50 yrs.	<50 yrs.
DASH	0.20	0.47	-0.08	0.26
EQ5D	-0.10	0.15	0.19	-0.21
PRWE	0.19	0.35	-0.01	0.23
Grip Strength (kg)	-0.22	0.50	-0.17	-0.55
Grip Fatigue (%)	0.02	-0.05	0.02	-0.34
Pinch (kg)	**-0.53***	-0.11	**-0.53 ***	-0.16
Supination	0.00	0.32	0.00	0.12
Pronation	-0.28	-0.32	-0.28	-0.55
Flexion	-0.39	-0.25	-0.40	-0.46
Extension	-0.19	0.01	-0.27	-0.48
Ulnar Deviation	-0.25	0.20	-0.15	0.17
Radial Deviation	-0.39	-0.31	-0.17	-0.18

0, 0.25
0.25, 0.5
0.5, 0.75
0.75, 1
-0.75, -1
-0.5, -0.75
-0.25, -0.5
0, -0.25

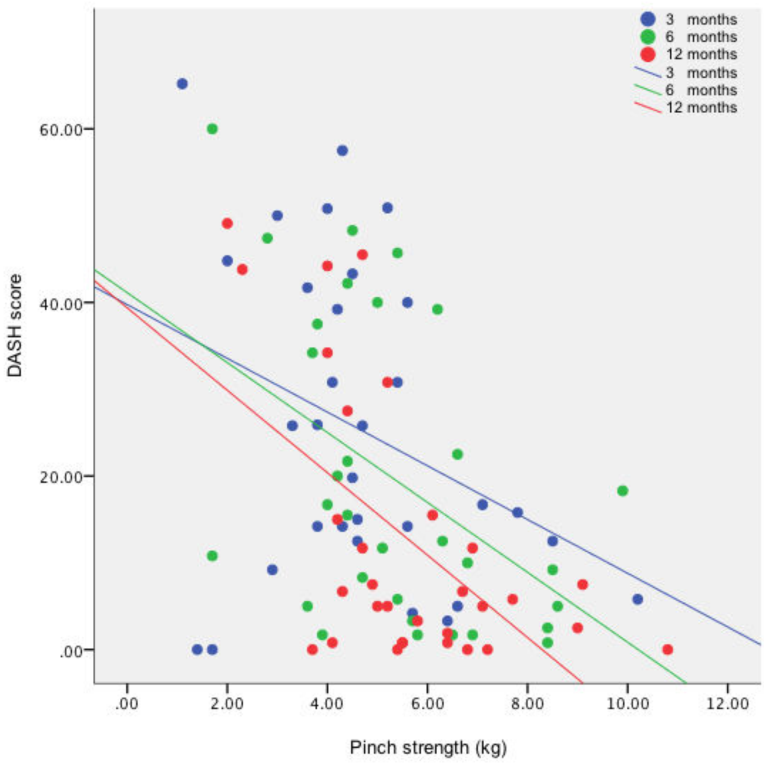
Appendix 8 – Correlation coefficients and curves of the correlation between the physical and patient reported outcome measures.

Figure 20 - Correlation curves for the correlation of the DASH score and the physical measures of function at 3, 6 and 12 months

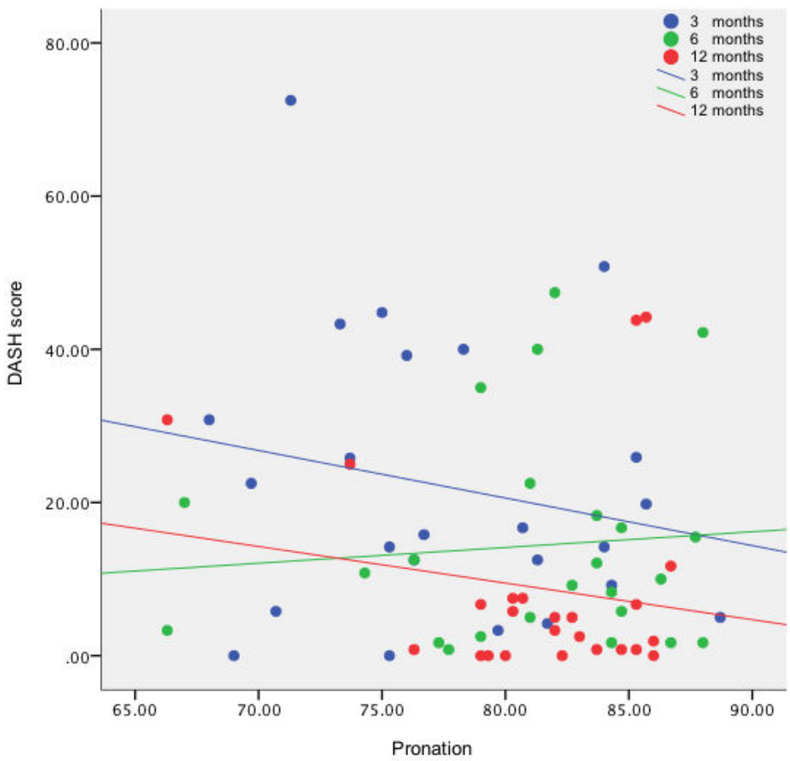


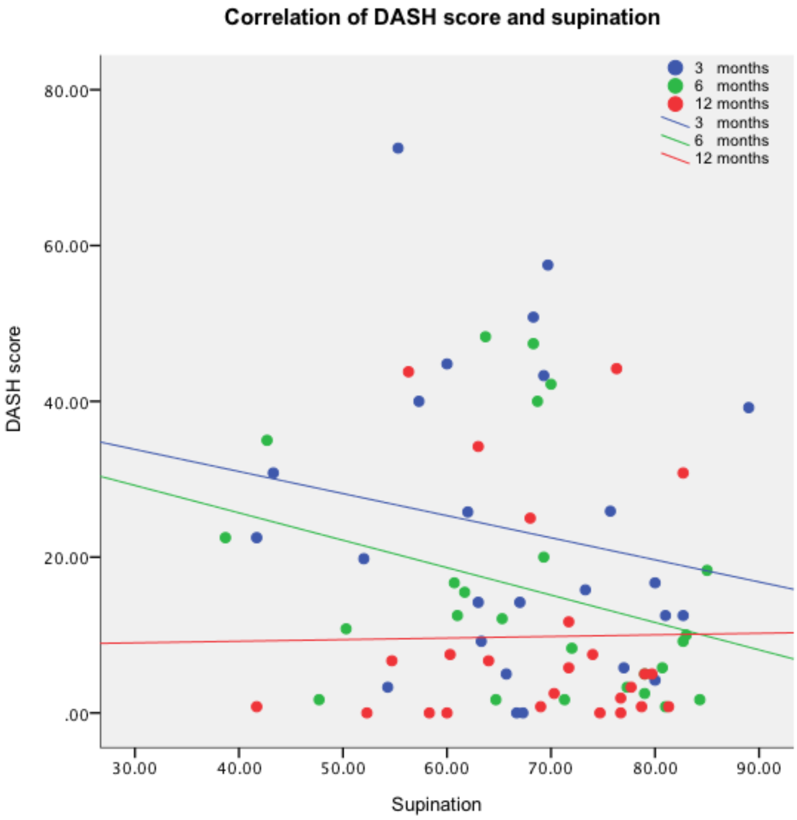


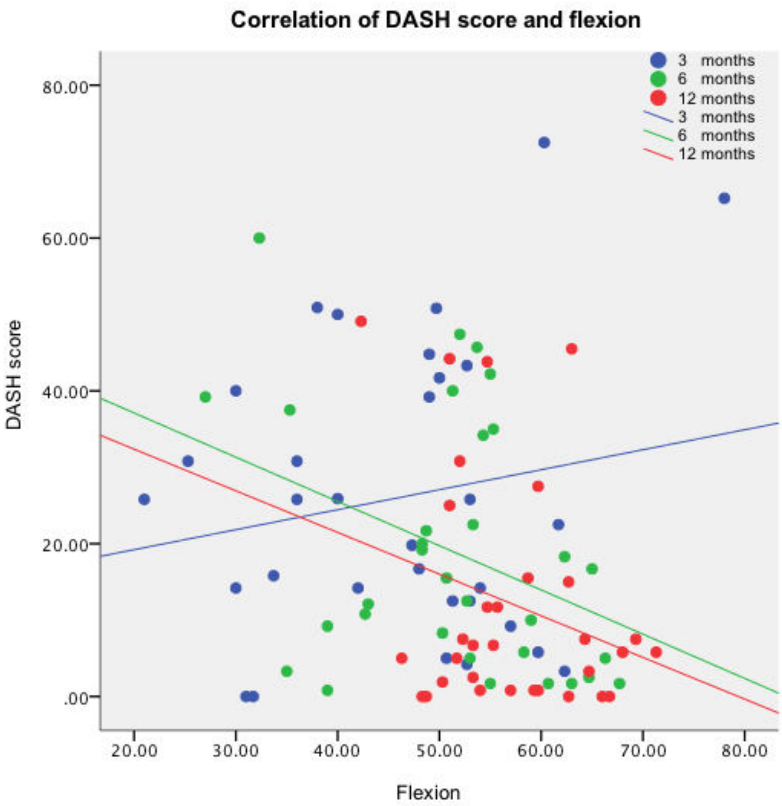
Correlation of DASH score and pinch strength

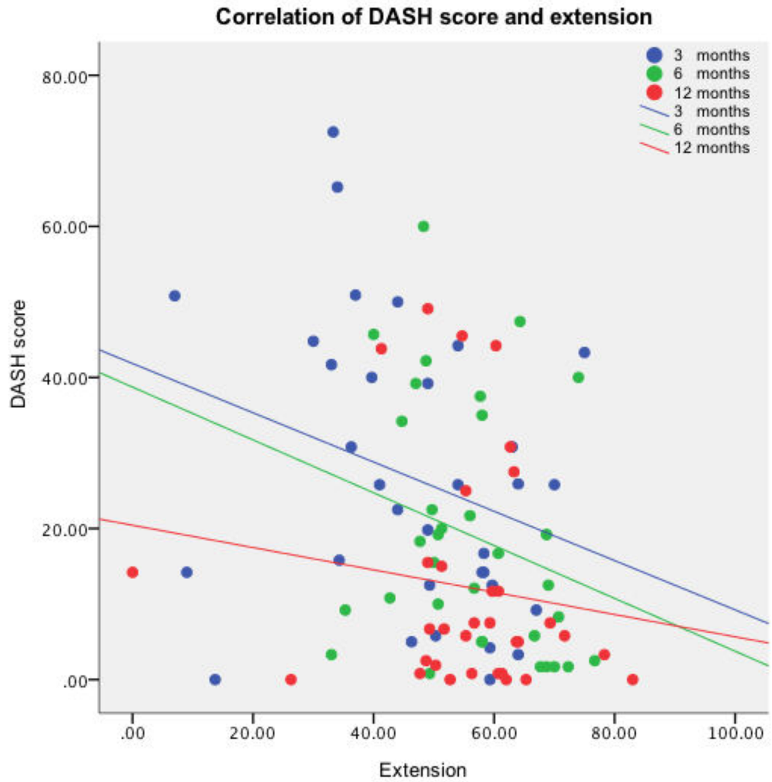


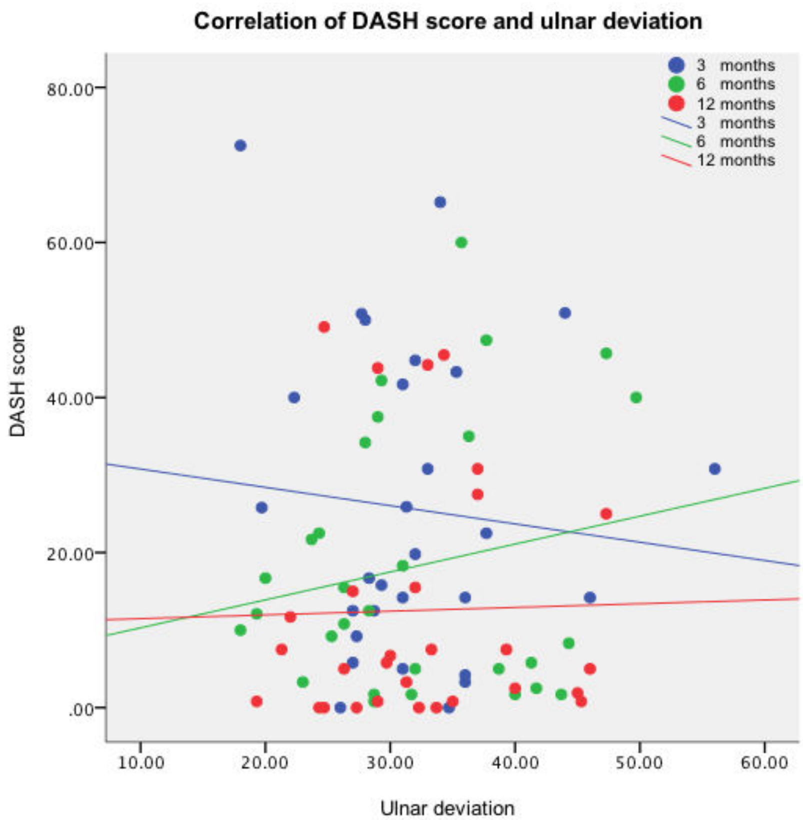
Correlation of DASH score and pronation




Correlation of DASH score and supination
3 months
6 months
12 months
3 months
6 months
12 months
80.00
60.00
40.00
20.00
.00
DASH score
30.00
40.00
50.00
60.00
70.00
80.00
90.00
Supination


Correlation of DASH score and flexion
3 months
6 months
12 months
3 months
6 months
12 months
80.00
60.00
40.00
20.00
.00
DASH score
20.00
30.00
40.00
50.00
60.00
70.00
80.00
Flexion


Correlation of DASH score and extension
3 months
6 months
12 months
3 months
6 months
12 months
DASH score
80.00
60.00
40.00
20.00
.00
.00
20.00
40.00
60.00
80.00
100.00
Extension


Correlation of DASH score and ulnar deviation
3 months
6 months
12 months
3 months
6 months
12 months
DASH score
80.00
60.00
40.00
20.00
.00
10.00
20.00
30.00
40.00
50.00
60.00
Ulnar deviation

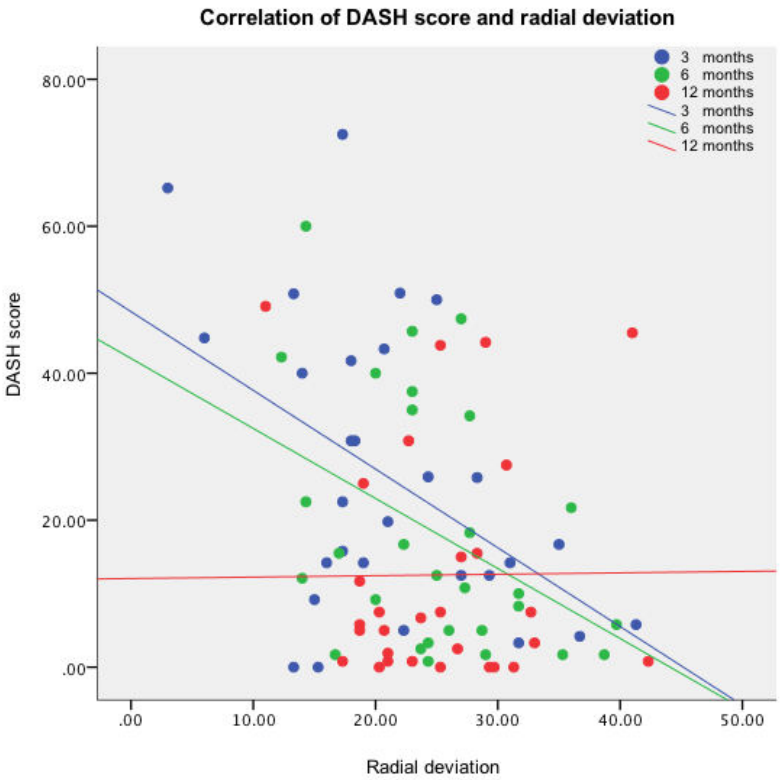
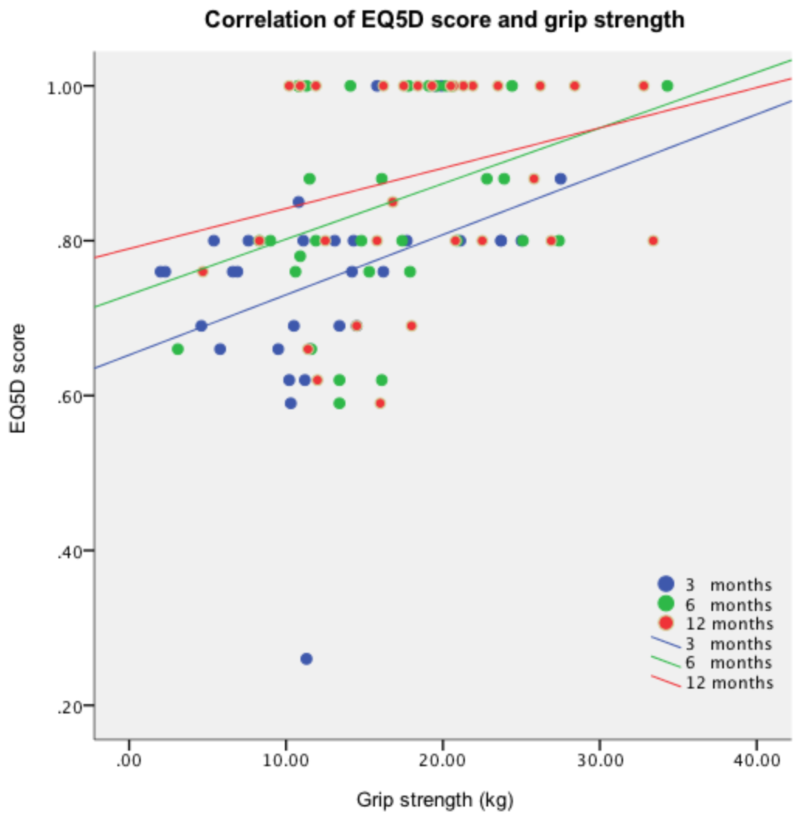


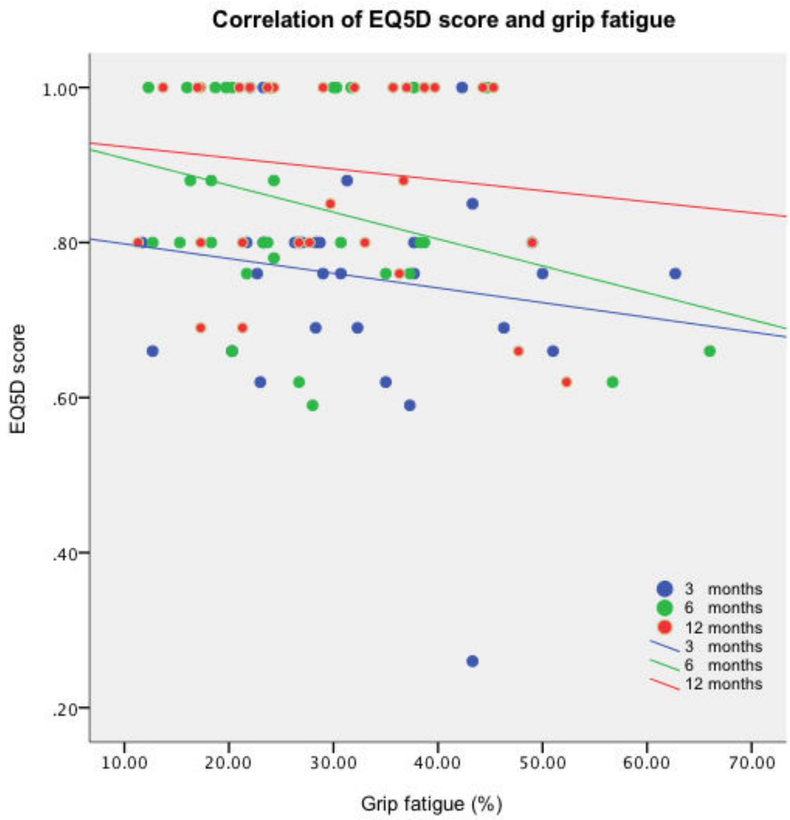
Table 36– Correlation of the DASH score and physical measures of function at 3, 6 and 12-months. (Sig. 2-tailed). Significant correlations (p<0.005) are highlighted

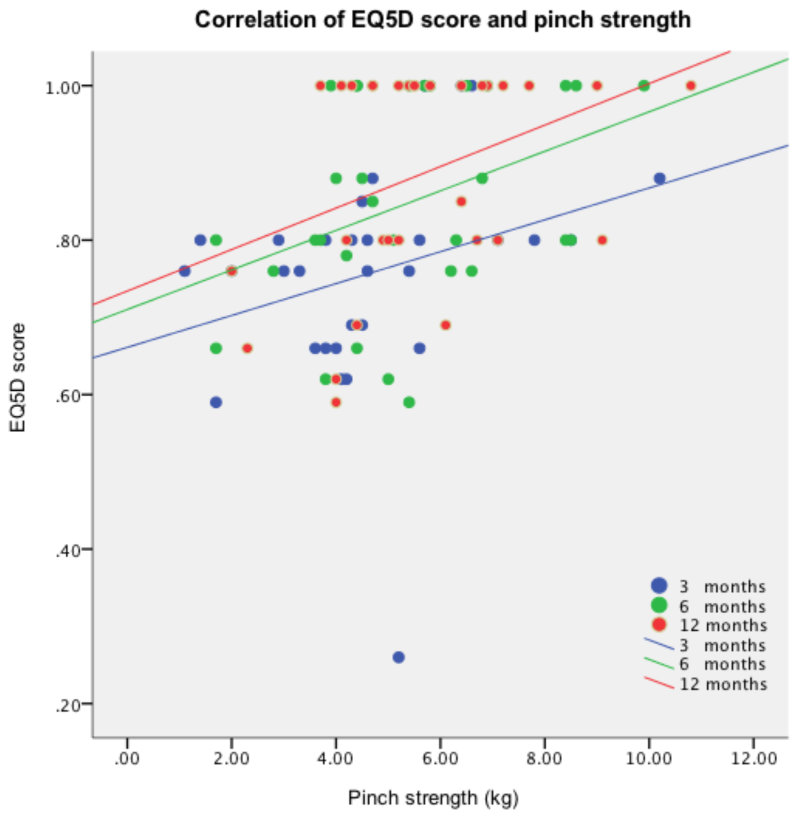
	3 months		6 months		12 months	
	≥50 yrs.	<50 yrs.	≥50 yrs.	<50 yrs.	≥50 yrs.	<50 yrs.
Grip Strength (kg)	-0.60	***-0.53****	0.08	***-0.52****	-0.40	***-0.56****
Grip Fatigue (%)	-0.06	0.13	-0.14	***-0.51****	-0.21	0.23
Pinch (kg)	-0.59	-0.23	-0.08	-0.40	-0.54	***-0.60****
Supination	-0.08	-0.35	-0.50	-0.08	0.61	-0.04
Pronation	-0.15	-0.37	-0.21	0.14	***-0.84****	-0.02
Flexion	-0.58	0.18	-0.53	-0.25	***0.81****	-0.11
Extension	-0.76	-0.22	-0.46	-0.11	0.06	-0.24
Ulnar Deviation	0.06	-0.31	-0.24	0.03	0.59	-0.03
Radial Deviation	0.73	-0.16	-0.30	-0.34	-0.35	0.05

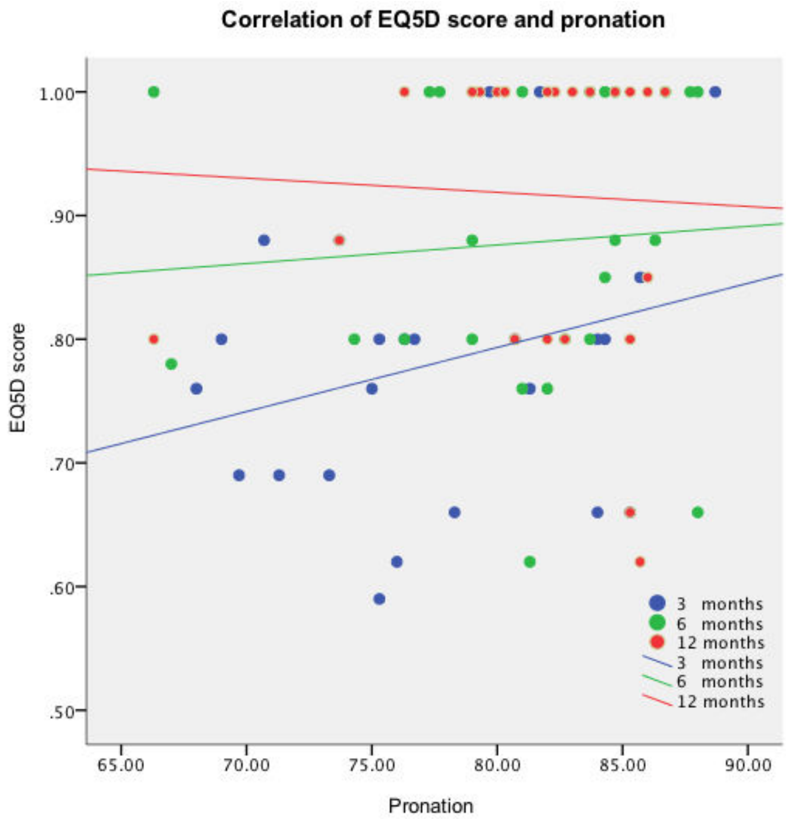
0, 0.25
0.25, 0.5
0.5, 0.75
0.75, 1
-0.75, -1
-0.5, -0.75
-0.25, -0.5
0, -0.25

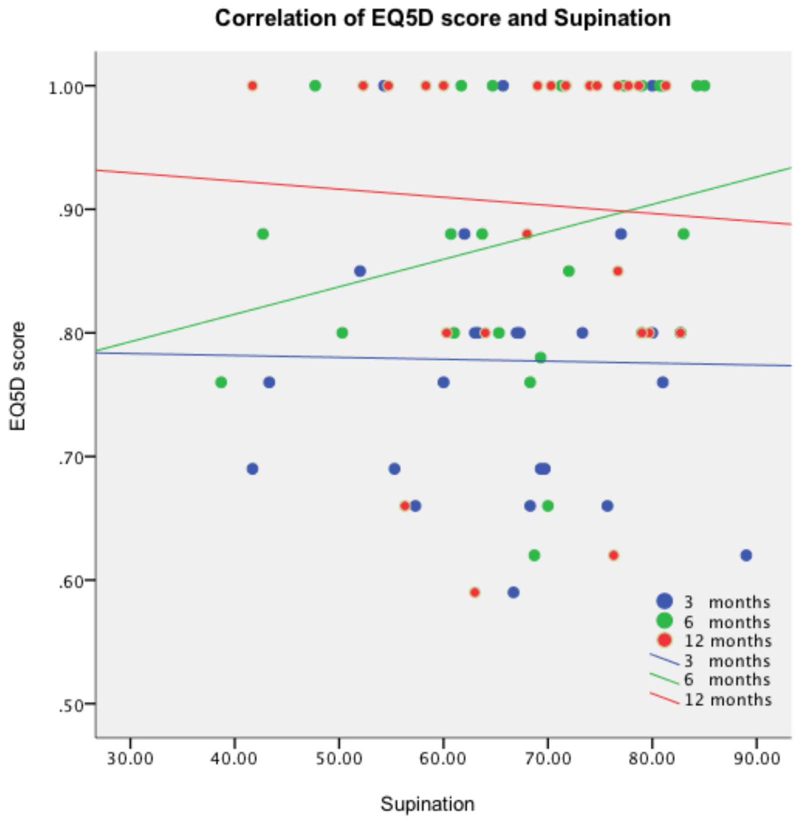
Figure 21 – Correlation curves for the correlation of the EQ5D score and physical measures of function at 3, 6 and 12 months

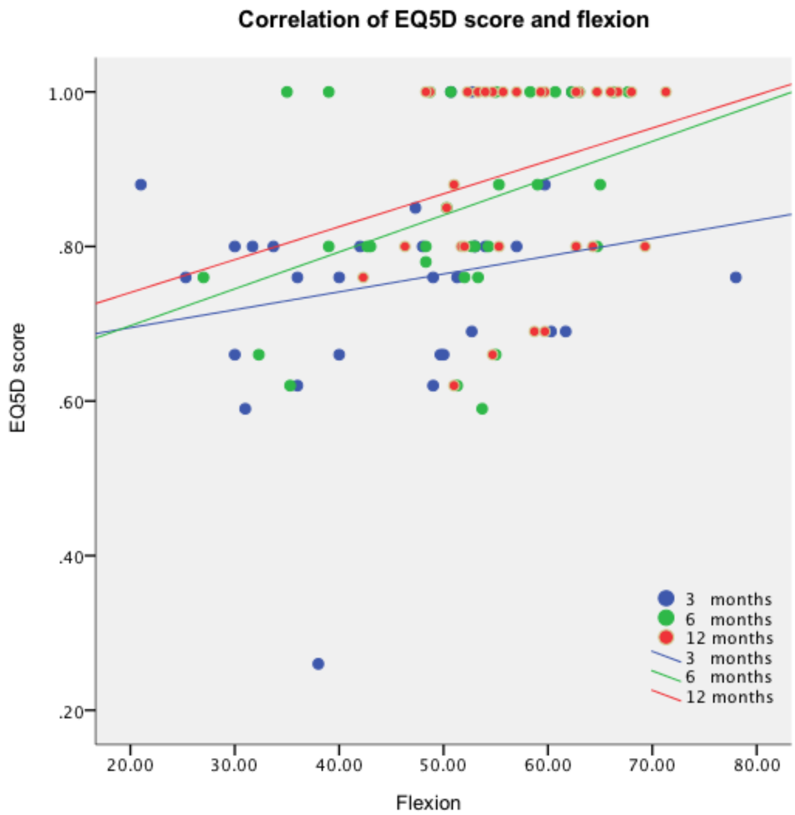


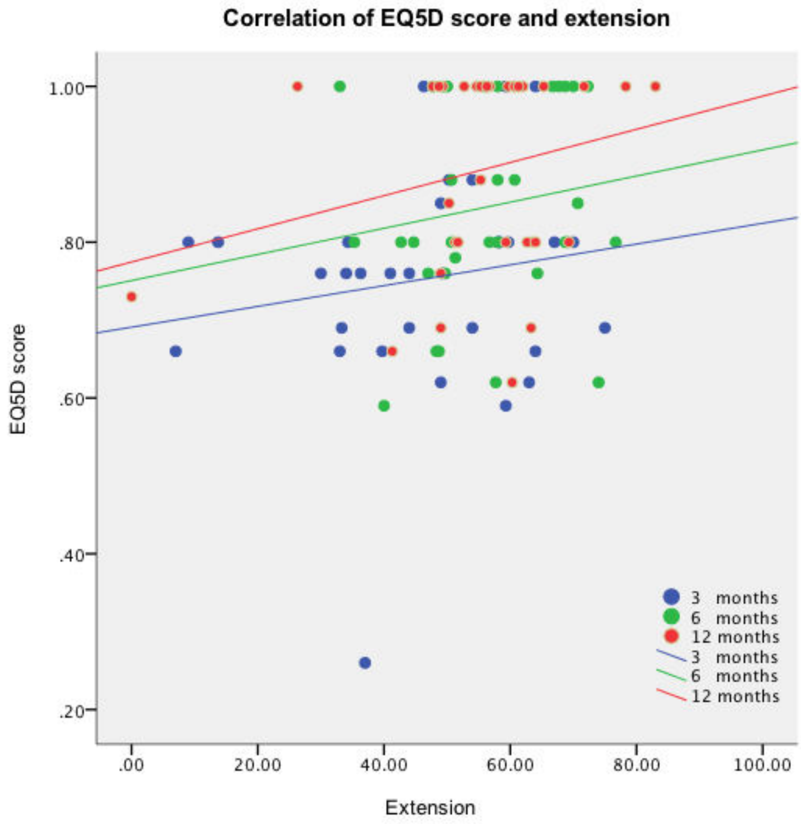



Correlation of EQ5D score and pinch strength
EQ5D score
1.00
.80
.60
.40
.20
.00
2.00
4.00
6.00
8.00
10.00
12.00
Pinch strength (kg)
3 months
6 months
12 months
3 months
6 months
12 months

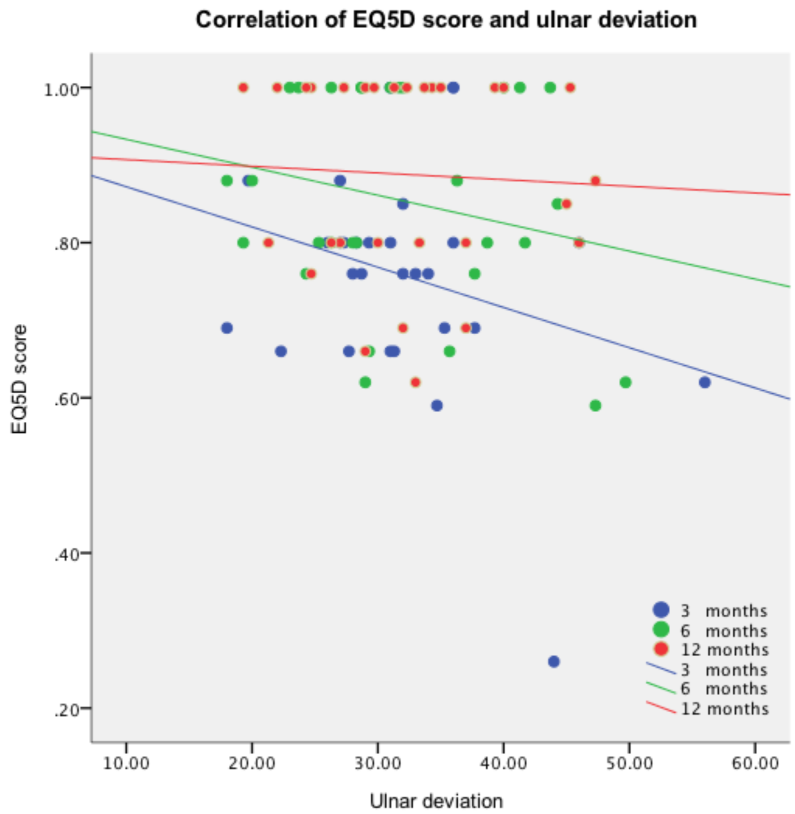

Correlation of EQ5D score and pronation
EQ5D score
1.00
.90
.80
.70
.60
.50
65.00
70.00
75.00
80.00
85.00
90.00
Pronation
3 months
6 months
12 months
3 months
6 months
12 months


Correlation of EQ5D score and Supination
EQ5D score
1.00
.90
.80
.70
.60
.50
30.00
40.00
50.00
60.00
70.00
80.00
90.00
Supination
3 months
6 months
12 months
3 months
6 months
12 months


Correlation of EQ5D score and flexion
EQ5D score
1.00
.80
.60
.40
.20
20.00
30.00
40.00
50.00
60.00
70.00
80.00
Flexion
3 months
6 months
12 months
3 months
6 months
12 months



Correlation of EQ5D score and extension
1.00
.80
.60
.40
.20
EQ5D score
.00
20.00
40.00
60.00
80.00
100.00
Extension
3 months
6 months
12 months
3 months
6 months
12 months



Correlation of EQ5D score and ulnar deviation
1.00
.80
.60
.40
.20
EQ5D score
10.00
20.00
30.00
40.00
50.00
60.00
Ulnar deviation
3 months
6 months
12 months
3 months
6 months
12 months

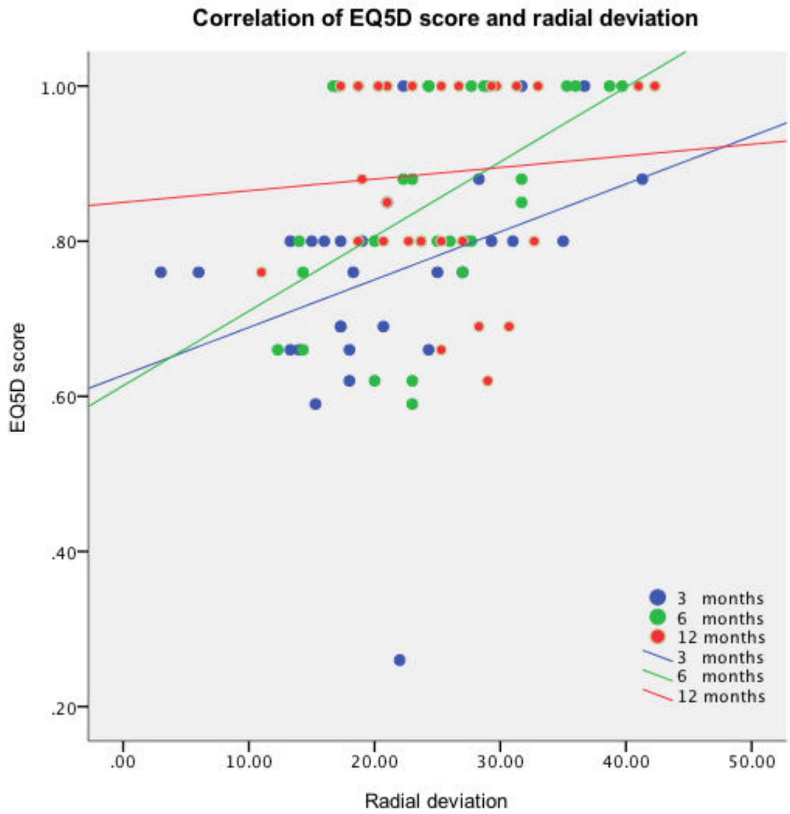
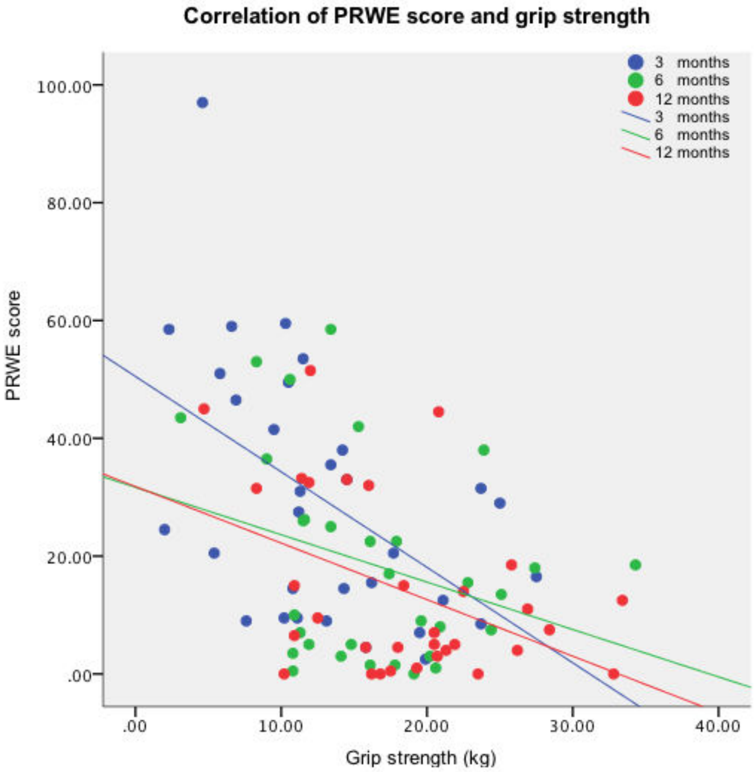


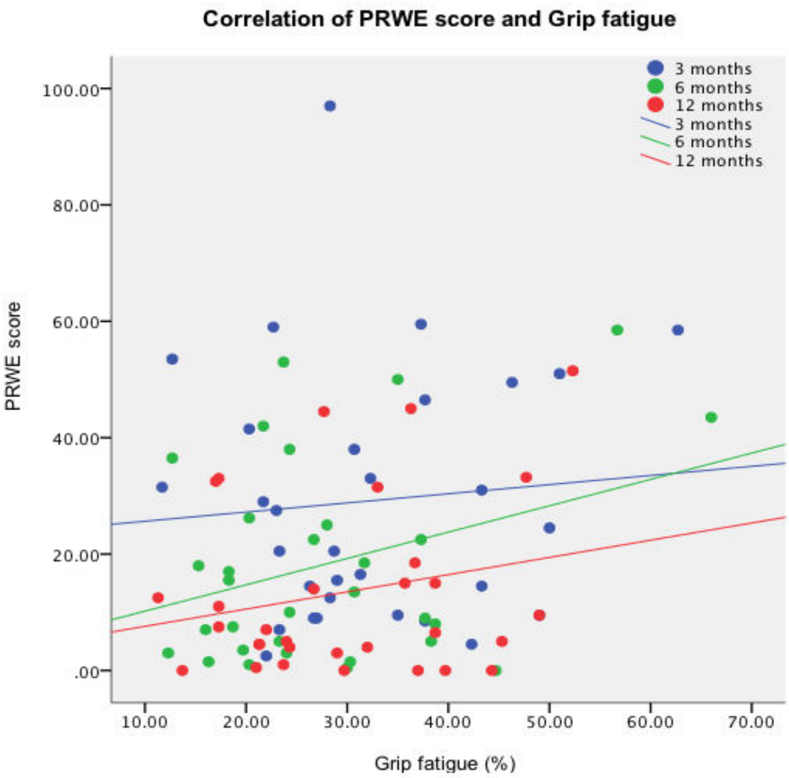
Table 37 – Correlation of the EQ5D score and physical measures of function at 3, 6 and 12-months. (Sig. 2-tailed). Significant correlations (p<0.005) are highlighted

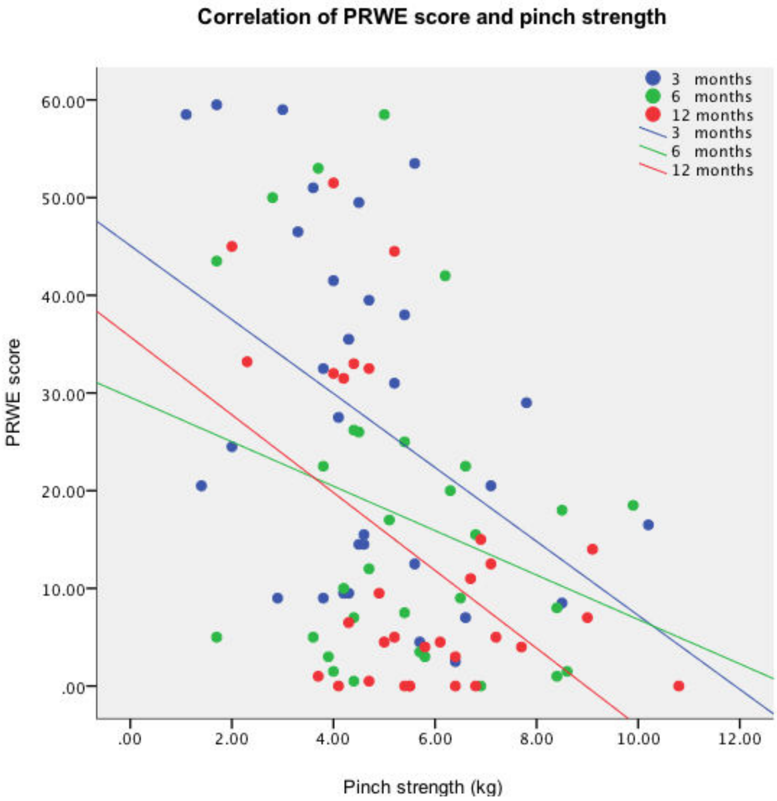
	3 months		6 months		12 months	
	≥50 yrs.	<50 yrs.	≥50 yrs.	<50 yrs.	≥50 yrs.	<50 yrs.
Grip Strength (kg)	0.24	0.26	0.15	0.30	0.63	-0.39
Grip Fatigue (%)	0.33	-0.26	0.18	-0.40	0.53	-0.14
Pinch (kg)	0.32	0.15	0.22	0.33	0.10	0.41
Supination	-0.28	0.06	0.33	0.12	-0.37	0.04
Pronation	0.10	0.31	0.20	-0.10	0.37	-0.21
Flexion	0.04	0.08	-0.06	0.31	0.62	0.11
Extension	0.26	0.06	-0.18	0.22	0.18	0.18
Ulnar Deviation	0.45	-0.24	0.08	-0.12	-0.07	-0.13
Radial Deviation	0.13	0.10	0.55	0.47	0.11	-0.07

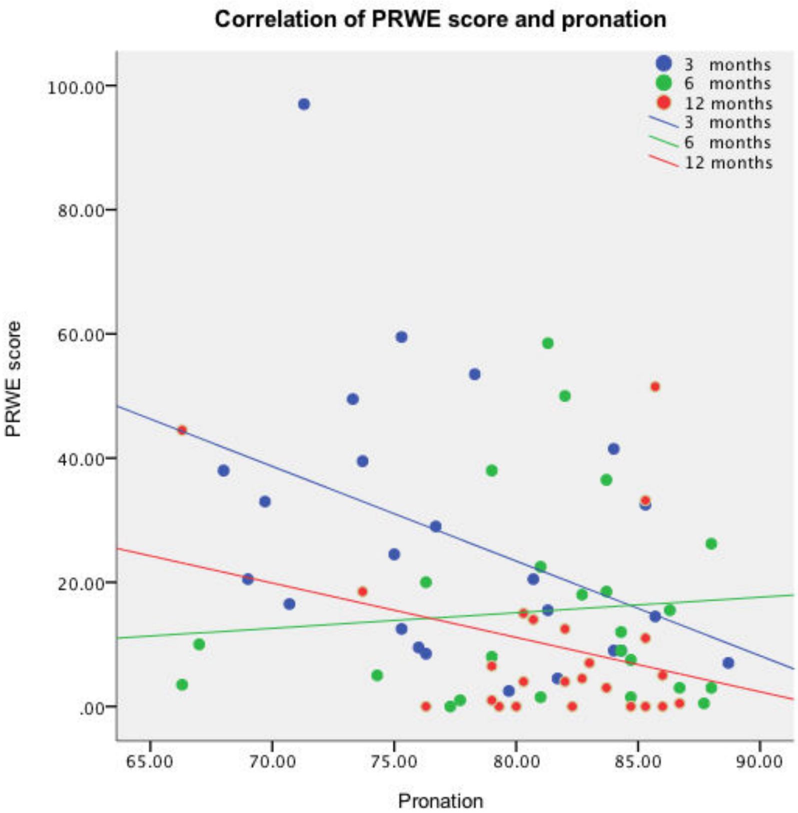
0, 0.25
0.25, 0.5
0.5, 0.75
0.75, 1
-0.75, -1
-0.5, -0.75
-0.25, -0.5
0, -0.25

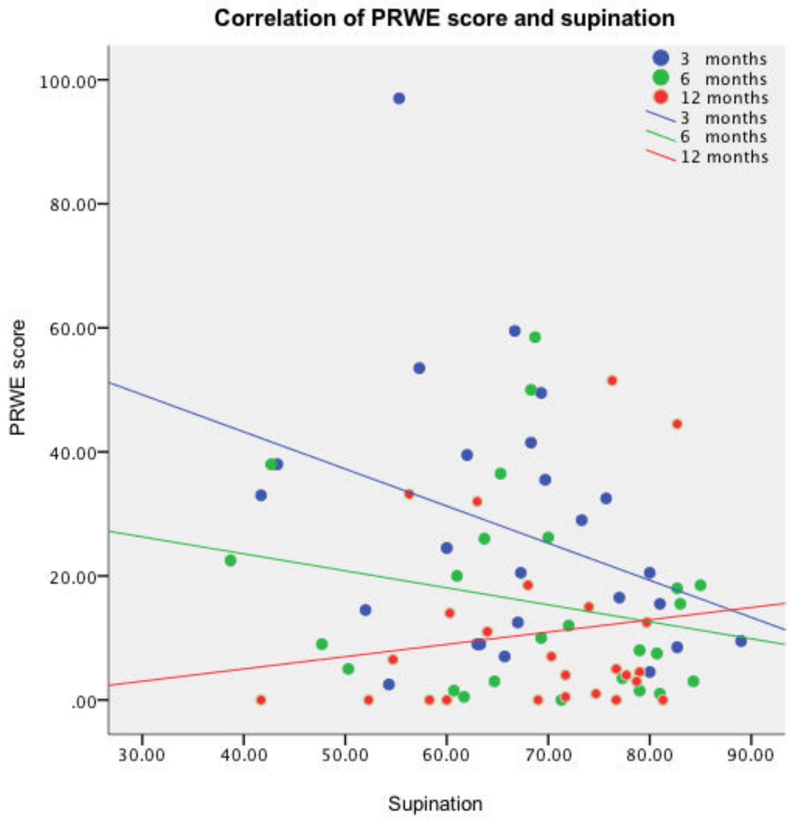
Figure 22– Correlation curves for the correlation of the PRWE score with physical measures of function at 3, 6 and 12 months

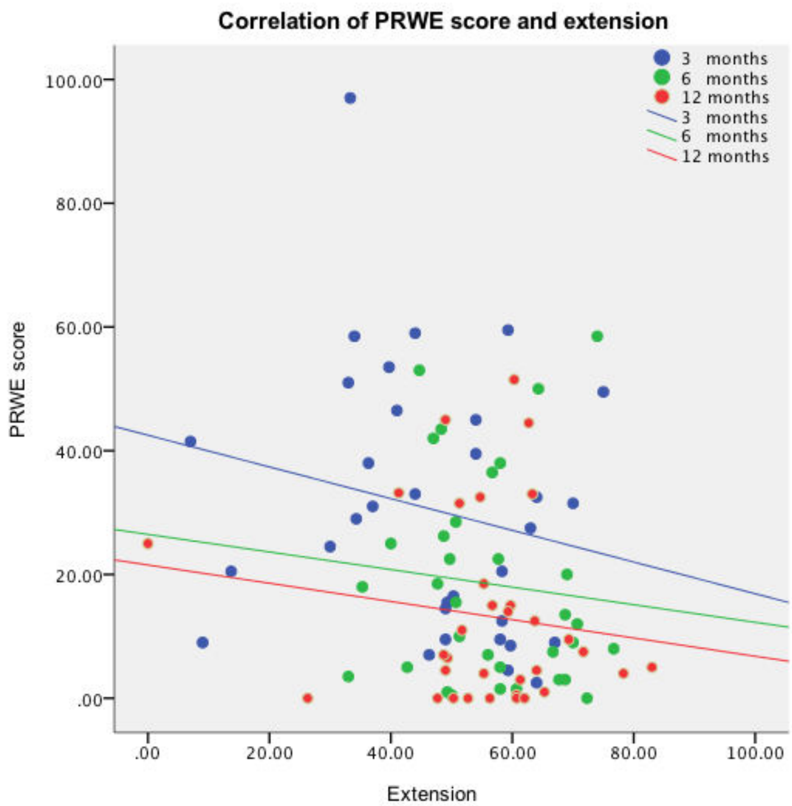




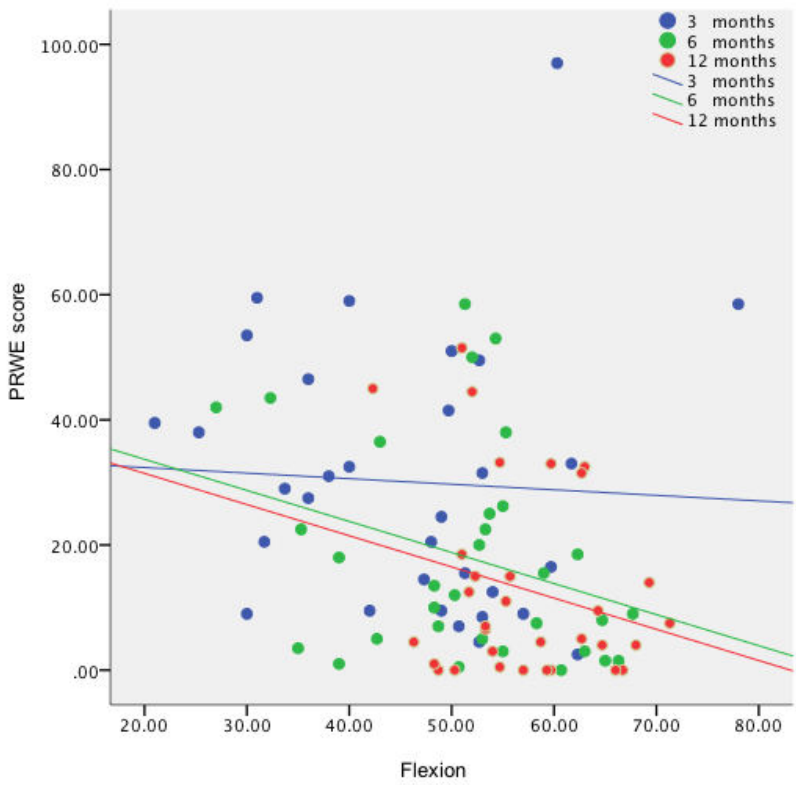

Correlation of PRWE score and pinch strength
3 months
6 months
12 months
PRWE score
60.00
50.00
40.00
30.00
20.00
10.00
.00
.00
2.00
4.00
6.00
8.00
10.00
12.00
Pinch strength (kg)


Correlation of PRWE score and pronation
3 months
6 months
12 months
PRWE score
100.00
80.00
60.00
40.00
20.00
.00
65.00
70.00
75.00
80.00
85.00
90.00
Pronation

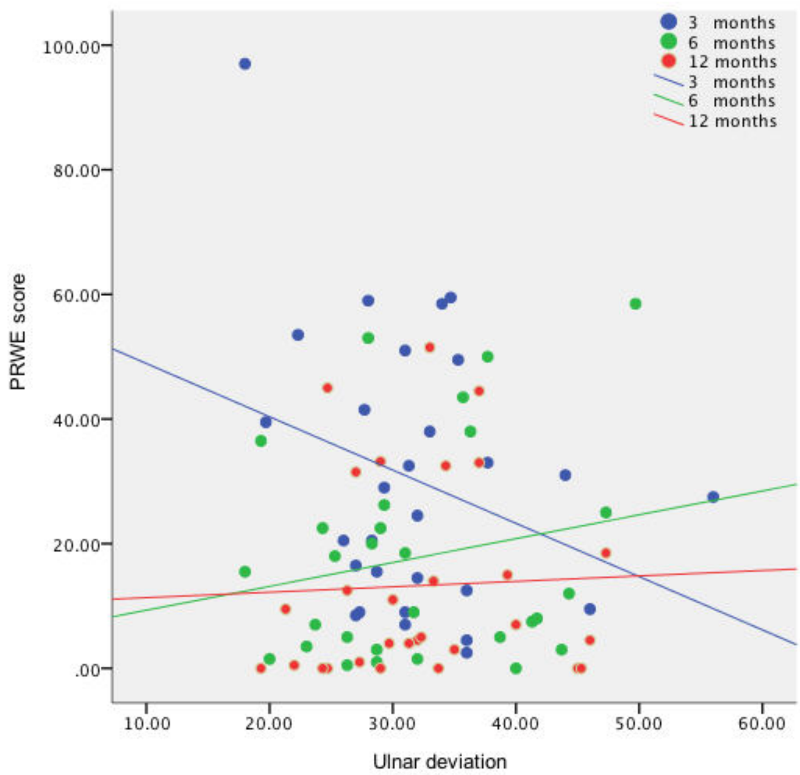

Correlation of PRWE score and supination
PRWE score
Supination
3 months
6 months
12 months
100.00
80.00
60.00
40.00
20.00
.00
30.00
40.00
50.00
60.00
70.00
80.00
90.00


Correlation of PRWE score and extension
PRWE score
Extension
3 months
6 months
12 months
100.00
80.00
60.00
40.00
20.00
.00
.00
20.00
40.00
60.00
80.00
100.00

Correlation of PRWE score and flexion



Correlation of PRWE score and ulnar deviation



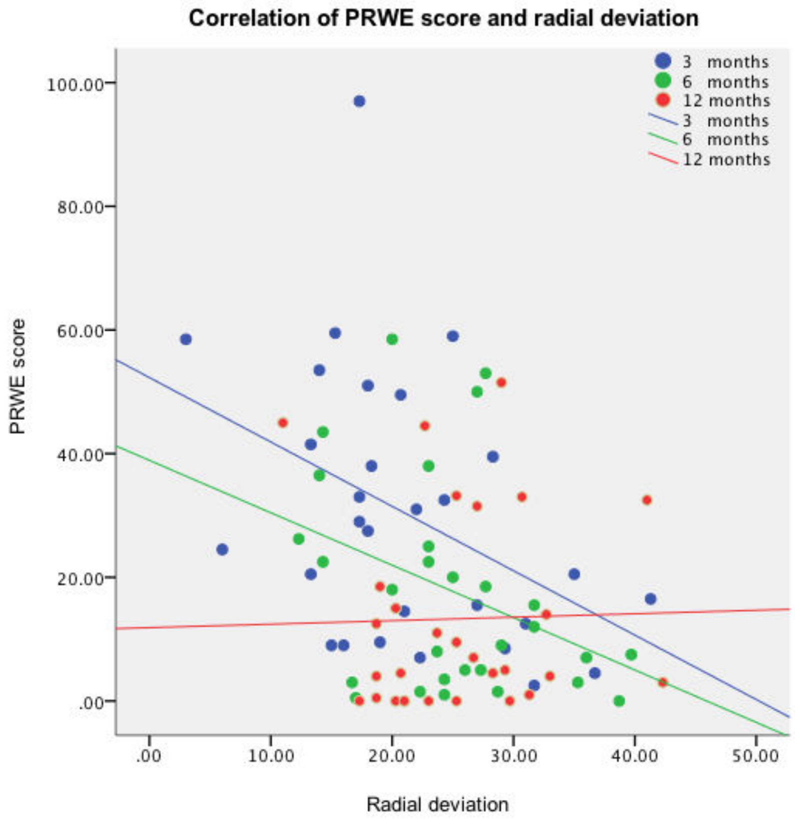


Table 38 – Correlation of the PRWE score and physical measures of function at 3, 6 and 12 months (Sig. 2-tailed). Significant correlations (p<0.005) are highlighted

	3 months		6 months		12 months	
	≥50 yrs.	<50 yrs.	≥50 yrs.	<50 yrs.	≥50 yrs.	<50 yrs.
Grip Strength (kg)	-0.73	-0.45	-0.07	-0.42	-0.55	-0.54
Grip Fatigue (%)	0.01	0.02	-0.11	0.37	-0.30	0.30
Pinch (kg)	-0.61	-0.34	-0.26	-0.26	-0.49	-0.53
Supination	-0.33	-0.48	-0.44	0.06	0.68	0.09
Pronation	0.00	-0.55	-0.04	0.06	-0.80	-0.09
Flexion	-0.70	0.01	-0.49	-0.22	-0.72	-0.10
Extension	***-0.93****	-0.22	-0.53	-0.06	0.15	-0.14
Ulnar Deviation	0.16	-0.36	-0.12	0.09	0.35	0.00
Radial Deviation	***-0.80****	-0.20	-0.21	-0.28	-0.22	0.04

0, 0.25
0.25, 0.5
0.5, 0.75
0.75, 1
-0.75, -1
-0.5, -0.75
-0.25, -0.5
0, -0.25

Appendix 9 – Correlation coefficient for the correlation of the physical measures with the PROMs subsections and individual questions

Table 39 - Correlation of physical measures of function with the PRWE subsections (Sig. 2-tailed). Significant correlations (p<0.005) are highlighted

	3 months			6 months			12 months		
	Pain	Function		Pain	Function		Pain	Function	
		Specific	Usual		Specific	Usual		Specific	Usual
Grip Strength (kg)	-0.39	***-0.50****	***-0.54****	-0.13	-0.25	-0.23	-0.34	***-0.55****	-0.42
Grip Fatigue (%)	-0.04	0.07	0.02	0.22	0.15	-0.01	0.09	0.26	0.16
Pinch (kg)	-0.36	-0.34	-0.37	-0.03	-0.20	-0.19	-0.32	***-0.53****	***-0.46****
Pronation	-0.41	-0.39	-0.43	0.04	-0.08	-0.21	-0.26	-0.31	-0.37
Supination	-0.35	***-0.55****	-0.43	-0.03	-0.24	-0.05	0.19	0.14	0.21
Flexion	-0.16	-0.13	-0.15	-0.01	-0.14	-0.16	-0.12	-0.29	-0.31
Extension	-0.23	-0.31	-0.33	0.13	0.00	-0.09	-0.19	-0.12	-0.11
Ulnar Deviation	-0.20	-0.24	-0.27	-0.03	-0.08	-0.12	0.12	0.02	0.01
Radial Deviation	-0.30	-0.38	-0.37	-0.18	-0.33	-0.23	0.03	-0.03	-0.07

0, 0.25	0.25, 0.50	0.50, 0.75	0.75, 1.0	-1.0, 0.75	-0.75, 0.50	-0.50, 0.25	-0.25, 0

Table 40 - Correlation of the physical measures of function with the individual DASH questions at 3 months. (Sig. 2-tailed). Significant correlations (p<0.005) are highlighted

	Grip strength	Grip Fatigue	Pinch	Pronation	Supination	Flexion	Extension	Ulnar deviation	Radial Deviation
DASH1 (Tight jar)	-0.39	0.14	***-0.42****	-0.14	-0.01	-0.12	-0.03	-0.06	-0.21
DASH2 (Write)	-0.21	0.06	-0.15	-0.18	-0.24	-0.03	-0.16	-0.15	-0.32
DASH3 (Key)	-0.22	0.10	-0.31	-0.08	-0.21	-0.07	0.13	-0.13	-0.13
DASH4 (Prepare meal)	**-0.52***	0.02	***-0.44****	-0.30	-0.32	-0.16	-0.23	-0.16	**-0.45***
DASH5 (Heavy door)	**-0.47***	0.00	-0.39	-0.31	-0.12	-0.19	-0.07	-0.17	-0.27

DASH6 (Object above head)	***-0.43****	0.21	-0.36	-0.16	-0.06	-0.29	0.03	-0.03	-0.13
DASH7 (heavy chores)	-0.40	-0.11	-0.35	-0.35	-0.19	-0.40	-0.06	-0.29	-0.14
DASH8 (garden work)	***-0.51****	0.09	-0.40	-0.21	-0.24	-0.08	-0.17	-0.25	-0.24
DASH9 (make a bed)	***-0.48****	0.23	***-0.43****	-0.35	-0.27	-0.20	-0.23	-0.03	**-0.49***
DASH10 (carry shopping)	***-0.56***	0.12	***-0.43***	-0.40	-0.30	-0.26	-0.10	0.01	-0.14
DASH11 (heavy object 10lb)	***-0.52***	0.11	-0.40	-0.11	-0.14	-0.06	-0.03	-0.05	-0.15
DASH12 (light bulb overhead)	***-0.57***	0.25	***-0.46***	-0.05	-0.14	0.03	-0.15	-0.19	-0.27
DASH13 (wash/ dry hair)	***-0.44***	0.01	-0.35	-0.31	-0.26	0.08	-0.07	-0.34	-0.12
DASH14 (wash back)	***-0.47****	0.00	-0.34	-0.28	-0.23	-0.12	-0.19	-0.31	-0.15
DASH15 (pullover sweater)	-0.35	-0.21	-0.14	-0.30	-0.45	-0.41	-0.05	-0.32	0.00
DASH16 (knife to cut food)	***-0.46****	0.14	***-0.43****	-0.29	-0.35	0.02	-0.32	-0.23	-0.43
DASH17 (little effort activities)	***-0.47****	0.17	***-0.45****	-0.31	-0.34	0.17	-0.11	-0.27	-0.30
DASH18 (forceful activities)	***-0.45****	0.10	-0.24	-0.27	-0.29	0.02	-0.27	-0.14	-0.29
DASH19 (free arm activities)	-0.36	-0.02	-0.12	-0.26	-0.29	-0.01	-0.13	-0.17	-0.07
DASH20 (transportation)	-0.30	-0.02	-0.17	-0.39	-0.35	0.02	-0.06	-0.30	-0.12
DASH21 (sexual activities)	-0.17	-0.12	-0.12	-0.23	0.04	-0.02	0.02	***-0.54****	0.12
DASH22 (social activity problems)	-0.28	0.20	-0.15	-0.18	-0.33	0.07	-0.18	-0.08	-0.14
DASH23 (limited activities)	***-0.55****	0.11	-0.37	-0.42	-0.31	-0.02	-0.28	-0.19	-0.32
DASH24 (pain)	-0.32	0.10	-0.18	-0.35	-0.28	-0.06	-0.30	0.00	-0.21
DASH25 (pain with specific activity)	-0.24	0.14	-0.07	-0.33	-0.21	0.00	-0.27	0.07	-0.20
DASH26 (tingling)	-0.09	0.11	-0.09	-0.14	-0.09	0.20	-0.17	-0.17	-0.20
DASH27 (weakness)	***-0.54****	0.24	-0.41	-0.29	-0.26	-0.07	-0.35	0.03	-0.43
DASH28 (stiffness)	-0.39	0.20	-0.27	-0.40	-0.34	-0.16	-0.34	0.08	***-0.45****
DASH29 (difficulty sleeping)	***-0.43****	0.24	-0.29	-0.23	-0.09	0.00	-0.10	-0.02	-0.17
DASH30 (loss of confidence)	***-0.45****	0.15	-0.30	-0.27	-0.29	0.02	-0.14	-0.07	-0.35

0, 0.25	0.25, 0.50	0.50, 0.75	0.75, 1.0	-1.0, 0.75	-0.75, 0.50	-0.50, 0.25	-0.25, 0

Table 41 - Correlation of the physical measures of function with the individual DASH questions at 6 months. (Sig. 2-tailed). Significant correlations (p<0.005) are highlighted

	Grip strength	Grip Fatigue	Pinch	Pronation	Supination	Flexion	Extension	Ulnar deviation	Radial Deviation
DASH1 (Tight jar)	-0.33	0.19	***-0.47****	-0.30	0.13	-0.20	0.18	0.17	-0.25
DASH2 (Write)	-0.17	0.07	-0.30	-0.28	-0.19	-0.24	-0.10	-0.18	-0.21
DASH3 (Key)	-0.24	0.00	-0.36	-0.17	-0.07	-0.17	-0.05	-0.13	-0.19
DASH4 (Prepare meal)	-0.24	0.14	-0.29	-0.22	0.03	-0.11	-0.02	0.04	-0.14
DASH5 (Heavy door)	-0.14	0.08	-0.14	-0.29	0.23	-0.05	0.13	0.08	-0.07
DASH6 (Object above head)	-0.09	0.07	-0.25	-0.15	0.17	-0.21	0.08	-0.12	-0.32
DASH7 (heavy chores)	-0.26	0.19	-0.36	-0.28	0.06	-0.12	0.06	0.15	-0.14
DASH8 (garden work)	-0.21	0.18	-0.22	-0.17	0.06	-0.12	-0.04	0.04	-0.18
DASH9 (make a bed)	-0.26	0.19	-0.23	-0.17	-0.02	-0.15	0.03	0.07	-0.25
DASH10 (carry shopping)	-0.27	0.19	-0.24	-0.02	0.17	-0.11	0.07	0.12	0.08
DASH11 (heavy object 10lb)	-0.27	0.10	-0.30	-0.23	-0.03	-0.20	0.09	0.16	-0.19
DASH12 (light bulb overhead)	-0.22	0.02	-0.38	-0.14	0.02	-0.23	0.03	-0.10	***-0.43****
DASH13 (wash/ dry hair)	-0.27	0.14	-0.38	-0.35	0.15	-0.19	0.02	0.00	-0.23
DASH14 (wash back)	-0.12	0.19	-0.38	-0.19	-0.01	-0.17	0.02	0.07	-0.23
DASH15 (pullover sweater)	-0.25	-0.05	-0.39	-0.08	0.08	-0.09	-0.17	0.12	-0.35
DASH16 (knife to cut food)	-0.28	0.09	-0.33	-0.26	0.05	-0.04	-0.16	0.15	-0.10
DASH17 (little effort activities)	-0.05	0.07	-0.04	-0.30	0.01	0.01	0.00	-0.05	-0.37
DASH18 (forceful activities)	-0.26	0.05	-0.30	-0.20	0.10	-0.26	0.06	-0.06	-0.18
DASH19 (free arm activities)	-0.30	-0.07	-0.41	-0.15	0.02	-0.23	-0.08	-0.05	-0.31
DASH20 (transportation)	-0.05	0.21	-0.05	-0.07	0.01	0.00	0.17	-0.04	-0.19
DASH21 (sexual activities)	0.14	-0.09	0.02	-0.31	0.20	0.17	0.02	0.19	0.03
DASH22 (social activity problems)	-0.10	0.13	-0.13	-0.18	0.12	-0.17	-0.03	-0.03	-0.18
DASH23 (limited activities)	-0.16	0.07	-0.19	-0.31	0.12	-0.21	0.16	-0.19	-0.11
DASH24 (pain)	0.06	0.15	-0.17	-0.24	0.07	-0.04	0.25	-0.03	-0.34

DASH25 (pain with specific activity)	-0.15	0.23	-0.34	-0.25	0.02	-0.19	0.13	-0.02	-0.34
DASH26 (tingling)	-0.07	-0.05	0.07	-0.16	0.25	-0.20	-0.16	-0.37	-0.12
DASH27 (weakness)	-0.15	0.27	-0.31	-0.30	0.08	-0.20	0.15	-0.03	-0.14
DASH28 (stiffness)	-0.32	-0.14	-0.37	-0.26	0.04	-0.25	-0.09	-0.23	***-0.43****
DASH29 (difficulty sleeping)	-0.19	0.06	-0.24	-0.33	-0.15	-0.18	0.00	-0.12	-0.31
DASH30 (loss of confidence)	-0.14	0.08	-0.17	-0.22	0.12	-0.21	-0.02	-0.03	-0.16

0, 0.25	0.25, 0.50	0.50, 0.75	0.75, 1.0	-1.0, 0.75	-0.75, 0.50	-0.50, 0.25	-0.25, 0

Table 42 - Correlation of the physical measures of function with the individual DASH questions at 12 months. (Sig. 2-tailed). Significant correlations (p<0.005) are highlighted

	Grip strength	**Grip Fatigue**	**Pinch**	**Pronation**	**Supination**	**Flexion**	**Extension**	**Ulnar Deviation**	**Radial Deviation**
DASH1 (Tight jar)	***-0.50****	0.16	***-0.50****	-0.21	0.09	-0.14	-0.15	0.03	-0.07
DASH2 (Write)	***-0.49****	0.15	***-0.51****	-0.03	0.09	-0.31	-0.35	-0.17	-0.15
DASH3 (Key)	-0.36	0.03	-0.40	-0.25	0.14	-0.20	-0.17	0.07	0.13
DASH4 (Prepare meal)	***-0.49****	0.13	***-0.59****	-0.15	0.09	-0.29	-0.30	-0.08	-0.09
DASH5 (Heavy door)	***-0.48****	0.10	***-0.47****	-0.20	0.06	-0.12	-0.24	0.01	0.12
DASH6 (Object above head)	-0.35	0.11	-0.56	-0.16	0.04	-0.18	-0.12	0.09	-0.07
DASH7 (heavy chores)	-0.35	0.15	-0.43	-0.19	0.03	-0.18	-0.18	0.04	0.03
DASH8 (garden work)	-0.38	0.07	***-0.47****	-0.01	-0.10	-0.15	-0.11	-0.10	0.00
DASH9 (make a bed)	-0.33	0.23	***-0.53****	-0.18	-0.08	-0.36	-0.18	0.05	-0.20
DASH10 (carry shopping)	-0.43	0.16	***-0.48****	0.14	-0.09	-0.13	-0.29	-0.04	0.16
DASH11 (heavy object 10lb)	-0.40	0.09	-0.31	-0.01	-0.12	0.00	-0.28	0.02	0.36
DASH12 (light bulb overhead)	***-0.52****	0.19	***-0.60****	-0.20	0.11	***-0.45****	-0.16	0.20	-0.21
DASH13 (wash/ dry hair)	-0.42	0.10	***-0.54****	-0.34	0.11	-0.35	-0.17	-0.03	-0.23
DASH14 (wash back)	-0.36	0.09	***-0.49****	-0.21	-0.08	-0.36	-0.27	0.10	-0.22
DASH15 (pullover sweater)	-0.29	0.06	-0.44	***-0.46****	0.15	-0.29	-0.11	0.06	-0.12
DASH16 (knife to cut food)	***-0.45****	-0.05	-0.42	-0.08	0.06	-0.21	-0.12	-0.04	0.11

DASH17 (little effort activities)	**_-0.46*_**	0.25	**_-0.56*_**	-0.07	-0.07	-0.32	-0.18	-0.24	-0.32
DASH18 (forceful activities)	-0.13	0.26	-0.35	-0.39	-0.01	-0.22	-0.11	0.14	-0.36
DASH19 (free arm activities)	-0.20	0.23	-0.38	-0.39	-0.03	-0.19	-0.20	-0.06	-0.31
DASH20 (transportation)	-0.25	0.09	-0.27	0.08	0.01	-0.11	-0.10	0.05	0.21
DASH21 (sexual activities)	-0.16	-0.17	-0.18	-0.04	0.01	0.08	0.00	0.00	0.36
DASH22 (social activity problems)	-0.38	-0.02	**_-0.45*_**	-0.36	0.00	-0.26	-0.17	0.01	0.01
DASH23 (limited activities)	-0.40	-0.03	**_-0.54*_**	-0.28	0.01	-0.34	-0.37	0.04	-0.15
DASH24 (pain)	-0.34	-0.12	-0.31	-0.06	-0.07	-0.06	-0.23	0.12	0.08
DASH25 (pain with specific activity)	-0.27	-0.24	-0.16	-0.16	-0.02	-0.20	-0.20	0.14	-0.05
DASH26 (tingling)	-0.34	0.06	-0.36	-0.43	0.13	-0.37	-0.14	0.03	-0.20
DASH27 (weakness)	**_-0.45*_**	0.01	**_-0.49*_**	-0.24	0.06	-0.17	-0.28	0.08	0.10
DASH28 (stiffness)	-0.15	-0.07	**_-0.46*_**	-0.35	0.07	-0.22	0.00	0.26	-0.17
DASH29 (difficulty sleeping)	-0.10	-0.32	-0.05	-0.30	0.06	0.07	-0.07	0.15	0.27
DASH30 (loss of confidence)	-0.31	0.11	-0.37	-0.35	0.13	-0.28	-0.05	0.09	-0.20

_0, 0.25_	0.25, 0.50	0.50, 0.75	0.75, 1.0	-1.0, 0.75	-0.75, 0.50	-0.50, 0.25	-0.25, 0

Table 43 - Correlation of the physical measures of function and the EQ5D subsections (Sig. 2-tailed). Significant correlations (p<0.005) are highlighted

	Grip strength	**Grip Fatigue**	**Pinch**	**Pronation**	**Supination**	**Flexion**	**Extension**	**Ulnar Deviation**	**Radial Deviation**
3 months									
EQ5D mobility	-0.11	0.17	-0.07	0.10	0.14	0.04	0.34	0.21	0.02
EQ5D Self-care	-0.11	0.09	-0.15	0.14	0.07	-0.15	-0.14	0.10	-0.17
EQ5D Usual Activities	-0.24	0.08	-0.17	-0.24	-0.03	-0.04	-0.15	-0.04	-0.07
EQ5D Pain	-0.34	0.16	-0.35	-0.31	-0.12	-0.09	-0.16	0.14	**_-0.43*_**
EQ5D Anxiety	-0.21	0.08	-0.11	-0.42	-0.20	-0.03	-0.05	0.01	0.11
6 months									
EQ5D mobility	-0.16	0.20	-0.18	-0.26	0.05	-0.18	0.11	0.14	-0.23
EQ5D	-0.35	0.25	-0.26	0.21	0.08	-0.13	-0.28	0.17	-0.33

Self-care									
EQ5D Usual Activities	-0.18	0.14	-0.19	0.06	-0.26	0.02	-0.08	-0.07	-0.23
EQ5D Pain	-0.28	0.21	-0.33	0.05	-0.06	***-0.42****	-0.13	0.00	-0.39
EQ5D Anxiety	-0.18	0.18	-0.18	-0.08	0.00	-0.14	0.07	0.33	-0.13
12 months									
EQ5D mobility	-0.26	0.07	-0.19	0.21	0.09	-0.12	-0.04	0.24	0.24
EQ5D Self-care	-0.20	0.26	-0.34	0.12	-0.22	-0.07	-0.19	-0.05	0.00
EQ5D Usual Activities	-0.31	0.20	-0.33	-0.07	-0.05	-0.24	-0.11	0.10	-0.15
EQ5D Pain	-0.32	-0.07	-0.25	-0.05	0.03	-0.14	-0.21	-0.01	0.03
EQ5D Anxiety	-0.19	0.00	-0.16	0.23	-0.03	-0.06	-0.34	0.10	0.20

0, 0.25	0.25, 0.50	0.50, 0.75	0.75, 1.0	-1.0, 0.75	-0.75, 0.50	-0.50, 0.25	-0.25, 0

Appendix 10

Interview schedule: patients' long-term perspectives

Good afternoon/morning. I am Caroline Plant, the orthopaedic research doctor that spoke to you on the phone about taking part in an interview to talk about your wrist fracture. This interview is for a research study to help us understand more about how wrist fractures affect peoples lives in the long term, and as part of the study I will be interviewing other people who have also had a fracture of the wrist. The knowledge gained from this study help other orthopaedic surgeons gain a greater insight into how their patients might be affected by their fractures.

Pause

So today I would like to talk about your home life, hobbies, work and any other part of your life that is important to you and has been affected by your fracture. I will be asking you about how your life was before your fracture and how it is today.

Pause

With your permission I would like to record our conversation using a Dictaphone, so that I don't miss any of the important details you tell me when I come to analyse this interview later. The recording will only be heard by myself and my supervisor XXXXXX from the University of Warwick and will be kept confidential at all times. After this interview I will type out a copy of the interview removing all identifiable information to analyse and will send you a copy for you to read. You are welcome to remove or contribute any further information to it, or keep it as it is. Once all the interviews have been analysed the recordings will be destroyed. If you would however prefer not to be recorded that is also absolutely fine, and I will instead some write brief notes as a memory aid and show them to you at the end of the interview.

Pause

I expect the interview will last about 20-30 minutes. Feel free to stop the interview at any point for a break or to end it.

Pause

If during the interview you have concerns about your wrist and would like to be seen by the orthopaedic team, I can speak to the orthopaedic consultant in charge of the wrist fracture study you were originally entered into on your behalf.

Prior to the fracture

If you are ready to begin I would like to start by talking about before your fractured your wrist.

- Can you tell me about yourself?
- Would you mind telling me about your home life before your fracture?
    - Prompt - Did you live by yourself?
    - Prompt – Any others in your household?
    - Prompt – How about housework?
    - Additional comment - How about before your fracture?
- For our research you have told us that you worked (part time/ full time etc.), can you tell me some more about your work before your fracture?
    - Prompt - What would you do on a normal day at work or during the week?
    - Prompt – What did that involve?
    - Prompt – office work – did your work involve a lot of typing on a computer?
    - Prompt – manual work – did you do a lot of lifting? Can you tell me about that?
    - Prompt –Can you tell me more about it?
- Can you tell me about any hobbies or interests you enjoyed before your fracture?
    - Prompt - Was that something you used to enjoy on a regular basis or more occasionally?
    - Prompt – Did you do this with others such as friends or as part of a social group?
    - Additional phrase - that really helps me get an idea of your life before your fracture
- Are there any other things you used to do that have been affected by your fracture?

Fracture Management

May be included depending upon how the interview goes

- Can you tell me what happened after you fractured your wrist?
    - Prompt – were you seen in the fracture clinic?
    - Prompt – what did the doctors do for you?
    - Additional comment - Thank you that was very helpful

Long-term consequences

I would like to talk about how your wrist is now and how your break might have affected your life.

- Perhaps we can start with how your wrist is now?
    - Prompt – what can you do?
    - Prompt - What can't you do?
    - Prompt – Did you used to be able?
    - Prompt – What is different from before your fracture?
    - Prompt – What about pain?
    - Prompt – What do you when you're wrist bothers you?
    - Prompt – Have you need to seek additional medical attention for your wrist? ... can you tell me about that?

- Can you tell me how your wrist has affected your home life?
    - Prompt – You mentioned you used to do the .... (ironing/ washing etc.) are you still able to do that?
    - Prompt – Have you need to change how you do that?
    - Prompt – advantages and disadvantages of doing it like that
    - Additional phrase – you telling me this could be useful for others in your position
    - Prompt – Do your family/ friends help more with the housework/ gardening?
    - Prompt – Has that put strain on your relationship with others at home?

- What kind of impact has your break had on your working life?
    - Prompt – Have you needed to make changes to how you work?
    - Prompt - How about your duties, have they changed?
    - Prompt – Was that because of your wrist fracture?
    - Prompt – What couldn't you do anymore?
    - Prompt - Have you made any changes to how you work because of your wrist?
- You mentioned earlier that you used to enjoy ....(activities). What activities do you enjoy now?
    - Prompt – if the same hobbies
        - Have you needed to change how you do that since you broke your wrist?
        - What kind of changes have you made?
    - Prompt – if different – These are different from the ones you used to do, what made you decide to take up these new hobbies?
    - Additional comment – please tell me more about that?
- Lastly I would like to finish by asking you some personal question about whether your wrist has affected how you care for yourself?
    - Prompt – Do you have any problems washing or dressing yourself?
    - Prompt – How about using the toilet?
    - Prompt – Does your ..... help you to do that?
    - Additional comment – is that different from before you fractured your wrist?
    - Additional comment – thank you for sharing that with me

Thank you for speaking to me today, that was very helpful. I have brought another copy of the information sheet with me today with my details on if you would like to contact me about the interview or tell me more about your wrist. If you have concerns about your medical treatment or this interview today there are also details about the patient advice and liaison service and the university support services as well. Thank you again.