The impact of wrist and forearm fractures on return to driving

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A thesis submitted in fulfilment of the requirements for the degree of a Doctor of Philosophy

Faculty of Medicine and Health

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CANDIDATES STATEMENT OF ORIGINALITY

I, Susan Belinda Stinton, certify that this thesis entitled "The impact of wrist and forearm fractures on return to driving" is a product of my own work and has not been submitted to any other university or institution as a part of a whole requirement for any other degree.

I, Susan Belinda Stinton, declare that I was the principal researcher of all work including in this thesis, including work published with multiple authors. All of the assistance received in preparing this thesis and sources have been acknowledged.

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SUPERVISORS STATEMENT

This is to certify that the thesis entitled “The impact of wrist and forearm fractures on return to driving” submitted by Susan Belinda Stinton in fulfilment for the requirements for her Doctor of Philosophy is in a form ready for examination.

I attest that the following author attribution statement provided for the published and submitted papers presented in this thesis are a true and accurate representation of the candidate's contribution to the publication.

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Chapter		Author contribution
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I, Susan Belinda Stinton, attest that the above table of contribution for the published and submitted papers is a true and accurate representation of my contribution to each study in this thesis.

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Oral Presentations:

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2019 (Accepted abstract) WA Society for Surgery of the Hand Annual Meeting. "Longitudinal recovery following distal radial fractures managed with volar plate fixation."

2016 (Accepted abstract) Australian Hand Therapy Association National Conference. "When Can I drive? Return to driving following a wrist fracture: A critical review."

2016 (Accepted abstract) Australian Hand Therapy Association National Conference. "Longitudinal recovery following distal radius fractures managed with volar plate fixation: a systematic review with meta-analysis."

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3. **Stinton SB**, Pappas E, Edgar DW, Moloney NA. Driving Performance Following a Wrist Fracture: A Pilot Study. *Hand Therapy. 2020;25(1):26-36.*

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ADDITIONAL WORK UNDERTAKEN DURING PHD CANDIDATURE

Completion of the Public Health Unit

PUBH5215 Introductory Analysis of Linked Data

Peer-review experience

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Invited member of the Editorial Board

PREFACE

This thesis is organised into seven chapters, written so that each chapter can be read independently or together as a series of studies forming the whole body of work. The University of Sydney allows manuscripts that arise from the candidature to be included in the body of the thesis. This thesis includes an introduction (Chapter One), five studies that have been published or are submitted for publication (Chapters Two to Chapter Six) and a conclusion (Chapter Seven). Each chapter contains its own reference list. Any relevant appendices that were published as online supplementary material or additional unpublished work performed relating to these studies are provided at the end of the chapter or in the appendices section at the end of this thesis.

Ethics approval was granted prior to the commencement of the studies in Chapters Three, Five and Six. Ethics approval was granted from the Western Sydney Local Health District Human Research Ethics Committee (4220/AU RED HREC/15/WMEAD/52) for the study reported on in Chapter Five. Separate ethics approval was granted from the Department of Health Western Australia Human Research Ethics Committee (PRN RGS0000001352) for the series of studies reported on in Chapter Three and Chapter Six.

Chapter One is an introduction to the thesis and provides an overview of the relevant literature and the topics relevant to the remaining chapters.

Chapter Two is a critical literature review paper detailing the prior relevant literature to the thesis. This manuscript is presented as published in the *Hand Therapy* Journal.

Chapter Three is the first of two papers using state-wide linked government health data, which reports on the contemporary Australian epidemiology of wrist and forearm fractures, detailing management preferences,

complication rates and variables associated with increased likelihood of complication and/or undergoing secondary surgical procedures. This manuscript is presented in the format required for *PLoS One Journal.*

Chapter Four is a systematic review and meta-analysis paper detailing the longitudinal recovery following distal radius fractures, from the date of surgical fixation until two years post-surgery. This manuscript is presented as published in the *Bone and Joint* Journal.

Chapter Five is a pilot study reporting on the feasibility of using a driving simulator to measure differences in driving performance between adults recovering from a wrist fracture and uninjured controls. This manuscript is presented as published in the *Hand Therapy* Journal.

Chapter Six is the second paper in the series using state-wide linked health and car crash data. This manuscript reports on the occurrence of car crashes before and after wrist fractures, and also identifies variables associated with increased odds of car crash following wrist fracture. This manuscript is presented as published in the *Journal of Hand Therapy.*

Chapter Seven summarises the key outcomes and clinical relevance of the results of this thesis and provides recommendations for future research.

ABSTRACT

Due to the importance of driving in activities of daily living and work, individuals recovering from wrist fractures commonly pose the question “when is it safe to return to driving?” The broad aim of this thesis was to develop a deeper understanding of wrist and forearm fractures; including their recovery, management, complications rates, and impact of these on return to driving. Given the complexity of the clinical decision-making process regarding return to drive following wrist and forearm fractures, each chapter within this thesis discusses findings relating to a more specific aim within this topic.

The first aim was to identify current indicators of, and recommendations for safe return to driving following wrist and forearm fracture based on prior literature. The results from the literature review in Chapter Two demonstrate that previous research on driving following any upper limb injury is exceedingly limited. Survey studies show that there are vast differences in advice given regarding return to drive in this patient group. Clinical papers investigating the effect of wrist immobilisation casts on uninjured participants provide low level evidence to suggest driving performance is impaired when the wrist is immobilised. There were no clinical papers at the time of publication of that manuscript that investigated any aspect of return to driving among participants with wrist fracture pathology.

Wrist and forearm fractures are commonly reported to be among the most prevalent fracture types. However, up-to-date wrist fracture epidemiology in Australia is lacking. The manuscript in Chapter Three is the first of two papers using state-wide linked health data to report on wrist and forearm fracture epidemiology in the state of Western Australia. This paper highlights a 14% increase in the annual incidence of wrist fractures recorded between 2008 to 2017, specifically in middle-aged and older women. Surgical management preferences follow world-wide trends with increasing utilisation of acute fracture fixation using open reduction and internal fixation over external fixation options. Complication(s) were reported in 12.6% of the cohort: acute complications were reported in 3.6% and secondary procedures were utilised in an additional 9.8% of individuals recovering from a wrist or forearm fracture. As physical and functional outcomes are worse when

complications occur, Chapter Three also identifies the profiles of individuals who are most likely to suffer complications.

Wrist fractures result in considerable functional limitation, especially in the acute recovery period. Given the difficulty in undertaking other daily activities, it is hypothesized driving performance is also impaired. To understand how return to driving fits in the overall recovery pathway, it is important to first understand the longitudinal recovery. The manuscript in Chapter Four is a systematic review and meta-analysis, which details the expected longitudinal recovery throughout the first two years following distal radius fracture. Physical and functional outcomes show initial high disability with rapid improvement over the first three months, followed by slower but continued improvement for up to one year post fracture.

There are no standardised procedures to measure and assess the driving performance or car crash risk following upper limb injury. The pilot study in Chapter Five shows that the driving performance of individuals recovering from wrist fracture can be assessed using a driving simulator. The feasibility of using this methodology was acceptable, as the assessments were completed by 91% of participants and retention rates were 83%. In addition, the results from this study provide preliminary data indicating impairment in steering wheel control and more cautious driving behaviours following wrist fracture, when comparing those recovering from wrist fracture to uninjured controls.

Even if the driving performance is impaired following wrist fracture, it is not clear if this equates to an increased actual risk of car crash. The manuscript in Chapter Six is the second of two papers using the state-wide linked government health and car crash data. This paper reports on a surprising 3.3% reduction in the proportion of individuals involved in car crashes in the two-year period following wrist fracture (2.7%, n=1006/37017), when compared to the proportion involved in a crash prior to the fracture date (6.0%, n=2234/37107). Important findings relating to those most likely to be involved in a car crash were identified; when accounting for the known influence of age and sex on car crash, those with more severe wrist fracture injury patterns are 79% more likely to be a driver in a car crash in the first three months following wrist fracture, when compared to those with

simpler/isolated wrist fractures. In addition, workers with wrist fracture were 59% more likely to be a driver in a car crash, when compared to those who were not employed at the time of their fracture.

This thesis has reported on the impact of wrist fractures on driving. Given the incidence of wrist fractures are increasing, the burden of injury is escalating. This series of studies provide early evidence to suggest that driving performance is impaired in the acute recovery period, most noticeably in the first six weeks following wrist fracture when the physical and functional impairments are highest. Those with more severe wrist fracture injury patterns are more likely to be involved in car crash than those with simple wrist fractures. By three months following the wrist fracture, there were no ongoing fracture or demographic variables associated with increased likelihood of crash. The final conclusion chapter in this thesis draw together these key findings and discuss these with reference to other relevant studies in the field, as well as highlighting recommendations for future research. The results from this thesis will assist in decision making regarding return to driving following wrist fracture, so that individuals can be given timely and well-informed advice.

DEFINITION OF TERMS

Driving capacity: the ability to perform the tasks involved to control the vehicle and drive safely.

Driving behaviour: the way in which an individual chooses to perform the driving task. This may involve variables including adherence to speed limits, preference to be cautious or perform riskier manoeuvres and/or engage in driver distractions such as mobile phone use.

Driving performance: the way in which an individual carries out the driving task, as a result of their driving capacity and their driving behaviour.

TABLE OF CONTENTS

CHAPTER ONE

INTRODUCTION

1.1 THE COMPLEX DECISION-MAKING PROCESS WHEN RETURNING TO DRIVE FOLLOWING UPPER LIMB INJURY

After sustaining a wrist or forearm fracture, many individuals ask "when is it safe?" to return to drive. Individuals often have perceived safety risks and concern regarding motor vehicle insurance coverage if they return to drive too soon after their injury. However, not driving has ramifications including social isolation, reliance on family or other forms of transportation, time off-work, and associated financial strain. From the health practitioner's perspective, it is not possible to give evidence-based recommendations regarding safe return to drive following upper limb injuries due to lack of research. In addition, there are associated medico-legal and safety risks to the community if inappropriate advice is given to individuals with restricted capacity who return to drive. Despite the high incidence, related cost to the health care system, risks to the individual and community and the significant upper limb disability expected following wrist and forearm fractures, there is no prior research to ascertain the potential influence on driving performance.

1.1.1 Significance of the problem

Driving is a fundamental part of life and culture for the majority of Australians. Much of Australia has a large urban sprawl as well as remote country towns with limited access to alternate transportation options, which compounds the importance of being able to drive safely. Driving is required for individuals to perform daily activities including work, grocery shopping, social outings and attending healthcare appointments. Many medical conditions or injuries result in individuals being unfit to drive, with subsequent loss of independence and negative financial and social consequences.[1]

Due to the increasing population as well as an increase in the proportion of adults who have a driver's licence, the number of licenced drivers in Australia has been steadily growing since the 1940s.[2] Based on data from 2016, there were nearly 17.9 million adults in Australia who were registered to drive.[2] Given that the population in 2016 included 18.75 million adults,[3] this equates to over 95% of adults of driving age holding current licences.

Car crashes have substantial financial and health consequences.[4] In Australia, car crashes were estimated to cost the economy $29.7 billion in 2020, which is equivalent to 1.4

percent of the gross domestic product.[5] In addition to the financial cost, there can be devastating social and health impacts. Worldwide, car crashes contribute to more than 1.2 million fatalities annually and an even greater number of non-fatal injuries.[4] Although car crash fatalities in Australia have reduced in the last decade by 13.6%, hospitalised injuries increased by 16.2% between 2012 and 2018.[6] Over 25% of those hospitalised had injuries classified as high threat to life (those with an International Classification of Disease derived Injury Severity Score of less than 0.941, which is the probability of survival derived directly from ICD injury diagnoses).[6] Although most injuries sustained from car crashes are not life threatening, road injuries are known to be a major cause of health loss globally.[7] The most common injuries sustained in a car crash are fractures, amputation, burns, open wounds and traumatic brain injury.[7] Despite the wealth of information regarding the burden of road injuries, there is no known literature reporting on the car crash incidence following upper limb injuries, including wrist and forearm fractures.

Fractures of the wrist and forearm occur at all ages[8, 9] and are among the most common fractures treated in Australia,[10] the United States[11] and the United Kingdom.[12] Due to the high prevalence of wrist fractures among those of working age, there are additional financial consequences at a national level relating to lost workforce productivity due to medical leave. The significance of the return to drive decision also impacts individuals with wrist and forearm fractures who are unnecessarily advised to abstain from driving for a period following their fracture. Timely return to driving is important to minimise absences from work and the associated financial burden of injury.

In summary, appropriate guidance regarding the optimal timeframe in which adults recovering from wrist fracture should return to drive is important at an individual, societal and national level. The effects of a car crash on individuals and their community can be devastating. Conversely, delaying return to drive also has consequences to the individual and due to the high prevalence of injury there are also negative implications for the economy.

1.1.2 The driving task

Driving a motor vehicle is a complex task and requires adequate cognitive and physical function, along with sufficient sensory input to drive safely.[13, 14] Cognitively, drivers need the ability to process information from their environment to determine appropriate responses.[14] Physically, drivers use multiple upper limb motor functions to allow them to control their vehicle (for example, starting the ignition, grip and turn the steering wheel, operate the indicators, gear lever and hand brake consistently), and need to be able to do these tasks quickly and accurately in case of an unexpected event or to evade a hazard.[13, 14] When considering the multifaceted demands of the driving task, it follows that conditions that impair the physical or cognitive status of the driver have a potential influence on driving capacity.[13, 14]

Regardless of cognitive and physical capacity, driving performance is also influenced by each driver's individual behaviour.[15] Driver behaviour is the way each individual chooses to manoeuvre their vehicle and interact with other road users.[16] An individual's risk-taking choices such as speeding or aggressive overtaking, illicit drug or alcohol consumption prior to driving or potential use of driver distractions such as mobile phone use are all examples of driving behaviour that may also affect driving safety and outcomes.[15]

1.1.3 Medical fitness to drive

In Australia, medical fitness to drive is outlined in the Ausroads guidelines.[14] These guidelines advocate for the use of evidence-based recommendations where available. However, due to the limited literature regarding return to drive following upper limb injury, recommendations following wrist and forearm fracture are predominately based on expert opinion. These guidelines recognise fractures as a temporary injury where recovery is expected. They acknowledged that injuries to the limbs or recovery from orthopaedic surgery may temporarily affect the ability to drive safely and potentially increase car crash risk. These guidelines recommend that people with "short-term musculoskeletal conditions (such as injury or following orthopaedic surgery) should be advised not to drive for the duration of their treatment" with the return to drive recommendation determined by the treating doctor rather than licensing laws.[14] However, this recommendation is arguably not practical, as the physical effects of fractures often persist for much longer than 3 months

and fracture treatment including therapy or secondary surgical requirements may last for more than a year.[17-20] Abstaining from driving for this length of time is usually not practical in an Australian context, nor routinely recommended, especially if the ongoing impairments are minor. The Ausroads and other national return to driving guidelines[21, 22] all lack evidence-based recommendations regarding specific timeframes and objective measures or scores in clinical tests that could be used to inform decision making on fitness to drive for temporary injuries, including wrist and forearm fractures.

Following diagnosis of various chronic health conditions, a formal driving assessment is recommended in many countries for individuals with persistent physical impairments to retain a current drivers licence registration.[14, 21-23] However, driving assessments are not routinely recommended for Australians with temporary injuries including most fractures, due to the cost and the time commitment involved in testing.[14] For injuries where full recovery is expected, the Ausroads guidelines also recommend "the non-driving period should be determined by the treating health professional based on a consideration of the driving task, and the impact of treatments on the capacity to undertake these tasks, including responding to emergency situations."[14] In combination the lack of objective recommendations in the available guidelines and inappropriate nature of formal driving assessments for those recovering from wrist and forearm fracture, health practitioners are left to base their decision regarding fitness to drive on their clinical opinion rather than on evidence-based guidelines.

1.1.4 Known human contributors to car crashes

A number of human factors are associated with increased risk of car crashes, including alcohol consumption, speeding and driver fatigue.[15, 24, 25] In addition, driving is not recommended while taking some medications due to an increased risk of crash. Opioid-based medication is often prescribed for analgesia following orthopaedic surgery, including acute wrist fracture fixation procedures.[15, 26] As those using opioid medication have up to a two-fold increase in risk of car crash compared to those not using opioids,[26] it is routinely advised that individuals do not drive while using this medication.[23, 26] Despite a reported understanding of increased crash risk, many individuals admit to driving while using such medication following their wrist fracture.[1]

There are a number of chronic health conditions that are known to impair driver performance and increase crash risk.[23, 27-31] These include (but are not limited to) visual impairment, dementia, seizures, heart disease, arthritis, head injury and other neurological conditions.[23, 27-31] The few papers that focus on crash risk among people suffering from chronic musculoskeletal disorders found that up to 50% of individuals with conditions including osteoarthritis and rheumatoid arthritis reported driving difficulties[27, 29] and further, those with osteoarthritis were up to 1.8 times more likely to have a car crash than those without osteoarthritis.[30] A meta-analysis concluded the relative risk of a crash was 1.17 (p=0.002) among patients with other general musculoskeletal disorders, compared to those without such disorders.[31] However, the overall increased risk is small.[31]

There is limited research regarding the impact of temporary upper limb conditions and injuries on driver performance and crash risk.[13] However, there is a greater body of literature relating to the impact of temporary lower limb injuries on driving.[32] Such injuries include lower limb fractures,[33] total hip and knee replacements[34, 35], anterior cruciate ligament surgery [36, 37] and knee arthroscopy.[38] These papers focus on the requirements of the lower limb in driving, such as brake pedal force and reaction time, to assess the ability to stop the vehicle in an emergency situation.[34-38] However, the results from these studies do not directly generalise to recovery from upper limb injury, due to the different vehicle control tasks (e.g. fine control of steering wheel, indicator, key and lever use of the upper limb and pedal use in the lower limbs) and arguably more complex demands of the upper versus lower limbs.[13] The research relating to acute lower limb trauma is therefore, not clearly relevant to the upper limb trauma population and is not appropriate for preliminary evidence from which to form inferences.

Aside from the cessation of opioid medications, there are no recommendations in the Ausroads document about expected timeframes, objective physical requirements (such as grip strength or wrist range of motion), or key clinical assessments which may guide decision making regarding return to driving following upper limb injury.[14] The lack of recommendations and policies likely relates to the lack of research investigating the driving performance or car crash risk following any upper limb injury.[1, 13] To fully understand and to

identify the extent of the gaps in the research, Chapter Two provides a comprehensive review of the research on return to driving after a wrist fracture.

1.2 FACTORS THAT CONTRIBUTE TO THE IMPACT OF WRIST AND FOREARM FRACTURES ON RETURN TO DRIVE

The impact of wrist and forearm fractures on return to driving is informed by the epidemiology and understanding of the clinical course, resultant symptoms and impairments following these injuries. The epidemiology highlights the incidence and consequences of the problem: namely the number of individuals (and their healthcare practitioners) who are faced with determining the optimal timing for return to drive. Secondly, understanding the common acute fracture management approaches and subsequent stages of functional recovery will help to acknowledge the stage in which return to drive fits into the overall recovery pathway.

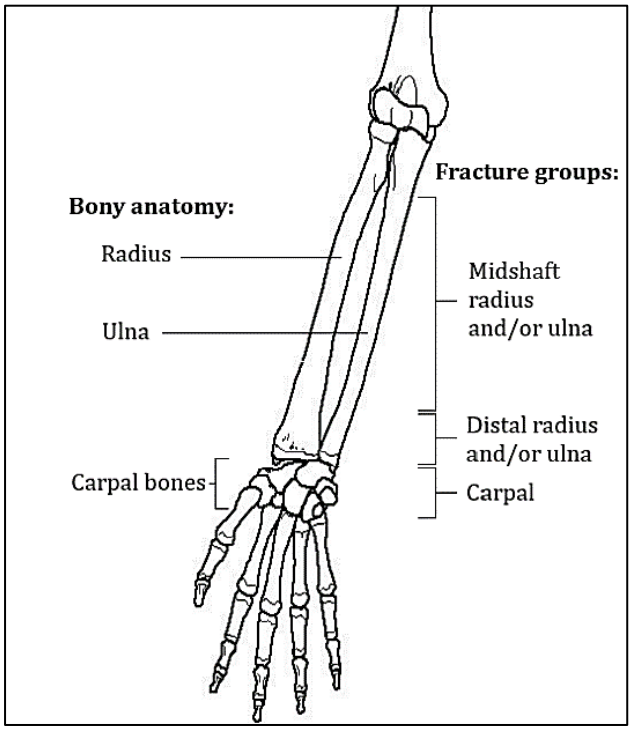
1.2.1 Wrist and forearm fracture epidemiology

Wrist fracture incidence has been reported in other countries between 195-480 per 100,000 people each year.[20, 39, 40] However, the recent majority of the epidemiological research related to wrist and forearm fractures has been limited to specific demographic subgroups such as older adults[41-44], or specific causes of fracture such as osteoporosis.[9] Studies conducted on state wide or other national cohorts are available,[39, 41-46] but these do not include contemporary Australian epidemiology. In addition, some recent literature suggests that the incidence of wrist fractures is increasing in other countries.[8, 46, 47] Current and local incidence data is fundamental to understanding how many adults are faced with making decisions regarding their return to drive following their wrist or forearm fracture. Chapter Three provides updated Australian wrist and forearm fracture incidence from 2008 to 2017 for all types of wrist and forearm fractures, across all adult age and sex groups.

1.2.2 Wrist and forearm fracture aetiology

Fractures to the wrist or forearm are often classified according to the location of the fracture[48] (*Figure 1*): 1) the midshaft of the radius and/or ulna, 2) the distal radius and/or ulna and 3) carpal bone(s).

Figure 1: Types of wrist and forearm fractures



*Modified image by Topinard, P, Anthropology, Human beings, 1890, London: Chapman and Hall. Accessed online on 22 September 2022 from http://commons.wikimedia.org

Distal radius fractures occur within 2cm of the distal articular surface of the radius, involve the metaphysis of the distal radius and may also include the distal ulna and/or distal radioulnar joint.[8] Fractures of the midshaft of the radius and/or ulna are those involving the diaphysis of either bone. Carpal fractures may involve any of the eight carpal bones. Although each of these subgroups are broadly classified as wrist and forearm fractures, they each involve different aetiology and demographics.

Fractures of the distal radius and/or ulna (DRF): Adult DRF have a bimodal, age-stratified incidence, with peaks in young adults and older people, although the mechanism of injury is different for each group.[8] The younger population usually sustains a DRF as a result of high-energy trauma, whereas the older population from low-energy trauma for example, from a fall from standing height.[8, 41] The younger population is more likely to be male, with the older population more likely to be female, but females constitute 75-77% of the total population with DRF.[8, 39, 49] A DRF can be the first clinical sign of osteoporosis, as DRF occur at a younger age than other osteoporotic fractures (such as at the hip, head of humerus or spine).[8, 50, 51] DRF are early and independent predictors of future osteoporotic fractures at

other skeletal sites,[8] with one study reporting that those with DRF have a relative risk of 1.9 times the likelihood of sustaining a future osteoporotic fracture than those without DRF.[52]

Fractures of the midshaft of the radius and/or ulna: Midshaft, or diaphyseal fractures of the radius and/or ulna are much less common than DRF and consequently, the epidemiology papers are scarce.[9, 53, 54] Midshaft forearm fractures are most common in young adult males.[9] The mechanism of injury is most often high-level trauma, particularly from a direct blow or through rotational force on the forearm.

Fractures of the carpal bone(s): Carpal fractures most commonly occur in adults under 40 years of age and are most common in males.[55-57] Typical mechanisms of injury involve falling on the outstretched hand with hyperextension or radial deviation at the wrist during sporting accidents or other high energy trauma.[55-57] The scaphoid is involved in up to 90% of carpal fractures.[56, 57] The triquetrum is the second most common carpal bone to fracture.[58] While fractures of the trapezium, trapezoid, lunate, capitate, hamate and pisiform are documented, they are much less common.[57-60]

Given the variation in characteristics among each wrist and forearm fracture type, it follows that the demographics cover a broad and variable range of drivers, both males and females across all age groups over 18 years. When also acknowledging the high incidence of wrist fractures it is apparent that many Australian adults and their health-care providers are faced with the complex decision-making regarding return to drive following their wrist fracture.

1.2.3 Management of wrist and forearm fractures

Wrist and forearm fractures can be treated conservatively with immobilisation (with or without closed reduction) or surgically. Most individuals with wrist or forearm fractures are treated conservatively but acute fracture surgery is often used for unstable fractures.[49] Surgical management techniques can be open or closed and involve internal or external fixation. Internal fixation methods include Kirschner wire (k-wire), screw or plate fixation.[61, 62] It is routinely recommended that the wrist is immobilised until fracture stability is achieved but this timeframe will vary depending on the fracture type and management choices.[62] In conservatively managed wrist fractures immobilisation is often longer than in

those with acute surgical fracture fixation as conservatively managed fractures rely on secondary bone healing pathways.[61] Even among those managed with similar surgical procedures there is inconsistency with the duration of immobilisation between authors.[62] Loading of injured upper limbs is routinely limited to light activity (or the equivalent of approximately 0.5-1 kg lifting restriction) in the early stage of fracture healing.

Following the immobilisation period, exercises and therapy to regain wrist and forearm range of motion are undertaken.[63] The subsequent phase of bone healing involves consolidation of the bony union and occurs from approximately week 6 to 12, and continues for up to 1 or 2 years following most wrist and forearm fractures.[64, 65] During this stage progressive functional return is usually encouraged, along with progressive exercises to improve strength and proprioception. Despite the common recommendations regarding rehabilitation progression, there is a need for ongoing research to provide best evidence-based knowledge to inform therapy practices.[63] For the purpose of this thesis, it is necessary to understand the management and rehabilitation pathways of common wrist and forearm fracture types, so that potential associations between the fracture or management processes, driving performance or increased risk of car crash can be identified.

Management of distal radius fractures: Fractures of the distal radius are most often managed with immobilisation casting for 6 weeks, with or without closed manipulation.[62, 66-68] Over 80% of DRF are managed conservatively.[69] However, even with adequate closed reduction the fracture is often unstable and casting alone may not maintain reduction of the fracture.[67] Clinical practice guidelines approved by the American Academy of Orthopaedic Surgeons in 2009 advocate for internal fixation rather than conservative management when there is more than 10 degrees of dorsal tilt and/or radial shortening of more than 3mm and/or more than 2mm of step deformity in the radiocarpal joint in patients younger than 65 years.[40, 63] Indications for surgical fixation in patients over 65 years are less clear, as acute surgical fracture management in those older than 65 years does not result in better long term functional outcomes and there are potential for post operative complications.[70-72] The "Choosing Wisely" movement in Australia is a national campaign that encourages clinicians to have informative conversations about procedures where evidence shows they provide no benefit and, in some cases, lead to harm.[73] There is no direct recommendation from this

campaign that relates to wrist or forearm fracture management, but they none the less highlight the need for appropriate conversations when surgical risks may outweigh the benefit of earlier functional return, given that long term outcomes are equivocal.

The best acute fixation method remains controversial,[40, 50, 69, 74] but there is a growing worldwide trend towards using volar locking plates over other methods including external fixation or k- wire.[49, 50, 68, 75-77] Even though the popularity of internal fixation with volar locking plates is increasing, many studies have shown no difference in outcomes at one year post surgery among those managed with volar plate fixation compared with other surgical options.[40, 75, 76, 78] However, there is a growing body of evidence to advocate for volar plate fixation due better short term outcomes and earlier return to function,[40, 77, 79, 80] which is especially important for younger patients and/or those with higher functional demands of the upper limb.

Management of midshaft radius and/or ulna fractures: There is very little research regarding optimal management of midshaft fractures. It is common for radius or ulna midshaft diaphyseal fractures to require surgical fixation due to displacement (especially if both bones are fractured) to prevent loss of forearm rotation or fracture non- or mal-union.[81] It is rare to fracture the midshaft of both forearm bones with no displacement, but if this occurs the fracture can be managed conservatively in a long arm cast.[81] Surgical management frequently involves fracture stabilisation using plate and screw fixation[81, 82] or less commonly, intra-medullary nailing.[82]

Management of carpal fractures: As scaphoid fractures are involved in most carpal fractures[60] most of the literature regarding management of carpal fractures is specific to the scaphoid. Non-displaced distal scaphoid fractures are often managed conservatively with immobilisation for 6 weeks.[60, 83] Due to the poor blood supply of the proximal scaphoid, there is a higher likelihood of longer, delayed or non-union when compared to other wrist and forearm fractures, especially if the scaphoid fracture is at the waist or proximal pole.[60] Individuals with proximal and displaced scaphoid fractures often undergo surgical management.[60] However, due to the lengthy time to union and risk of non-union, internal fixation is also used in non-displaced scaphoid fractures, with the additional advantage of

earlier return to function.[60] These advantages have led to the increased use of internal fixation, with the proportion of those undergoing surgical management rising from 22% in 2006 to 34% in 2012, despite no increase in overall fracture severity.[83] Compared to scaphoid fractures, the research regarding optimal management following other carpal fractures is limited. Current practice shows that other carpal fractures are most often managed conservatively with wrist immobilisation, but if displacement occurs fixation may be required, usually with k-wires or screws.[58, 60]

In summary, there is limited contemporary research detailing the incidence of wrist and forearm fractures in the Australian context and acute wrist fracture management is changing worldwide. To broaden the understanding in this area, epidemiology and management practices relating to each type of wrist and forearm fracture are presented in Chapter Three, across a ten-year period from 2008 to 2017. In addition, there has been no investigation of differences in return to driving timeframes or driving performance between those managed conservatively compared to those who undergo acute fracture fixation for any wrist or forearm fracture types. Such differences are explored in Chapter Six.

1.2.4 Complications following wrist and forearm fractures

Complications are surprisingly common and can occur after both conservative and surgically managed wrist and forearm fractures. Potential complications (detailed in *Table 1*) may include problems relating to bone healing (non-union, delayed union or malunion), surrounding soft tissues such as secondary tendon rupture or carpal tunnel syndrome, or other issues including finger stiffness and complex regional pain syndrome.[66, 80, 84] Although operative techniques have advanced over time, complications relating directly to the surgery still occur, including hardware failure or secondary rupture of the surrounding tendons.[51, 66, 85, 86] Some post operative complications such as infection are less common with the increasing use of internal fixation (e.g. volar locking plates), rather than pin fixation and external fixation which are associated with higher infection rates.[74, 87] Other complications such as fracture malunion are more likely after conservative management of DRF.[70, 74] However, malalignment is not always associated with worse long term outcomes, especially in the older patient.[72, 74] Consideration of complications associated with different treatment options adds to the complexity of determining best management.

Table 1: Common types of early and late complications following wrist and forearm fractures

Complication sub-group	**Example(s) of early complication (within 30 days of fracture)**	**Example(s) of delayed complication (more than 30 days post fracture)**
Fracture healing	Loss of reduction	Malunion Delayed or non-union
Tendon	Rupture of tendon (flexor or extensor) Tendinopathy	Rupture of tendon (flexor or extensor) Tendon adhesion
Nerve injury or compression neuropathy	Direct injury to peripheral nerve(s) Carpal tunnel syndrome	Carpal tunnel syndrome
Pain	Complex regional pain syndrome	Persistent pain Complex regional pain syndrome
Wound	Superficial infection Deep infection	Osteomyelitis
Orthopaedic implants		Failure Tendon irritation or rupture
Post traumatic arthritis		At the radiocarpal, distal radioulnar, ulnocarpal, intercarpal or midcarpal joints
Requirement for secondary procedures		Washout/debridement of infection Removal of orthopaedic implants Secondary ligament or tendon repair Release of adhesions Carpal tunnel release Secondary fracture stabilisation

Complications following wrist and forearm fractures are defined and reported inconsistently.[74, 88] Some authors have advocated use of a standardised complication checklist following some wrist fracture types such as DRF,[89] but this is not widely used.[74] Consequently, comparisons of complication rates between studies are difficult. The varying definitions of complications also contribute to the wide-ranging complication rate of 3 to

65% reported in recent literature.[66, 74, 88, 90] Despite the variation in severity and types of complications reported after wrist fracture, it is widely agreed that outcomes are worse when complication arises when compared to wrist fractures with no complications,[66, 91, 92] with the exception of the previously mentioned relationship between malunion and functional outcomes.

Depending on the severity and nature, complications can be managed in various settings. Mild complications, such as superficial wound infections, may be managed by a general practitioner or hospital fracture outpatient clinic, while other mild complications such as post operative stiffness may be managed through therapy clinics. Therapy clinics may also manage more severe complication such as complex regional pain syndrome, with ongoing therapy requirements for intensive and lengthy rehabilitation. Severe complications may require hospital re-admission or secondary surgical procedures, which are arguably most important to report due to the greater impact on patients, as well as the associated costs and extended time off work.[66, 74]

It is challenging to accurately predict the likelihood of complications using variables relating to the fracture or patient demographics. Although some associations between such factors and the likelihood of complications have been reported, a wide variety of predictor variables have been investigated for both early and delayed complications, with resultant varied findings specific to the wrist or forearm fracture location.[66, 90, 93-96] The severity of the fracture has been associated with increased risk of complication, with fracture-related variables including the "AO/Orthopaedic Trauma Association Classification of Fractures" DRF type C fracture configuration increasing the complication risk compared to DRF type A and B,[66, 88, 91, 95] with the presence of a type C fracture, open fracture and collapse of the lunate fossa each increasing the likelihood of complication by at least 2.6 times.[66] Other variables relating to fracture severity including high energy trauma and concurrent elbow injury, have also been associated with an increased likelihood of complication.[96] Younger age,[88, 90] the presence of co-morbidities (diabetes mellitus, hypertension, heart failure and current cancer treatments)[97, 98] and less surgeon experience[66, 85, 91] have also been reported to increase likelihood of complication by some authors, but these findings are not consistent.[66, 88, 91, 96] Developing a clear profile of those most likely to experience a complication following

their wrist fracture would assist in health planning and patient management, but this is difficult due to the wide range of potential predictors and resultant variation in the literature.

Understanding the profile of those at higher risk of complication may give insight into those most likely to have worse or longer lasting functional restrictions: potentially also those at higher risk of car crash following their wrist or forearm fracture. A current analysis of complications following wrist and forearm fractures is provided in Chapter Three. In addition, profiles of patients most likely to suffer complications are identified. A better understanding of the complications and identification of any potential demographic or fracture related variables the increase the likelihood of complications will assist in the early identification of high-risk individuals to optimise their management and follow-up requirements.

1.2.5 Assessing outcomes following wrist and forearm fractures

A wide variety of outcome measures are used in contemporary practice to assess impairments and to monitor recovery after wrist and forearm fractures. Despite the large array of studies that report objective outcomes it is not clear which of these measures are most responsive to change at each stage of recovery following wrist and forearm fracture. Currently, the most commonly used assessments of wrist fracture outcomes include range of motion, grip strength, pain and self-reported functional questionnaires:[99-101]

Range of motion

Active and passive range of motion (ROM) of the wrist and forearm into flexion, extension, radial deviation, ulnar deviation, supination and pronation are usually measured clinically with a goniometer. Standardised testing procedures are recommended by the American Society of Hand Therapists.[102] Measurements can be reported either as motion in degrees or range as a percentage of the contralateral wrist.[84] The accuracy and reliability of measuring ROM with a goniometer has been compared to gold-standard measurements using fluoroscopy, with reported highest inter-rater reliability when using dorsal/volar wrist measurement procedures, when compared to ulna and radial measurement procedures.[103,104]

Grip Strength

Isometric grip strength is measured using a dynamometer and there are standardised procedures for testing.[102] A difference of 7-10% is expected between dominant and non-dominant sides, with additional normative data available.[105] After wrist fracture, grip strength has strong concurrent validity, with moderate to strong correlation with functional assessments including the subtests in Jebsen's Test of Hand Function (Spearman's r=0.51 to 0.76)[106] and strong correlation (Pearson's r=-0.76) with the Disabilities of the Arm, Shoulder and Hand questionnaire.[107, 108] Reductions in grip strength have been reported more than 1 year following DRF[109] and consequently may be appropriate for detecting longer term progress.

Patient reported outcome measure (PROM): Disabilities of the Arm, Shoulder and Hand (DASH) questionnaire

The DASH is a 30-question self-reported outcome measure of function of the whole upper limb. A shortened version of the DASH, the QuickDASH is also available.[110] Questions relate to symptoms and difficulty undertaking usual daily activities.[111] It is scored out of 100, with higher scores reflecting higher disability. The minimum detectable change for patients with upper limb musculoskeletal disorders ranges between 6.5-14.5 points.[112] The DASH has been shown to have high content validity (Pearson's r > 0.7 with multiple measures of upper limb function)[111] and very high test-retest reliability (ICC > 0.9)[111, 113] for patients with upper limb injury.

Patient reported outcome measure: Patient Rated Wrist Evaluation (PRWE)

The PRWE is a self-reported outcome measure developed specifically for individuals recovering from wrist fractures.[114] The questionnaire contains 15 questions relating to pain and function, which can be analysed together or as separate subdomains.[114] The maximum score is 100, with higher scores representing greater disability. Preliminary estimates suggest a minimum clinically important difference is 10 points.[115] For patients with DRF, the PRWE has been shown to have excellent test-retest reliability (ICC > 0.85),[113, 115] high content validity (Pearson's r > 0.7) with the DASH and multiple other patient-reported outcome measures,[115] and has performed slightly better than the DASH in measuring change in DRF patients.[114, 115] Although PROMs including the PRWE and QuickDASH

questionnaires have been frequently reported as valid and reliable[110], there has been recent concern in using these PROMs after DRF due to a ceiling effect of both questionnaires.[110] Despite reaching the best possible score in the QuickDASH and PRWE, individuals report that their wrist still did not 'feel normal' compared to their pre-injury status. These findings suggest that further research is required to determine the best PROM to use following DRF.

Patient reported outcome measure: Pain

Due to the simplicity of assessment and the short time taken to administer, pain is often assessed using the Visual Analogue Scale (VAS) or a Numeric Pain Rating Scale (NPRS).[116, 117] The VAS and NPRS are 0-10 numerical scales, with 10 being the greatest level of pain imaginable.[118] The VAS and NPRS are highly correlated (Pearson's $r > 0.7$)[117] and as a result either can be used in clinical practice. The NPRS and VAS have moderate to high test-retest reliability (ICC = 0.67 to 0.96 and 0.71-0.99 respectively).[116] However, there has been criticism of the use of simple pain scores due to the difficulty in capturing the complexity and idiosyncratic nature of the pain experience.[116] In addition, they may be less useful in detecting change in pain over time and for long term outcomes, with poor correlation between change in pain rating scales and the VAS (Spearman's $r < 0.3$).[116]

Each of the above commonly reported outcome measures has been shown to be useful for measuring progress following wrist and forearm fractures. To determine which of the above outcome measures are most responsive for detecting change throughout the recovery process, Chapter Four presents a meta-analysis compiled from research sourced from a systematic review to investigate the longitudinal change in outcomes at multiple time points in the first 2 years of following wrist fracture.

1.2.6 Usual recovery timeframes

Many studies have measured outcomes following wrist fracture, but few have documented the longitudinal course from the injury date through to the point of either full recovery or when recovery plateaus. As expected, there is high upper limb disability in the early recovery period, especially for the first 2 to 3 months following fracture.[19, 107, 119] In the healthy adult, long bones including the radius and ulna and most carpal fractures take 3 months to heal.[64, 65] The early high functional disability following wrist and forearm

fractures roughly parallels the bone healing timeframe; this is the period when immobilisation is required and when impairments in range of motion and grip strength are highest. Given that the upper limb disability is greatest in the initial 3 months following fracture, any potential impairment in driving capacity is most likely evident during this stage of recovery.

Longer term deficits have been documented for at least 6 months following wrist and forearm fracture, with many studies reporting persistent impairments at 1 to 2 years post fracture.[19, 107, 118-120] These ongoing symptoms are often reported at late time points when bony recovery would be expected to be complete.[115] Eleven percent of patients reported moderate to very severe pain and 16% reported moderate to very severe disability at 1 year following DRF.[118] Due to the long lasting and often variable effects of wrist fractures, it is not clear when final outcomes are best assessed.

There is a sub-group of patients who take longer than average to recover following their wrist fracture or have poor outcomes. As discussed in Section 1.2.4, those who suffer complications often have inferior functional outcomes to those with an uncomplicated recovery.[91] However, some patients may have poor outcomes such as ongoing deficits in range of motion or pain, despite having no reported complication. Many studies have attempted to determine the clearest predictors of poor outcomes with a wide variety of findings.[93, 115, 121, 122] It would make logical sense for the severity of injury to influence final outcomes. However, there is evidence to suggest that the severity of radiographic disruption either at the time of injury or after reduction/surgical fixation is not associated with worse long term outcome functional outcomes, especially in those older than 65 years.[17, 93, 123] Other authors have indicated that other factors relating to the patient including older age, lower education levels, lower income and compensation are associated with worse outcomes, but these findings were not all consistent between studies.[20, 115, 122, 123] Acute pain may also be a useful predictor in outcomes, as pain scores over 35/50 in the PWRE in the first week following DRF are important predictors of chronic pain 1 year post fracture.[124] It is hypothesised that the patients with slower recovery and/or poor functional outcomes are most likely to have impaired driving performance (especially in their early recovery) or have longer return to drive timeframes. Further research is justified to clarify

and highlight which fracture, clinical, and/or demographic variables are best able to identify those at greatest risk of inferior functional outcomes.

A deeper understanding of the recovery process would provide appropriate expectations regarding timeframes in which driving performance is likely to be impaired following wrist and forearm fractures. To better understand the whole recovery pathway, Chapter Four describes the expected physical and/or functional recovery from the fracture date and monitored until 2 years post fracture.

1.3 DRIVING FOLLOWING WRIST AND FOREARM FRACTURES

Given the high prevalence of wrist and forearm fractures, and the fact that most adults are current drivers in Australia, optimal timeframes for return to drive following wrist and forearm fractures is a common clinical discussion. Due to the gaps in the research and resultant lack of objective clinical guidelines, advice given to this patient group is often vague, inconsistent and based on clinician opinion rather than high quality evidence.[125] To refine the understanding of the return to drive problem, it first needs to be confirmed if driving performance is actually reduced following wrist or forearm fracture. Once this is proven, it is then important to ascertain if the impaired driving capacity is likely to increase crash risk.

1.3.1 Physical upper limb requirements to enable return to drive

The Ausroads guidelines recommend that general upper limb requirements for return to drive entail sufficient range of motion, sensation, co-ordination and power to achieve essential functional movements to operate the ignition, hold and turn the steering wheel, and manipulate vehicle controls (e.g. the indicators, gear lever and hand brake).[14] However, due to the limited literature in this area, these recommendations do not include specific objective requirements and are based on expert opinion. The guidelines acknowledge that it is possible to drive safely with severe functional impairment, but driver insight into limitations, stability of the medical condition, and compensatory body movements or vehicle modifications are usually required.[14]

The Ausroads guidelines do not provide recommended minimum levels of such physical requirements to drive safely. One pilot study from 2018 recorded the upper limb movements of 36 uninjured volunteers when driving in a simulator during routine urban driving and hazard reaction identifying shoulder flexion, shoulder rotation, forearm pronation and supination as key upper extremity movements in the driving task.[126] The mean maximum of each wrist and forearm movement used in the driving assessment were: 19.6° supination, 77.2° pronation, 25.9° extension, 36.5° flexion, 17.3° radial deviation and 39.0° ulnar deviation.[126] Another study measured the steering wheel grip force used by participants when driving in a vehicle fitted with pressure mapping pads wrapped around the steering wheel.[127] They found that 13 healthy, young drivers used an average of 31% of their maximum grip force during routine driving.[127] These studies provide a useful preliminary benchmark of upper limb movement requirements and grip force used in routine driving. However, the minimum range of motion, grip force (and grip strength) required at the wrist and forearm to drive safely remains unknown. In addition, the physical requirements to appropriately respond in emergency situations is also not understood. Given the high levels of impairment and disability in the early recovery phase, it is likely that any reduction in driving performance is most apparent within the first 3 months following a wrist and forearm fracture when impairments are greatest.

The biomechanical studies relating to driving performance only provide preliminary data, and all data are from young, healthy adult drivers rather than from individuals recovering from upper limb injury or pathology.[126, 127] It is assumed that when movement or strength deficits arise, there is potential to use compensatory movement patterns from surrounding joints or the contralateral limb. Individuals usually adapt to their impairments and/or immobilisation orthoses following injury, with subsequent new behaviours or compensatory movements.[128] Such adaptations enable individuals to continue to undertake activities of daily living, such as using the contralateral limb for tasks or holding objects with different grips. To understand driving performance following wrist and forearm fractures, assessments need to be undertaken on participants with actual wrist fracture pathology, rather than on uninjured individuals.

1.3.2 Assessing driving performance and car crash risk

Driving performance can be assessed using a variety test conditions and apparatus such as on-road driving tests, naturalistic studies and driving simulation. In addition, driving performance is reported using a variety of outcome measures such as proportion of participants that pass/fail an on- or off-road driving test, qualitative rating of individual driving tasks such as starting the ignition and turning the steering wheel, measures of vehicle control such as the number of cones knocked over in an off-road driving test, the swerving/lateral deviation of the vehicle during driving manoeuvres, or the number of crashes occurring in simulation studies. One of the difficulties in researching, and interpreting research findings on driving performance and crash risk is that there are no standardised or 'gold-standard' assessment procedures.[13, 27]

It is not known which method is best for measuring driving performance following wrist and forearm fractures.[13] All methods have advantages and disadvantages. The advantages of on-road assessments include a 'real-life' driving environment, but they are expensive and time consuming. An alternative on-road testing procedure includes naturalistic driving assessments using video or recording equipment in participants' vehicles to assess real-time driving behaviours, car crash incidence or 'near misses' in on-road evironments.[129] These on-road testing procedures have the advantage of using participants' cars and as they monitor actual daily driving tasks they have become more popular in recent years.[129] For consideration of return to driving following injuries such as wrist fractures that affect the physical performance of the driver, the assessment needs to assess driving performance in routine driving as well as more physically demanding situations including reaction to potential hazards. This is often difficult with on-road testing procedures due to the safety risk involved with such methodology. Driving simulation has the potential to include assessment of hazard reaction, with the additional advantages of being cost effective and relatively safe for recovering drivers and their assessors.[130] Driving simulation is not without disadvantages that need to be considered, including a less realistic environment with varying quality of driving equipment, and possible occurrence of simulator sickness (a type of motion sickness).[131]

Driving simulators have been proven effective in assessing driving performance of other conditions[132-136], for example, driving simulators have a specificity of 82% and sensitivity of 91% for evaluating the likelihood of crash among elderly drivers.[137] However, driving simulators have not been validated for individuals with any upper limb pathology, including those recovering from wrist and forearm fracture. There is a need for standardised, accurate methods to measure driving performance following upper limb injury. Given the lack of standardised driving assessment procedures, the aim of the study in Chapter Five was to establish the feasibility of methods using a driving simulator to measure the driving performance of individuals recovering from wrist fracture. The secondary aim of the research described in Chapter Five was to ascertain if there are measurable differences in the driving performance of individuals recovering from wrist fracture, compared to healthy controls, when assessed using a driving simulator.

1.3.3 Car crash occurrence following wrist and forearm fracture

It is clear that significant knowledge gaps exist relating to driving performance following wrist and forearm fracture. In addition, there are no reports documenting car crash incidence following any upper limb injury, and further, whether any impairment in driving performance following wrist or forearm fracture is associated with increased car crash occurrence. To address this gap, a detailed analysis was conducted to identify the incidence of car crashes in the first 2 years post wrist and forearm fracture. These findings are reported in *Chapter Six*.

Understanding potential clinical, demographic or injury related variables that may indicate if an individual is fit to drive following a wrist fracture will assist a large number of adults with this common injury. At a national road safety level, Australia has adopted a "Safe System" approach which advocates for ambitious targets and the aspiration to eliminate all fatalities and serious injuries caused by car crashes.[138] In addition, car crashes are a common high velocity mechanism of injury resulting in additional fractures. Though not a formal part of this road safety vision, improved knowledge regarding optimal return to driving following wrist and forearm fractures has potential to improve road safety and arguably will assist with this national target. The secondary aim of the analysis presented in Chapter Six was to

identify any clinical or demographic factors that increase the likelihood of car crash following wrist and forearm fractures.

1.4 SUMMARY

Many aspects of the interaction between wrist and forearm fracture recovery and the complex task of return to driving are poorly understood. Wrist and forearm fractures are commonly reported to have high prevalence but current Australian data is lacking. It is hypothesised that driving performance is most likely to be impaired during the stage of early recovery when physical impairment and functional restrictions are the greatest. It is therefore important to have a clear understanding of the recovery process and how this may vary with different wrist and forearm fracture types and/or management choices. Modern literature has not yet confirmed if driving performance is impaired or if car crash rates increase among those recovering from wrist and forearm fractures. Given that this is an emerging area of research and the lack of standardised testing procedures, it is necessary to assess the feasibility and validity of driving assessment methodology to measure driving performance in those with wrist fracture pathology. There is also a poor understanding of potential associations between car crash and injury related variables such as wrist and fracture subgroups, management types or the presence of complication. Better understanding, appropriate education and active advice given to individuals regarding their fitness to drive following wrist fractures will improve road safety in this patient group and for other road users.

1.5 THESIS AIMS

The broad aim of this thesis is to develop a deeper understanding of wrist and forearm fractures, including the expected recovery, contemporary management pathways and complications and impact on return to driving.

The specific aims addressed in the following chapters are to:

1) identify current recommendations and indicators of safe return to driving following wrist fracture based on current literature
2) determine the epidemiology, management pathways and complication rates following wrist fractures in Western Australia, as well as to identify any potential predictors of complications
3) examine the expected recovery following wrist fractures in terms of physical outcomes and functional ability
4) explore whether a driving simulator can differentiate driving performance between individuals recovering from distal radius fractures and uninjured controls
5) establish if car crash risk is increased following wrist and forearm fracture and identify if any clinical or demographic factors increase the likelihood of car crash

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CHAPTER TWO

When can I drive? Return to driving following a wrist fracture: A critical review

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2.1 Authorship statement

The authors of the paper "Stinton SB, Edgar DW, Moloney NA, Refshauge K & Pappas E. When can I drive? Return to driving following a wrist fracture: A critical review. *Hand Therapy*, 2015; *20*(3), 95-101" confirm that Susan Belinda Stinton has provided the following contributions to the study:

- Conception and design of the research
- Data acquisition
- Data analysis and interpretation of the findings
- Writing the manuscript and critical appraisal of the content.

Susan Stinton

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As the primary supervisor for the candidature upon which this thesis is based, I can confirm that the authorship attribution statements above are correct.

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When can I drive? Return to driving following a wrist fracture: A critical review

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Abstract

Introduction: The primary aim of this review was to identify literature that examined factors which influence driving performance following a wrist fracture. Given the known scarcity of research in this area, secondary aims were to detail current practices including the driving habits of patients following a wrist fracture and health professionals' opinions on safe return to driving.

Methods: We performed a search in April 2015 using three electronic databases to obtain relevant literature in the English language. Relevant studies including clinical trials, surveys and case reports were reviewed.

Results: The search identified 12 relevant studies. Five of these were clinical studies with a crossover design that investigated the driving ability of uninjured individuals with the wrist immobilised in a cast. The remaining were survey-based studies. The clinical trials showed that the presence of a wrist cast reduced driving performance in uninjured individuals. No studies investigated driving performance in individuals with a wrist fracture. The surveys showed that this patient group returns to driving despite perceived safety risks. Inconsistency in expert opinions on whether individuals with a wrist fracture are safe to drive was highlighted.

Conclusions: There is evidence to suggest that driving performance is reduced in uninjured individuals when wearing a cast immobilising the wrist; however, the influence of wrist fracture is unknown. This, along with safety implications resulting from current driving behaviours and inconsistent information provided to patients regarding return to driving, highlights the need for further studies to ascertain which factors influence driving performance following wrist fracture.

Keywords

Wrist, wrist injuries, fracture, automobile driving

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Introduction

Health practitioners are commonly asked by patients at what point 'it is safe' to return to driving following a wrist fracture. There is a poor understanding of the clinical factors that may influence the driving capacity in individuals with a wrist fracture. As a result, health professionals may base their responses on radiographic and clinical factors of fracture healing rather than on evidence-based measures of the individuals' physical capacity to drive safely.

Driving a motor vehicle is a complex task requiring a combination of cognitive and physical performance. Drivers need to be able to use the ignition, grip and turn the steering wheel, operate the indicators, gear lever and hand brake consistently,[1] and to be able to do these tasks quickly and accurately in case of an unexpected event. Driving with restricted ability poses obvious risks to the driver and to other road users.

Inaccurate advice on driving capacity given to individuals following a wrist fracture could result in people returning to driving before they are safe to do so. If the individual was involved in a motor vehicle accident,

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negative medico-legal consequences could arise. Conversely, unnecessarily delaying the return to driving may lead to loss of independence and time away from daily activities, including work.

Fractures to the wrist occur more frequently than in any other area of the body.[2] The incidence is highest in older females; however, wrist fractures occur in all age groups. The wrist is one of the most common fracture sites in the under 55-year-old age groups.[3,4] It follows that a high number of individuals who sustain a wrist fracture are current motor vehicle drivers.

Wrist fractures result in a significant reduction in wrist range of motion and grip strength.[5] These impairments contribute to a significant limitation in activities of daily living, especially in the first 3 months following fracture.[5] Given the resultant limitation in other activities of daily living, it is likely that driving performance in individuals recovering from a wrist fracture will be reduced.

Formal driving assessment of people with disabilities is a specialised field. Some national guidelines[6] require people with some permanent disabilities to have a driving assessment by a specialised driving occupational therapist prior to resumption of driving. With non-permanent impairments including most fractures, these assessments are usually neither feasible nor routinely recommended due to their financial expense and time consuming nature.[1] The use of objective tests in a clinical setting to guide recommendations has the potential to be both cost effective and result in increased safety among this group.

The primary purpose of this critical review was to investigate the effect of wrist fracture on driving performance. The secondary aims were to describe the current driving habits of patients following a wrist fracture and health professionals' opinions on when it is safe to return to driving.

Method

In this review, we sought to examine all studies in the English language investigating any element of driving a motor vehicle following a wrist fracture. The EMBASE, CINAHL and PubMed databases were searched for relevant studies from the inception of each database to April 2015. The search strategy used the following key words: ('driving' OR 'drive' AND 'fracture,' 'injury,' 'upper limb,' 'wrist' OR 'arm'). Given the known paucity of clinical trials in this field, the search terms used were deliberately broad to capture any related research in this area. The types of studies included were limited to clinical trials, observational studies and survey studies, while review articles were excluded.

Following removal of duplicate articles, one author (SS) performed a title and abstract screen to obtain published and completed studies of relevance. We completed a manual reference check of the retrieved articles to identify additional articles not captured by the original search. A qualitative analysis of the data was then performed. As the method of assessing driving performance and outcome measures differed between studies, the results could not be pooled and a meta-analysis could not be performed.

Results

The initial search identified 958 articles. The search process is described in Figure 1. Following article exclusion using the selection method detailed, 12 articles were included. Out of the 12 eligible articles, 5 were clinical trials and 7 included surveys (one article included both a clinical trial and a survey).

There were no studies that investigated the driving performance of individuals with a wrist fracture. All of the clinical trials investigated the driving performance of uninjured individuals when wearing a wrist cast. The surveys outlined driving behaviours of patients following a wrist fracture and health practitioners' opinions regarding return to driving in this patient group.

Driving performance whilst immobilised in a wrist cast or splint

The five clinical studies investigated the driving ability of uninjured people whilst wearing a cast or splint. Details of each study are detailed in Table 1. The sample size varied from one to 30 healthy participants. Each of these studies used a crossover study design where each participant had their driving performance assessed in a number of different cast types. Statistical analysis of significance was only performed in three studies.[7–9] Subsequently, the results need to be interpreted with caution, especially when considering the small sample sizes.

A variety of elbow, wrist and thumb casts were used. Each study included trials for both left and right hand casts. All of the studies used a group with a short arm cast. Two studies also used short arm casts that included the thumb.[9,10] Three studies used long arm casts.[7,9,11]

The method of driving assessment varied among studies with on-road driving tests used by the majority.[9–11] Kalamaras[11] and Stevenson[9] used a formal driving test. Blair[10] used an informal on-road test which assessed performance where points were given for components of the driving task including gear changing, steering, reversing, hand brake control, indicator/horn control and on-road performance. Other studies used off-road tests. Chong[7] used an off-road driving course with cone markings and recorded the time taken to complete the course and the number of cones knocked down.

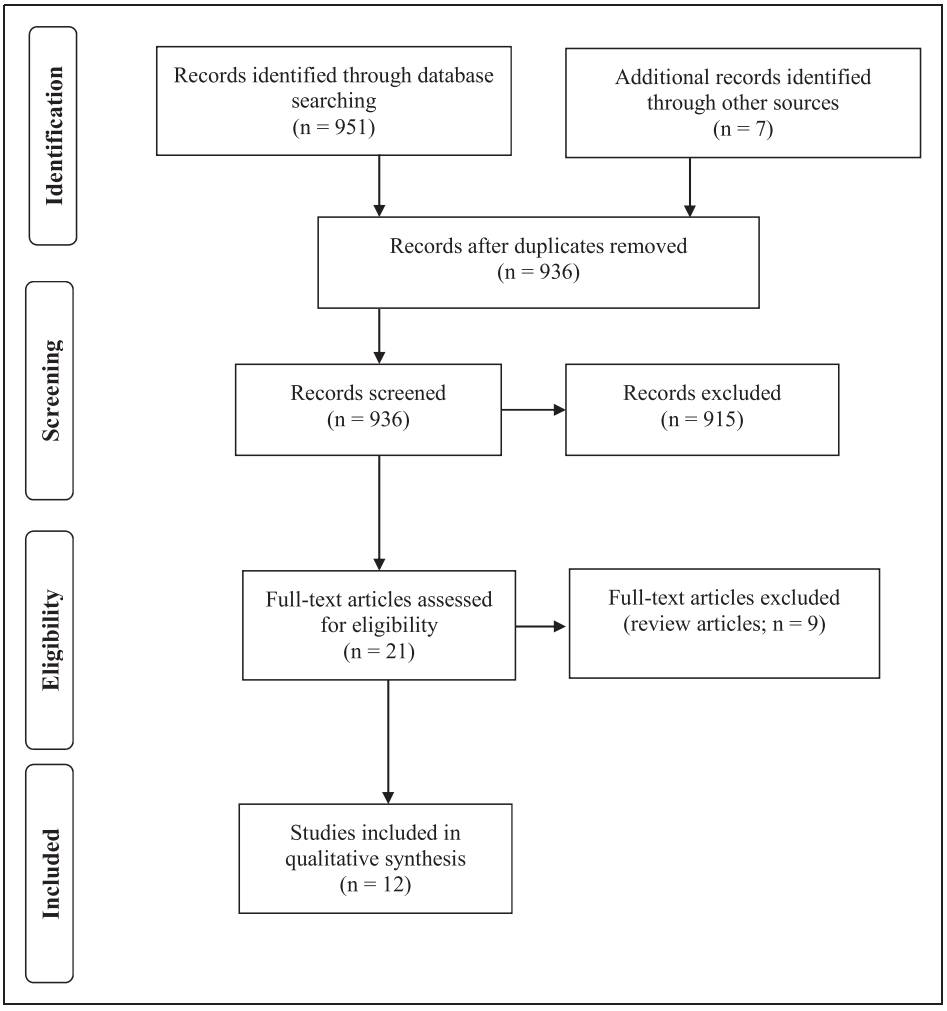

Figure 1. Search strategy.

Gregory[8] assessed performance in a driving simulator equipped with *STISIM*™ software to record aggregate indices relating to speed and lateral control of the vehicle as well as the number of collisions.

These studies were performed in different countries including the United Kingdom,[8–10] the United States[7] and Australia,[11] with resultant differences in left- or right-hand drive cars used in the driving assessments. Right-hand drive cars are used in the United Kingdom and Australia while left-hand drive cars are used in the United States.

Wearing a wrist-only cast showed a trend towards altered driving performance in four studies.[7,8,10,11] The impairment in driving performance was reported as increased time taken to complete the assessment,[7] poorer response to hazards,[8] failing the on-road driving test[11] and loss of points in an on-road driving test.[10] The size of this effect varied among these studies, with a significant reduction in performance only in one study.[7] Gregory[8] showed that wrist immobilisation also led to more cautious driving, with less adjustment of speed and lateral road position than when unrestricted.

Above-elbow casts showed some trends towards reduced driving performance in all relevant studies.[7,9,11] Chong[7] showed that those with both left and right above elbow casts took longer to complete an off-road driving course, but this was only significant in the left hand above elbow cast groups. Studies by Stevenson[9] and Kalamaras[11] also highlighted impaired performance where the single participant failed the driving assessment when using both the left and right above elbow cast[11] and four out of six individuals failed the driving assessments when using the left above elbow cast, with significantly worse driving assessment scores when compared to the other groups.[9]

Casts including the thumb had varying effects on driving performance.[9,10] All cast groups including the thumb in the study by Blair and colleagues failed the driving assessment.[10] One out of the six participants using a left sided cast including the thumb failed the driving test by Stevenson.[9]

Table 1. Details of clinical studies investigating driving in a cast.

Author	Study type	Method of driving assessment	Study group	Type of casts worn by participants in driving assessment	Groups with reduced driving ability	Place of study
Blair (2003)	Crossover trial	On road test using a points system	1 healthy participant assessed using each type of cast	Colles cast Scaphoid cast Bennett's cast	Left Colles cast Left Scaphoid cast Right Scaphoid cast Left Bennett's cast Right Bennett's cast	UK
Chong (2010)	Randomised crossover trial	Driving course with cone markings. Time was recorded and cones knocked down were counted, giving a cone-adjusted time.	30 healthy police officers assessed using each type of splint	Short arm splint Long arm splint Control (no splint)	Significant time reduction in left hand splint groups All groups with splints trend towards worse performance	USA
Gregory (2009)	Randomised crossover trial	Driving simulator test recording indices of driving performance	8 healthy participants each assessed with/without the cast	Short arm cast Control (no cast)	Cast group deterioration in performance when responding to hazards. More pronounced in right sided casts.	UK
Kalamaras (2006)	Crossover trial	On road driving test, assessed by specialised OT and driving instructor (pass/fail)	1 healthy participant (the author) assessed using each type of cast	Short arm cast Long arm cast Control (no cast)	All casts groups failed test	Australia
Stevenson (2013)	Randomised crossover trial	On road driving test, assessed by a driving instructor (pass/fail)	6 healthy participants assessed using each type of cast	Short arm cast Long arm cast Bennett's cast	5 individuals in long arm cast failed test 1 individual with Bennett's cast failed test	UK

Colles cast: a short arm cast, with the wrist immobilised in slight flexion.
Scaphoid cast: a below elbow cast, with the thumb immobilised up to the interphalangeal joint.
Bennett's cast: a below elbow cast, with the thumb immobilised in extension.

There were some reported differences in driving performance depending on the side of the immobilised arm.[7–9] Two of these studies were completed in right-hand drive cars,[8,9] and found driving performance was worse in left arm cast groups in one study,[9] but the other showed worse driving performance when responding to hazards in right arm cast groups.[8] The third study was completed in a left-hand drive car[7] and found significantly reduced driving performance in left arm cast groups.

Current driving behaviour reported by individuals with a wrist fracture

Five of the surveys questioned individuals with wrist fractures about current driving behaviours whilst in a wrist cast or splint.[11–15] The proportion of individuals who reported driving in the cast varied greatly among the studies; 12 out of 144 (9%) of individuals in the United Kingdom reported driving whilst in a Colles plaster cast,[13] 18 out of 118 (15%) of individuals in Ireland reported driving in a wrist cast,[15] and 84 out of 168 (50%) of individuals in Australia[11] with an arm cast reported driving at least once.

Not all individuals sought professional advice before returning to driving following a fracture. In the United Kingdom, only 52 out of 144 individuals (36%) in a Colles or scaphoid cast reported consulting their doctor, and 46 out of 144 individuals (32%) consulted the plaster technician before driving.[13] In the United States, 64% of the 70 survey respondents reported consulting their doctor before driving following their musculoskeletal injury.[12] In Ireland, 4 out of 18 (22%) of individuals sought advice from their doctor prior to returning to driving whilst in a wrist cast, and 2 out of 18 individuals (11%) asked their insurance company.[15]

There are safety concerns related to driving whilst in a wrist cast which are reported or perceived as potential issues by survey respondents. Two of the survey studies questioned patients about perceived driving ability when using a variety of wrist casts and thermoplastic splints. Over 85% (125 out of 144) of patients thought that driving in a wrist splint or cast would be unsafe[13] and 19% reported feeling unsafe while driving.[12] Despite known safety implications, many of those surveyed also began driving while on narcotic pain medications or returned to driving despite advice to the contrary from their doctor, family or friends.[12]

The inconvenience and loss of independence associated with not being able to drive is significant. One survey reported that 42% of the 70 respondents found not being able to drive following a fracture was a major difficulty and 26% found there was associated major financial hardship.[12]

The influence of legal implications and potential loss of insurance coverage also did not seem to deter patients from driving following a wrist fracture. The majority (83% of 168 respondents) of people surveyed thought they might be breaking the law or were not sure if they were breaking the law by driving when using a wrist cast.[11] Most of these individuals (98% of 168 respondents) also thought they were either not covered by their insurance company, or were unsure if they would be insured if they drove.

Reported advice to patients by clinicians

Health practitioners were questioned about their opinions on driving following a wrist fracture. Five surveys were sent to surgeons,[12,16,17] plaster technicians[18] and general practitioners (GPs)[9] including a variety of questions regarding the driving ability of patients following a wrist fracture or when the wrist was immobilised.

The opinions from health practitioners on driving ability following a wrist fracture were variable. Surgeons' opinions regarding whether patients were safe or not safe to drive whilst immobilised in a wrist cast varied by up to 50%.[16,17] The timeframes suggested by surgeons after which patients could return to driving following a wrist fracture varied from zero to 12 weeks following the injury.[12] The majority of GPs gave advice that was more conservative than the surgeons' advice for driving whilst using a wrist cast: more than 20 out of 24 GP's survey respondents (over 80%) were of the opinion that patients using varying upper limb splints would not be safe to drive. There was less clarity about the safety of driving whilst wearing soft wrist supports. The consensus from plaster technicians regarding return to driving following a wrist fracture was to seek further advice from their car insurance company (166 out of 188 respondents) the local driving authority (22 out of 188 respondents), their doctor (20 out of 188 respondents) or the police (11 out of 188 respondents).[18]

Some studies[14,17,18] reported that doctors advise patients to seek advice from their insurance company as a guide on return to driving. In contrast, the advice from insurance companies was for patients to follow the advice of their doctor.[11,15–18]

Discussion

There is some evidence to suggest that uninjured individuals' driving performance is worse when wearing a wrist cast.[7–11] The size of this effect varied among studies. Casts that immobilise the thumb and elbow had a larger effect on driving ability than casts that only immobilised the wrist. These studies used a variety of test methods and outcome measures, recruited small

sample sizes and not all studies performed significance analysis, making grouped comparison of results impossible.

The sample size of all of the studies was small, though being a crossover study design, two of the studies used only one participant. One study had 30 participants, and this approached the sample size requirements for the Central Theorem Limit sample size guidelines. It is likely that all other studies were too underpowered to infer clinical significance. Further, the largest trial with 30 participants recruited police officers in training, affecting the generalisability of the results. Consequently, none of the studies included provided evidence to support strong conclusions.

This review found no studies which investigated the effect of wrist immobilisation on the driving ability of patients with wrist fracture, as all studies were performed on uninjured participants. Extrapolating from the findings of studies on healthy people, it is reasonable to assume that driving performance will also be impaired in patients with wrist fracture and immobilisation, but the extent of this effect is unknown.

In individuals with wrist fractures, the effect of wrist immobilisation is compounded by medication use, pain and arm weakness. Impairments including reduced movement and weakness are often still present following removal of the cast or splint, especially in the first three months following fracture.[5] Studies are needed to quantify the effect of these impairments and identify criterion-based or time milestones that are associated with safe return to driving in this population. While the investigation of individuals with a wrist fracture may be limited due to ethical considerations of on-road driving safety, the risk of disrupting fracture healing, or provoking pain in the injured limb, it remains an important area to study.

The surveys on driving practices of patients with a wrist fracture show that a proportion of these individuals report returning to driving prior to gaining medical clearance, despite the perceived safety, legal and insurance-related risks of this behaviour. This review was not able to detail the risk of this behaviour, as we located no studies detailing the driving performance of individuals with a wrist fracture. The surveys also highlighted the inconsistent information health practitioners provide in regards to driving ability following a wrist fracture. Von Arx[17] concluded that doctors may offer varied advice that is based on expert opinion rather than being guided by evidence based practice.

Three studies[11,13,15] revealed that individuals are likely to return to driving whilst in a wrist cast and not all individuals sought advice from their doctor before doing so.[12,13,15] It is perhaps substantial loss of independence of not being able to drive that prompts individuals with a wrist fracture to return to driving despite the perceived safety implications of this behaviour. However, it has been shown that drivers judge their own performance inaccurately and tend to overestimate their skills and underestimate impairment.[19] It can be ethically argued that it is the role of the treating health practitioner to actively educate patients of any risks they take when driving with a wrist fracture. Research reporting on timeframes and explanations on guiding factors will assist the patient in making an informed decision on returning to driving following their wrist fracture.

The majority of the studies used on-road driving assessments to assess driving performance. The advantage of this method is the real life correlation as well as the option of using assessments parallel with those used for drivers licensing requirements. Conversely, off road tests have better potential to assess drivers' reactions to hazards and more difficult vehicle control tasks such as those examined by Gregory[8] and Chong.[7]

It could be argued that reduced driving performance in individuals with a wrist fracture may not be highlighted in routine driving scenarios where unplanned reactions are not required. In fact, some studies showed a more cautious, or arguably safer, driving behaviour in individuals when using a wrist cast[8] with routine driving scenarios. A complete picture of driving performance is perhaps better reflected when also including the driver's response and reaction to hazards and unplanned or more demanding tasks. Some studies may not have shown significant differences between groups if the driving assessment did not evaluate the performance in the more difficult components of driving such as hazard reactions.

The side of immobilisation had a varying impact on the results. As the studies varied between design in using left and right hand drive cars as well as using manual and automatic vehicles, it is unclear if it was the position of the arm in the car (i.e. the hand used on the gears), or if other factors such as hand dominance resulted in these differences.

There are no practice guidelines or policies that have been endorsed by an orthopaedic or speciality society, insurance company or the police that provide guidance about safe to return to driving following a musculoskeletal injury.[12] Guidelines that are endorsed by an orthopaedic professional society would be extremely valuable.

This review highlights the lack of published studies that investigated the driving performance of individuals who are recovering from wrist fracture. This evidence gap has been recognised by many authors in the field.[1,12,16,17] It is critical to note that the available research has been performed only on healthy individuals using a wrist immobilisation cast. This means that

other factors such as the pain and other factors present in the injured population have not been examined. There are also no studies on driving performance in the wrist fracture population in the immediate period following removal of the cast when they still have impairments such as reduction in wrist range of motion and strength.

Conclusion

There is low-level evidence to suggest that the presence of a wrist cast or splint reduces driving performance in uninjured individuals. Considering the high prevalence of wrist fractures, the importance of driving in daily life and the risks associated with poor driving ability, it is essential for future research to assess performance in the wrist fracture population as it relates to driving safety.

Declaration of conflicting interests

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CHAPTER THREE

Growing incidence in wrist and forearm fractures, changing management and complication rates:

A data linkage study involving 37K individuals

Chapter Three has been submitted for publication and is currently under review:

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This paper is presented in the following chapter in the format required for this journal.

Authorship statement

The authors of the paper "**Stinton SB**, Pappas E, Moloney NA, Edgar DW. Growing incidence in wrist and forearm fractures, changing management and complication rates: a data linkage study involving 37K individuals. 2022. *Submitted to PLOS One*." confirm that Susan Belinda Stinton has provided the following contributions to the study:

- Conception and design of the research
- Data acquisition
- Interpretation of the findings
- Writing the manuscript and critical appraisal of the content.

Susan Stinton

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Date: 6th February 2023

As the primary supervisor for the candidature upon which this thesis is based, I can confirm that the authorship attribution statements above are correct.

Evangelos Pappas

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Date: 6th February 2023

Growing incidence in wrist and forearm fractures, changing management and complication rates: a data linkage study involving 37K individuals

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ABSTRACT

Objectives: The aim of this study was to provide contemporary epidemiology and advanced understanding of the burden of wrist fractures by detailing incidence, management trends and complication types across age and sex groups. Additionally, variables associated with increased odds of complications and those who undergo secondary surgery following wrist fracture were identified.

Study design and setting: This cohort study analysed state-wide health data relating to adults in Australia with wrist or forearm fracture sustained between 2008-2017. Outcomes included fracture incidence, management approaches, complications and secondary surgery requirements. Logistic regressions examined change over time and identified variables associated with increased odds of complication or secondary surgery.

Results: Data from 37,107 adults showed an overall wrist/forearm fracture incidence of 199.5/100,000 people. Yearly incidence increased by 14%, mostly among middle-aged and older women. Complications and/or secondary procedure requirements were reported in 13% of individuals. Younger age, fracture fixation surgery, multi-trauma, males, compensation funding, and >2 co-morbidities (all $P<0.001$) were associated with increased odds of complication/secondary surgery.

Conclusion: Increasing wrist fracture incidence in middle-aged and older females warrants attention, highlighting a potential need to improve management of osteoporosis. Identifying those with higher likelihood of complication will assist health planning and longer-term follow-up requirements; 6 months post fracture appears an appropriate time-point to identify the need for secondary procedures.

INTRODUCTION

Wrist fractures are among the most prevalent fracture types, especially among post-menopausal women but they are also common in younger adults.[1-3] There has been increasing incidence of wrist and forearm fractures from the 1950's to the early 2000's, with more recent stabilising trends.[2, 4-6] Fracture management has changed over time: in the early 2000's there was a marked increase in volar plate fixation of distal radius fractures,[2, 7, 8] as well as increased surgical management of other types of wrist fractures.[9]

The health burden, individual morbidity, time off-work and rehabilitation following wrist/forearm fractures is substantial, especially if complications occur.[10-11] Most recovery occurs in the first two-to-three months following fracture, but it can take a year until progress plateaus.[12] Given the high frequency and increased use of open reduction and internal fixation (with higher costs than closed treatment or percutaneous pinning),[10] associated healthcare costs may also be increasing.

Many epidemiological studies on wrist/forearm fracture in the last decade have not reported on entire adult populations, instead focusing on subgroups e.g., older adults[1, 13] or those with osteoporotic fractures.[14] Most only report on epidemiology relating to a small region.[4, 6, 13, 15] Fewer studies from state/national cohorts are available.[7, 9, 16]

Given the high incidence and associated health burden, up-to-date knowledge of wrist/forearm fracture epidemiology is essential for health planning. Therefore, the aims of this study were to:

1) Define wrist/forearm fracture incidence and trends across age and sex groups in the state-wide adult population over a 10-year period;
2) Outline management trends for wrist/forearm fractures;

3) Identify the frequency and type of common complications and secondary surgical procedures following wrist/forearm fracture;

4) Determine if any variables are associated with increased odds of complication/secondary surgery following wrist/forearm fracture.

METHODS

Two West Australian (WA) government-based data collections were linked to identify retrospective population-based cohorts: The Emergency Department Data Collection (EDDC) and Hospital Morbidity Data Collection (HMDC). These are representative of public and private hospitals in city and rural locations. The cohort included adults with a wrist or forearm fracture managed by an emergency department (ED) or hospital.

The *Western Australia Data Linkage Service* was used to extract and assimilate the data from the above datasets, before secure online transfer to the authors for analysis. Ethics was granted from *The Department of Health WA Human Research Ethics Committee*. This paper is written in accordance with the STROBE reporting checklist for cohort studies.

Adults included had a diagnosed wrist/forearm fracture as defined by International Classification of Diseases, Australian Modification (ICD-10AM) and presented to hospital/ED between 01/01/2008-31/12/2017 (detailed in *Supplementary Table 1)*. The cohort was divided into four fracture groups:

1) Distal radius and/or ulna (DRF)
2) Midshaft radius and/or ulna
3) Carpal
4) Multiple (>1 wrist fracture codes in >1 of the above groups)

The following variables were recorded (detailed in *Supplementary Table 2)*:

- Demographics: sex, age, employment status
- Comorbidities: in the two-years before and after the fracture date (with resultant health data from 01/01/2006-31/12/2019)
- Concurrent injuries: to the wrist or elsewhere in the body (*Supplementary Table 3)*
- Acute fracture management: conservative or surgical
- Acute surgery (not relating to fracture fixation)

Acute fracture fixation procedures were grouped according to the Australian Classification of Health Interventions, 8th Edition (ACHI) codes in *Supplementary Table 4*. As these codes do not specify the type of fixation e.g., Kirshner-wires, screw or plate, the surgical groups included:

1) Closed reduction with internal fixation (CRIF)
2) Open reduction with internal fixation (ORIF)
3) Other (e.g., open reduction with no fixation, external fixation)

Most closed reductions are performed in ED with no subsequent hospital admission, however the EDDC does not include procedure details. Consequently, it was not possible to accurately report on closed reduction rates, therefore the conservative group includes individuals who had immobilisation +/- closed reduction.

Complications were defined according to predefined ICD-10AM codes (*Supplementary Table 5*). Early complications were those requiring hospital/ED (re)admission within 30 days post-fracture. Requirement for secondary wrist/forearm surgery was recorded (detailed in *Supplementary Table 6*), occurring >30 days but within two-years of the fracture. Those requiring isolated removal of orthopaedic implants were reported but not included in the complication figures.

Data cleaning and analyses were performed using Stata (16.1, StataCorp LLC, College Station, TX). A significance level *a* of 0.05 was used for statistical tests, including the final logistic regression models. To maintain data confidentiality, where necessary in reporting small cell counts were suppressed (if n<5).

To determine incidence, total numbers within each fracture/sex/age group were used in combination with population data, obtained from the Australian Bureau of Statistics (2008-2017). Incidence is reported as number of fractures per 100,000 people. Descriptive statistics, mean (standard deviation) of demographics, management (conservative or surgical), complications and secondary surgical requirements. To determine if

there was a change in incidence and management, univariate linear regression analyses were performed using incidence and management rates as dependent variables and year as the independent variable.

To determine if any variables (age, sex, fracture type, management type, length of stay, days from fracture to surgery and health status) were associated with odds of complication or secondary procedures, logistic regressions were performed. The relationship between the continuous variable (age in years) and complications/secondary surgical procedures were checked for linearity and transformed if non-linear. Starting with a full model, backwards elimination methods were used. Prior to elimination of a candidate variable the change in the remaining coefficients were checked to ensure no more than 15% change with each step. A likelihood ratio was calculated and the Akaike information criterion was checked to ensure goodness of fit was not reduced with the elimination steps. Finally, the model was checked for multicollinearity. The logistic regression results are presented as odds ratios (OR) and 95% CI.

RESULTS

The cohort comprised of 37,107 individuals: over half (58%, 21337/37107) sustained DRF, 23% (8477/37107) midshaft, 18% (6800/37101) carpal fractures, with multiple fractures accounting for 1% (493/37107) of the group (*Table 1*).

Table 1: Demographics of the cohort and for each of the fracture groups

		Midshaft	**DRF**	**Carpal**	**Multiple**	**Combined**
n (% of cohort)		8,477 (22.85)	21,337 (57.5)	6,800 (18.33)	493 (1.32)	37107
Sex n (% of cohort)	Female	4,072 (48.02)	14,433 (67.65)	2,384 (35.06)	206 (41.96)	21,095 (56.85)
Age group, n (% of cohort) *(n=37 107)*	18-29	2,708 (31.96)	3,633 (17.04)	3,042 (44.83)	135 (27.29)	9,518 (25.67)
	30-39	1,658 (19.54)	2,262 (10.63)	1,282 (18.89)	70 (14.26)	5,273 (14.22)
	40-49	1,296 (15.26)	2,403 (11.28)	887 (13.09)	64 (13.03)	4,650 (12.54)
	50-59	1,174 (13.88)	3,471 (16.31)	667 (9.83)	80 (16.50)	5,402 (14.57)
	60-69	755 (8.94)	3,898 (18.27)	447 (6.59)	63 (12.83)	5,163 (13.93)
	70-79	468 (5.51)	2,815 (13.20)	278 (4.10)	43 (8.76)	3,604 (9.72)
	80-89	330 (3.88)	2,232 (10.47)	152 (2.24)	30 (6.11)	2,744 (7.40)
	90+	84 (0.99)	598 (2.80)	30 (0.44)	6 (1.22)	718 (1.94)
Age in years, mean (SD)		42.52 (18.64)	54.53 (20.85)	37.42 (17.34)	46.98 (20.63)	48.55 (21.01)
Employment status n (% of cohort) *(n=37 107)*	Student	1,098 (12.95)	1,178 (5.52)	914 (13.44)	17 (3.46)	3,207 (8.64)
	Employed	3,799 (44.80)	8,427 (39.50)	3 538 (52.03)	261 (53.16)	16,025 (43.19)
	Unemployed	577 (6.80)	818 (3.83)	474 (6.97)	21 (4.28)	1,890 (5.09)
	Home duties	630 (7.43)	1,698 (7.96)	372 (5.47)	27 (5.50)	2,727 (7.35)
	Retired	451 (5.32)	2,689 (12.60)	240 (3.53)	31 (6.31)	3,411 (9.19)
	Pensioner	894 (10.54)	4,252 (19.93)	488 (7.18)	63 (12.83)	5,697 (15.35)
	Unknown	1,031 (12.16)	2,274 (10.66)	774 (11.38)	71 (14.46)	4,150 (11.18)
Funding source *n (% of cohort) (n=30 594)*	Public/State	3,785 (59.68)	11,143 (59.41)	2,864 (57.21)	253 (51.53)	18,045 (58.98)
	Private	1,769 (27.89)	5,847 (31.18)	1,563 (31.22)	130 (26.48)	9,309 (30.43)
	Self-funded	177 (2.79)	322 (1.72)	166 (3.32)	9 (1.83)	674 (2.20)
	Compensation	591 (9.32)	1,407 (7.50)	401 (8.01)	97 (19.76)	2,496 (8.16)
	Other	20 (0.32)	36 (0.19)	12 (0.24)	<5 (0.41)	70 (0.23)
Co-morbidity indices mean (SD) *(n=37 107)*	Elixhauser	0.47 (1.15)	0.59 (1.30)	0.36 (0.99)	0.54 (1.29)	0.52 (1.22)
	Charlson	0.25 (0.97)	0.39 (1.21)	0.18 (0.81)	0.26 (1.08)	0.31 (1.10)

Fracture Incidence:

The mean incidence of wrist or forearm fractures managed at a hospital in WA was 199.5 per 100,000 persons; 45.5 midshaft, 114.7 DRF, 36.6 carpal and 2.6 multiple fractures per 100,000 persons (*Table 2*). Overall incidence increased by more than 14% from 190.2 in 2008 to 218.7 in 2017 (P<0.001) (*Figure 1)*. Within each fracture group, incidence increased only in midshaft (P=0.006) and DRFs (P=0.002*)*.

Table 2: Change in incidence[+] by sex and age groups from 2008-17 for each fracture group

	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	p-value
MIDSHAFT FRACTURES (n=8477)											
Sex (n=8470)											
Male	47.71	43.17	43.50	50.28	49.03	46.55	48.37	46.31	45.27	52.27	0.26
Female	36.70	38.07	39.98	40.92	44.47	46.77	42.46	43.33	47.65	56.56	*0.001**
Age group (n=8470)											
18-29	56.31	66.79	60.78	63.00	63.88	62.10	59.34	63.41	65.34	72.35	0.09
30-39	50.39	34.30	41.15	50.15	43.57	51.11	55.37	47.41	43.82	50.97	0.28
40-49	37.88	31.57	35.57	37.39	40.22	36.90	36.31	35.48	41.06	45.97	*0.04**
50-59	31.82	30.37	33.78	41.92	41.32	44.69	40.66	35.32	33.99	51.29	0.08
60-69	27.55	31.37	27.13	26.89	34.03	32.83	31.15	36.47	38.64	45.58	*0.002**
70-79	29.77	28.08	35.90	33.96	40.75	34.81	31.16	30.06	42.77	49.14	*0.05**
80-89	53.17	54.65	41.42	49.62	51.72	46.18	46.95	60.90	46.57	62.20	0.43
90+	30.16	29.72	64.98	69.61	106.57	69.51	51.24	55.33	105.54	63.16	0.16
Overall	**42.22**	**40.63**	**41.75**	**45.67**	**46.81**	**46.76**	**45.53**	**44.87**	**46.46**	**54.43**	***0.006****
DISTAL RADIUS AND/OR ULNA FRACTURES (n=21337)											
Sex (n=21331)											
Male	68.55	79.48	70.42	71.12	71.62	72.83	72.66	76.48	77.49	80.79	0.08
Female	151.75	146.42	149.65	151.27	150.73	148.91	155.70	166.37	165.45	167.48	*0.002**
Age group (n=21323)											
18-29	88.30	89.56	82.91	76.17	87.13	78.18	84.14	89.84	88.19	85.89	0.85
30-39	65.61	69.53	59.13	71.05	58.29	65.00	66.77	60.20	68.48	59.51	0.48
40-49	61.35	65.89	72.64	65.95	64.06	72.67	64.39	73.23	78.70	81.67	*0.01**
50-59	109.92	101.00	106.17	108.66	106.25	110.92	115.30	121.42	129.66	134.17	*0.001**
60-69	167.41	172.51	149.23	162.71	173.75	155.94	172.59	198.75	183.66	187.43	*0.05**
70-79	203.00	219.41	216.25	219.47	219.74	222.81	203.30	231.17	215.90	226.97	0.18
80-89	340.26	348.39	359.55	360.17	344.83	335.55	369.55	344.59	315.77	371.77	0.98
90+	472.55	525.01	631.21	513.40	434.46	486.60	497.80	414.97	448.55	372.64	*0.04**
Overall	**110.10**	**112.84**	**109.92**	**111.13**	**110.98**	**110.75**	**114.15**	**121.43**	**121.70**	**124.36**	***0.002****
CARPAL FRACTURES (n=6800)											
Sex (n=6799)											
Male	48.31	44.69	49.75	51.05	49.03	49.98	46.83	44.27	43.44	48.11	0.33
Female	23.13	23.54	23.19	22.18	28.75	29.26	29.24	26.57	24.03	26.42	0.16
Age group (n=6786)											
18-29	75.34	68.54	73.91	78.05	77.42	68.93	70.85	63.41	65.11	70.72	0.76
30-39	35.81	33.38	38.10	36.42	37.22	45.28	36.64	35.69	29.65	36.48	0.10
40-49	26.61	25.13	24.11	27.09	27.00	24.41	27.51	23.84	25.95	27.41	0.79
50-59	19.52	17.66	19.30	15.43	18.69	29.90	27.95	24.28	21.72	24.08	0.69
60-69	11.13	19.73	19.38	13.44	24.63	21.17	18.94	22.95	21.91	22.40	0.09
70-79	20.75	11.41	19.66	21.53	22.37	24.76	25.23	22.90	18.62	25.87	0.05
80-89	14.18	25.62	14.91	19.21	28.21	29.25	21.20	32.68	29.10	22.62	0.11
90+	10.05	29.72	18.56	8.70	24.59	15.45	29.28	34.58	19.79	37.90	0.08
Overall	**35.75**	**34.15**	**36.51**	**36.66**	**38.99**	**39.66**	**38.05**	**35.42**	**33.70**	**37.21**	**0.80**

MULTIPLE WRIST/FOREARM FRACTURES (n=493)											
Sex (n=493)											
Male	3.39	2.58	2.86	2.99	2.26	3.15	4.44	2.96	2.74	3.52	0.39
Female	1.33	1.87	2.06	2.22	2.05	2.73	3.93	2.04	1.82	2.01	0.10
Age group (n=493)											
18-29	3.44	2.25	4.13	3.53	2.48	2.42	4.21	2.24	2.74	3.73	0.88
30-39	1.27	1.55	0.91	2.39	2.02	2.78	3.80	1.86	2.10	1.81	0.23
40-49	2.50	1.84	0.60	1.18	1.44	1.14	1.70	2.84	2.28	3.14	0.19
50-59	2.89	2.12	2.76	2.01	2.30	3.54	4.76	2.52	1.26	2.19	0.87
60-69	1.59	3.04	1.45	2.78	2.69	4.75	4.21	2.87	2.39	2.36	0.49
70-79	1.80	3.51	4.27	4.14	1.60	3.09	7.42	3.58	2.76	1.29	0.88
80-89	1.77	3.42	4.97	3.20	3.13	4.62	10.60	1.49	4.37	8.48	0.16
90+	0.00	0.00	18.56	8.70	0.00	15.45	0.00	6.92	0.00	0.00	0.62
Overall	**2.36**	**2.22**	**2.45**	**2.60**	**2.14**	**2.92**	**4.18**	**2.50**	**2.29**	**2.78**	**0.37**
ALL WRIST/FOREARM FRACTURES (n=37107)											
Sex (n=37093)											
Male	167.93	169.90	166.51	175.42	171.91	172.47	172.29	170.02	168.96	184.72	0.10
Female	212.91	209.90	214.88	216.60	225.99	227.67	231.33	238.31	238.95	252.47	*<0.001**
Age Group (n=37072)											
18-29	223.38	227.14	221.74	220.75	230.92	211.63	218.53	218.90	221.39	232.69	0.98
30-39	153.08	138.75	139.30	160.01	141.10	164.17	162.58	145.17	144.05	148.78	0.77
40-49	128.34	124.43	132.92	131.60	132.72	135.12	129.91	135.39	148.00	158.19	*0.004**
50-59	164.15	151.15	162.01	168.02	168.56	189.05	188.67	183.56	186.63	211.73	*<0.001**
60-69	207.67	226.64	197.20	205.82	235.11	214.69	226.90	261.04	246.60	257.77	*0.007**
70-79	255.33	262.41	276.08	279.10	284.46	285.47	267.11	287.71	280.05	303.27	*0.009**
80-89	409.38	432.07	420.86	432.21	427.90	415.60	448.31	439.65	395.81	465.07	0.32
90+	512.77	584.45	733.31	600.42	565.62	587.01	578.33	511.79	573.88	473.69	*<0.001*
Overall	**190.18**	**189.72**	**190.40**	**195.89**	**198.76**	**199.79**	**201.70**	**203.92**	**204.06**	**218.72**	***<0.001****

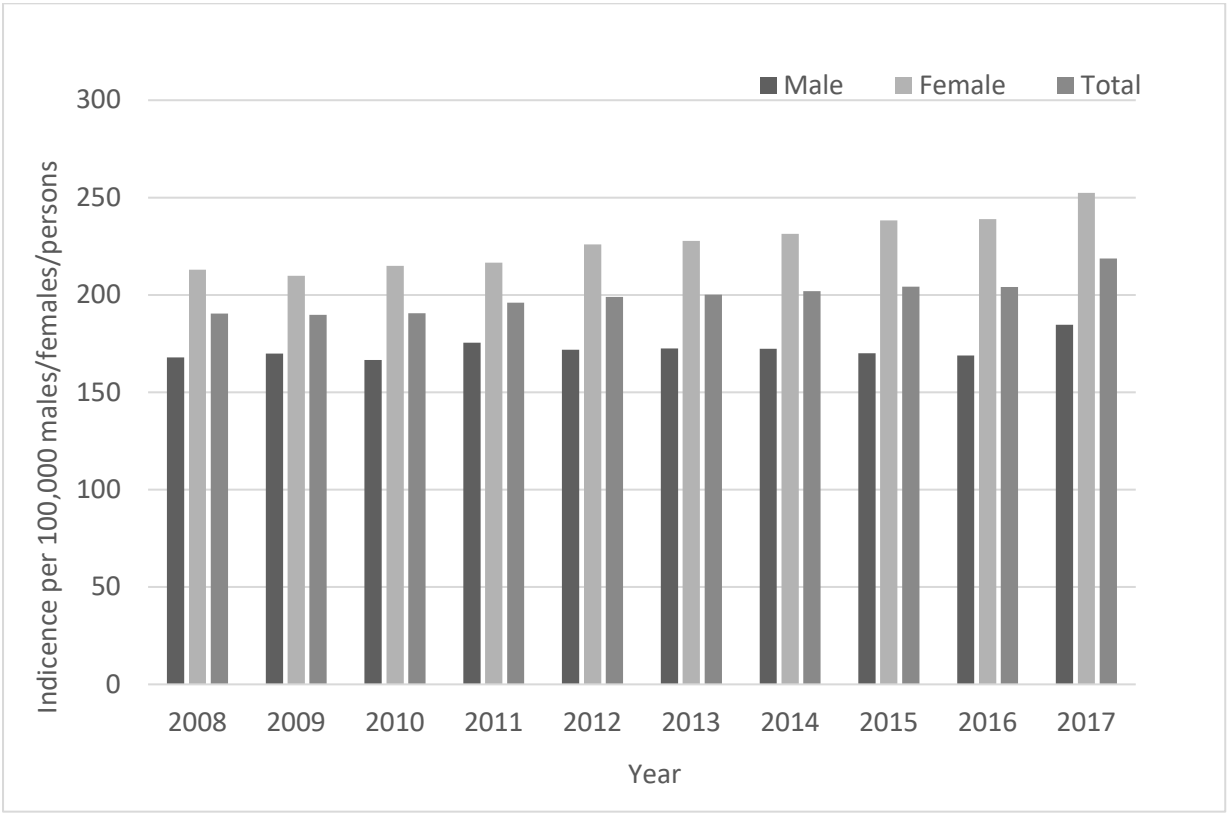
** p-value for change in incidence from 2008-2017 is significant if p<0.05*
[+] Incidence is per 100 000 males/females/adults in the relevant age group

Additionally, increasing incidence was only evident in females and in age groups between 40-79 and over 90 years.

There were 2734 concurrent wrist injuries (*Supplementary Table 7)* among 6.3% (2354/37,107) of the cohort. These occurred in association with 6.7% (570/8477) of midshaft; 6.4% (1363/21,337) of DRUF; 4.1% (280/6800) of carpal; and 28.7% (141/493) of multiple fracture types. There were 6987 concurrent (non-wrist) injuries among 12.5% (4650/37,107) of the cohort. These were diagnosed in association with

13.8% (1168/8477) of midshaft; 13.5% (2878/21,337) of DRF; 5.9% (404/6800) of carpal; and 40.5% (200/493) of multiple fracture groups.

Figure 1: Changing incidence of wrist fractures from 2008-2017, per 100 000 males/females/adults in Western Australia



Fracture management:

Over 88% (32723/37107) of individuals with wrist and forearm fractures were managed conservatively. The number of acute fracture fixation operations performed each year did not change, but given the increasing incidence, the proportion utilising surgical management reduced from 13.7% in 2008 to 9.7% in 2017(P<0.001). Surgical management was highest in the multiple fracture group at 25.4% (125/493) and the DRF group (16.5%, 3527/21337), compared to carpal (5.6%, 382/6800) and midshaft fractures (3.8%, 325/8477).

There was change in the type of acute fracture fixation surgery in the DRF group with an increase in the proportion of ORIF from 88.1% of surgical procedures in 2008 to 98.7% in 2017, with a corresponding

reduction in the number of CRIF from 11.5% to 0%. Nearly 9% (3324/37,107) of the cohort underwent additional acute wrist or forearm surgery unrelated to fracture fixation (*Supplementary Table 8*).

Complications and secondary procedures:

Overall, 12.6% (4678/37,107) of individuals had an early complication and/or required a secondary procedure: acute complications were reported in 3.6% and secondary procedures were utilised in 9.8% of individuals recovering from a wrist or forearm fracture. The rate of complications and secondary procedures remained stable between 2008-2017(P =0.73 and P =0.36). The 3.6% of the cohort with an acute complications (1337/37,107), were recorded in 4.5% (378/8477) of midshaft fractures; 3.5% (752/21,337) of DRF; 2.2% (149/6800) of carpal fractures; and 11.8% (58/493) of multiple fracture types. Complications occurred at a mean timepoint of 7.8 days (95%CI 7.2-8.5) post fracture and were predominately due to infection (n=343) and/or surgical debridement (n=771).

The 9.8% of the cohort (3628/37,107) who underwent a secondary surgical procedures, were recorded in 7.7% (641/8477) of midshaft fractures; 10.7% (2273/21,337) of DRFs; 8.5% (574/6800) of carpal fractures; and 28.5% (140/493) of multiple wrist fractures. Secondary procedures occurred at a mean timepoint of 7.7 months (95%CI 7.5-7.9 months) after injury, with 21% (770/3644) occurring after one year and 7.6% (278/3644) occurring within 18-24 months following the fracture. Secondary surgical procedures included correction of bony deformity, tendon repair, carpal tunnel release, bone graft, nerve procedures, release of adhesions, arthroplasty, fusion, arthroscopy and/or ligament repair (*Supplementary Table 9)*. Most individuals (70.6%, 2561/3628) had implant removal during their secondary procedure. An additional 1095 individuals had removal of implants performed in isolation, without other secondary procedure(s).

Factors associated with complications:

Multivariable logistic regressions identified several variables associated with increased odds of complications and/or secondary procedures (P <0.001 for both models) (*Table 3)*. Adults younger than 59

and older than 80 years were most likely to have a complication (*Figure 2a*). After accounting for age, the presence of concurrent wrist or non-wrist injuries were associated with the highest odds of early complication (OR 8.8, *P*<0.001 and OR 2.7, *P*<0.001). Fracture types associated with increased odds of complication were midshaft (OR1.7, *P* <0.001), DRF (OR1.5, *P* <0.001) and multiple wrist fracture (OR1.6, *P*=0.01) using carpal fractures as the reference group. Increased odds of complication were also associated with fracture fixation surgery (OR 1.8, *P*<0.001), males(OR 1.4, *P*<0.001), more than two co-morbidities (OR 1.6, *P*<0.001) and using compensable funding (OR 2.1, *P*<0.001) .

Table 3: Variables associated with increased odds of early complication and secondary surgical procedures

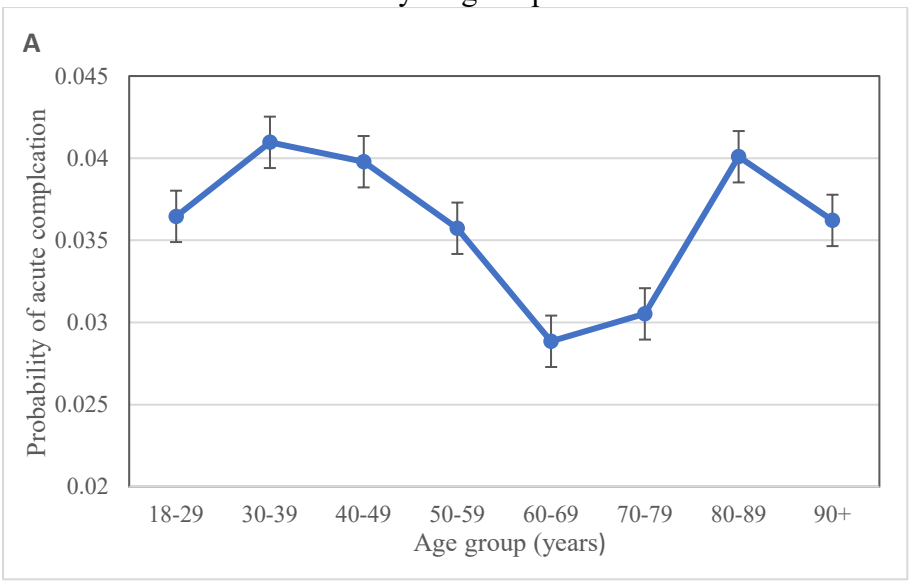
EARLY COMPLICATION	**OR**	**p-value**	**95%CI**	
			Lower	**Upper**
Concurrent wrist injury (non-fracture)	8.79	<0.001	7.69	10.04
Concurrent non-wrist injury	2.70	<0.001	2.35	3.11
Compensable funding	2.17	<0.001	1.84	2.56
Acute fracture fixation surgery	1.84	<0.001	1.60	2.23
Elixhauser score >2	1.52	<0.001	1.27	1.81
Males	1.48	<0.001	1.28	1.70
Fracture type (odds of complication compared to carpal fracture)				
Midshaft fractures	1.74	<0.001	1.41	2.14
DRF	1.46	<0.001	1.20	1.78
Multiple	1.59	0.011	1.11	2.28
SECONDARY SURGICAL PROCEDURE	**OR**	**p-value**	**95%CI**	
			Lower	**Upper**
Compensable funding	3.72	<0.001	3.36	4.12
Acute fracture fixation surgery	2.26	<0.001	2.06	2.48
Concurrent wrist injury (non-fracture)	1.97	<0.001	1.75	2.23
Acute complication	1.25	0.009	1.06	1.47
Males	1.24	<0.001	1.15	1.35
Elixhauser score >2	1.24	<0.001	1.10	1.41
Concurrent (non-wrist) injury	1.20	<0.001	1.09	1.33
Fracture type (odds of complication compared to carpal fracture)				
Midshaft	0.85	0.010	0.75	0.96
DRF	1.24	<0.001	1.12	1.38
Multiple	2.47	<0.001	1.96	3.12

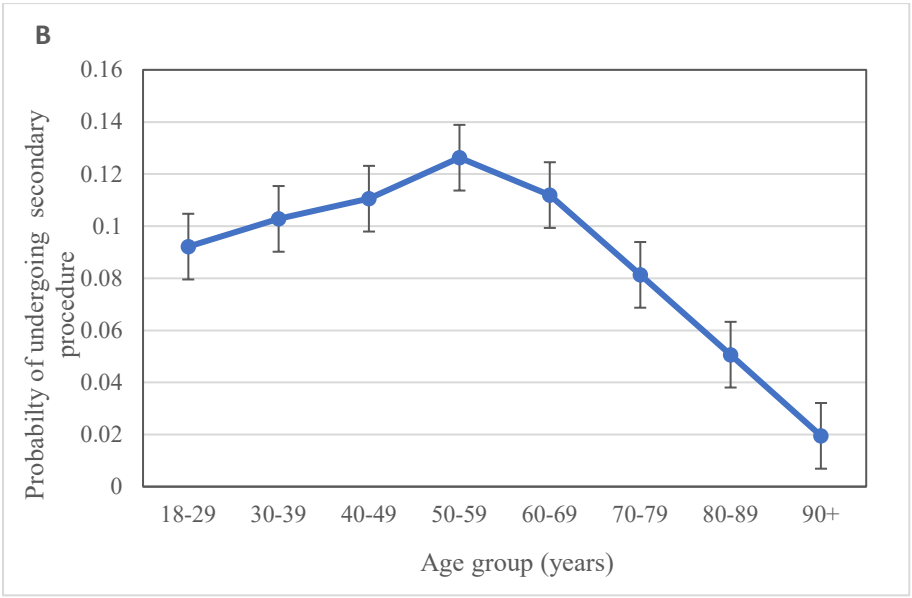
Adults younger than 69 years of age were most likely to undergo secondary procedures, with odds reducing with increasing age (*Figure 2b*). After accounting for age, fracture fixation procedures were associated with increased odds of secondary procedure requirements (OR 2.2, *P*<0.001) when compared with those who

were conservatively managed. DRF, carpal and multiple wrist fracture types had a higher association with secondary procedures (OR1.5,p<0.001; OR 1.2, *P*=0.006; OR2.8, *P*<0.001 respectively) compared to midshaft fractures. Additional variables associated with increased odds of secondary procedures were compensable funding (OR3.5, *P*<0.001), males (OR1.2, *P*<0.001), and concurrent wrist (OR2.1, *P*<0.001) or concurrent non-wrist injuries (OR 1.3, *P*<0.001).

Finally, length of initial hospital stay, time to surgery and employment status were not associated with increased odds of complication or secondary procedures.

Figure 2a and 2b: a) Relationship between age and acute complications; b) Relationship between age and those who underwent secondary surgical procedures





DISCUSSION

To our knowledge, this is the first study reporting on all adult wrist/forearm fracture types with detailed age and sex-specific incidences. Main findings included increased fracture incidence in middle-aged and older females and stable surgical management rates (12%). Higher complication rates and those undergoing secondary procedures were associated with a number of variables.

A key epidemiological finding was the increasing wrist/forearm fracture incidence by 14%, with continued and consistent change over the study period. Similar trends have previously been reported,[17] but global data is inconsistent.[4-6] Our finding of increasing fracture incidence specifically in the early pre-and post-menopausal female age groups has been reported previously.[5] It is widely accepted that DRF are common osteoporotic fractures and high-quality evidence suggests that DRF often presents the first opportunity to diagnose and treat osteoporosis.[17] The increasing incidence warrants attention, flagging a need for better osteoporosis prevention, screening and management.

The mean yearly incidence of 200 wrist/forearm fractures per 100,000 people is comparable to reports ranging from 175/100,000 adults with wrist/forearm fractures[5] to 236-239/100,000 adults with hand/wrist/forearm fractures.[18] Isolated DRF incidence alone varies between 100-300/100,000 people[2, 16] and is higher in North America and Europe than Asia and Africa.[17] As most carpal fractures involve the scaphoid,[4] our carpal incidence of 36.6/100,000 fits with other studies reporting an incidence of 23-43/100,000 people.[4] Data on midshaft forearm fractures in adults is scarce,[19] so the incidence of 45.5/100,000 people is a useful benchmark.

The 12% overall rate of surgical management lies within the wide range of 5-40% reported elsewhere.[20] However, our findings might reflect an overestimation of rate of surgery as our data only include fractures managed by a hospital. Some wrist fractures are managed by a General Practitioner, consequently, not all conservatively managed wrist fractures were captured.

In our study, ORIF almost entirely replaced other types of surgical fixation in the DRF group. This finding mirrors the increasing world-wide utilisation of volar locking plates.[2, 6, 8, 20] Despite the higher costs of volar plating compared to other management options,[10] operative interventions have not resulted in clear improvement in outcomes at one-year post-surgery.[2, 21] However, volar plate fixation has better outcomes in the early rehabilitation period[2, 21] which perhaps account for the noted change in surgical management. Given the increasing incidence and rates of ORIF, management costs for wrist/forearm fractures will also be increasing.

The overall complication (acute complications and secondary procedure) rate of 13% is at the lower end of previously reported ranges (4-39% for DRF,[11, 22-24] 10-30% of scaphoid fractures[25]). Prior literature relating to complications in broader wrist fracture cohorts, non-scaphoid carpal fractures and midshaft forearm fractures is scarce. Published complication rates vary widely depending on the types of complications reported and follow-up periods.[11, 17, 21-23] Our study only reported on complications requiring ED/hospital management therefore those managed with outpatient medical or therapy services e.g., minor infections and stiffness would not have been captured. However, complications requiring hospital admission are arguably the most severe due to higher medical costs, associated morbidity and work absences. The practicality of these figures means that one-in-ten wrist fracture patients will require longer follow-up periods and/or closer monitoring for the need for secondary procedures.

Multiple variables were associated with increased odds of complication or secondary surgery: age, fracture type, sex, surgical management, concurrent injuries and compensable funding. These findings are partially reported previously.[11, 19, 22, 24] The finding of increased complications rates and proceeding with secondary procedures in younger individuals of working age may relate to lower tolerance of impairment in those with higher functional upper limb demands.[24]

Identifying individuals most likely to require secondary procedures earlier in recovery assists health follow-up and planning, including timely therapy referrals and communication regarding prognosis and

management. There were two patient profiles associated with increased odds of complications or secondary surgery. Firstly, younger, working age males (especially those with compensation claims, multi-trauma, concurrent wrist injuries or more complex/multiple wrist fracture) and secondly older individuals with multiple co-morbidities and/or surgically managed fractures. Those with simple, conservatively managed wrist fractures were less likely to develop complications or undergo secondary surgery. It follows that older patients with >2 co-morbidities should be informed of their increased risk of complications/requirement for secondary procedures when acute surgical options are discussed, especially as long-term outcomes following surgery are not distinctly superior to other management types.[21]

The results from this study can be used to forecast follow-up requirements after wrist/forearm fractures. Most secondary procedures occurred around 7-8 months post-fracture, thus follow-up 6 months post-fracture is appropriate to assess recovery and to screen for secondary surgery requirements in higher risk individuals. Those with simple, conservatively managed fractures are less likely to require this longer-term follow-up. Less than 10% of secondary procedures occurred after 18 months, aligning with data of reducing complication rates over time.[11] Therefore, assessment of final outcomes at 12-18 months post-fracture is appropriate and is consistent with prior studies on recovery following DRF, showing minimal change after one year.[12]

There are limitations relating to the use of administrative datasets that were not created to answer the specific research questions. Thus, we were limited in the pre-recorded variables available and as there are no clinical assessment measures within the datasets, variables such as fracture classification or functional outcomes could not be included in the regression. Future studies should consider investigating these clinical variables and other potential factors, such as a deprivation variable. Finally, although the Data Linkage Service of WA reports quality checking protocols to ensure linkages are of high quality, it is possible that there was missing data or missing linkage not known to the authors.

This study confirmed increasing incidence of wrist/forearm fractures, especially in women with DRF/midshaft fractures. Surgery and complication rates remain stable, despite increasing rates of ORIF and resultant increasing management costs. Follow-up at six months post fracture is appropriate for early identification of secondary surgery requirements; for surgical patients, those with multi-trauma, more than 2 co-morbidities and compensable funding, especially for DRF and midshaft fracture.

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The published supplementary material relating to this article is provided in Appendix 1

CHAPTER FOUR

Longitudinal recovery following distal radial fractures managed with volar plate fixation

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4.1 Authorship statement

The authors of the paper "**Stinton SB**, Graham PL, Moloney NA, Maclachlan LR, Edgar DW, Pappas E. Longitudinal recovery following distal radial fractures managed with volar plate fixation. *Bone Joint J*. 2017;99-B(12):1665-1676." confirm that Susan Belinda Stinton has provided the following contributions to the study:

- Conception and design of the research
- Data acquisition
- Interpretation of the findings
- Writing the manuscript and critical appraisal of the content.

Susan Stinton

_____

Date: 6th February 2023

As the primary supervisor for the candidature upon which this thesis is based, I can confirm that the authorship attribution statements above are correct.

Evangelos Pappas

_____

Date: 6th February 2023

■ TRAUMA

Longitudinal recovery following distal radial fractures managed with volar plate fixation

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Aims

To synthesise the literature and perform a meta-analysis detailing the longitudinal recovery in the first two years following a distal radius fracture (DRF) managed with volar plate fixation.

Materials and Methods

Three databases were searched to identify relevant articles. Following eligibility screening and quality assessment, data were extracted and outcomes were assimilated at the post-operative time points of interest. A state-of-the-art longitudinal mixed-effects meta-analysis model was employed to analyse the data.

Results

The search identified 5698 articles, of which 46 study reports met the selection criteria. High levels of disability and impairment were reported in the immediate post-operative period with subsequently a rapid initial improvement followed by more gradual improvement for up to one year. The results highlight that the period associated with the greatest physical recovery is in the first three months and suggest that the endpoint of treatment outcomes is best measured at one year post-surgery.

Conclusion

Clinically meaningful improvements in outcomes can be expected for 12 months, after which progress plateaus and reaches normal values. This paper adopted a novel approach to meta-analyses in that the research question was of a longitudinal nature, which required a unique method of statistical analysis.

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The distal radius is one of the most common areas of the body to fracture.[1] The prevalence is highest in females over the age of 65 years, although wrist fractures occur in all age groups.[1] Treatment for distal radial fractures (DRF) remains controversial,[2-4] but open reduction and volar plate fixation has become increasingly common in the last decade.[5,6] With Medicare costs in 2007 for inpatient and outpatient management of a DRF in the United States reaching $170 million, and additional indirect costs from lost income due to work absences,[6] the financial burden of this injury is substantial.

In addition to the high prevalence of DRF, these fractures are also associated with a significant recovery period. The impairments after a DRF include loss of upper limb range of movement, reduced grip strength, pain and functional disability.[7] It is commonly accepted that these restrictions are significant for months following the fracture[7] and may persist for more than a year.[8] However, no systematic reviews with meta-analyses have evaluated the longitudinal change in outcomes across the entire recovery period, that is, from the initial post-operative stage until recovery has reached a plateau. The primary aim of this review was to examine the longitudinal recovery up to two years following a DRF managed with volar plate fixation, so that it can be used as a progress indicator in clinical treatment programmes. The secondary objective was to investigate whether independent factors such as age, fracture type and immobilisation time have a significant effect on recovery.

Materials and Methods

This review was registered with PROSPERO (International prospective register of systematic reviews; CRD42014010133) and was written in accordance with the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) checklist.[9]

Table I. Search terms used to identify relevant studies

	Search parameters
	("distal radius fracture", "Smith fracture", "Colles fracture", "radius fracture", "wrist fracture" OR "wrist injury")
AND	(("clinical trial", "randomised controlled trial", "trial", "randomly", "placebo", "controlled clinical trial" OR "randomised")
OR	limiting the topic search to "clinical trials"
OR	("observational", "non experimental" "prospective" "cohort" "longitudinal"))

Table II. Eligibility criteria

Inclusion criteria	Exclusion criteria
Original published articles reporting on post-operative recovery following distal radius fractures managed with volar plate fixation	Case studies or review articles
Participants over 18 years of age	Surgical procedure other than volar plate fixation
Studies have quantitatively reported on at least of one of the following outcomes: The Disabilities of the Arm, Shoulder and Hand questionnaire, Patient Rated Wrist Evaluation questionnaire, wrist/forearm range of movement and grip strength	Distal radius fractures managed by cast and/or closed reduction only
Results report outcomes for at least two time points within the first two years following surgery	Other surgical approach used (eg dorsal or radial)
	More than one plate used, or a combination of plate and other surgical technique (e.g. both plate and wire fixation)
	Mean or variance values not reported
	Outcomes only reported at a single time point

Information sources and search strategy . Three databases (PubMed, CINAHL and Embase) were searched from inception to August 2016. The search terms used were topic MeshTerms and keywords in the title and abstract, in combination with a search builder to incorporate the study design. The search terms are detailed in Table I.

Eligibility criteria. Studies that investigated adults with DRF, managed acutely with volar plate fixation and reported on at least one of the specified outcome measures at two or more time points in the first two years following surgery were considered for inclusion. The inclusion and exclusion criteria are detailed in Table II.

Where possible, we attempted to contact the authors of studies excluded due to lack of reported data. If appropriate data or analyses were subsequently provided the papers were included in our study.

Study selection and data collection process. Two of three independent reviewers (SS, NM, EP) conducted title and abstract screenings followed by full-text-article screening to confirm eligibility, with any conflicts resolved by the third reviewer. One out of two authors (SS, LM) extracted the data and two of three other authors (LM, DE, NM) cross-checked the extracted data.

Outcome measures. All outcome variables were predetermined, and include measures of disability and measures of physical impairment. The measures of disability include 1) the Disability of the Arm, Shoulder and Hand (DASH)[10] and 2) the Patient Rated Wrist and Hand Evaluation (PRWE)[11] are valid and reliable self-reported disability questionnaires.[12] Both are scored out of 100 with higher scores indicating higher disability. The QuickDASH is a shortened 11-item questionnaire from the DASH. The DASH and the QuickDASH have a similar reliability,[13] and the results reported were therefore considered interchangeable and appropriate to pool.

Measures of physical impairment include 1) range of motion of wrist flexion, extension, radial and ulnar deviation; and forearm pronation and supination, recorded in degrees or as a percentage (%) and 2) grip strength, recorded as an absolute value (kg) or as a percentage (%) of the uninjured arm.

Some studies reported the flexion/extension arc, rotation arc, and deviation arc, or gave a qualitative score. However, as the number of studies reporting in these formats were insufficient to allow meta-analyses, these outcomes were not included the results.

Risk of bias. Each study was assessed for quality using the Strengthening The Reporting of OBservational Studies in Epidemiology (STROBE) checklist, which is used to assist reporting of cohort and other observational studies.[14] We adapted the use of the tool to assess the quality of all included studies, inclusive of randomised trials. To score a full point for each item, all the sub-items for that point needed to be fulfilled. If any sub-item of each point was missing in the study, a score of 0 was given.

Each article was independently assessed by two of the five authors (SS, LM, NM, DE, EP). Any discrepancies for each point of the STROBE was reviewed and resolved by a third author. A sensitivity analysis was performed to ascertain whether the inclusion of low-quality studies, as determined by the STROBE assessment, significantly changed the results.

Synthesis of results and summary measures. A longitudinal mixed-effects meta-analysis model was used to determine the change in mean outcome over time, using a similar

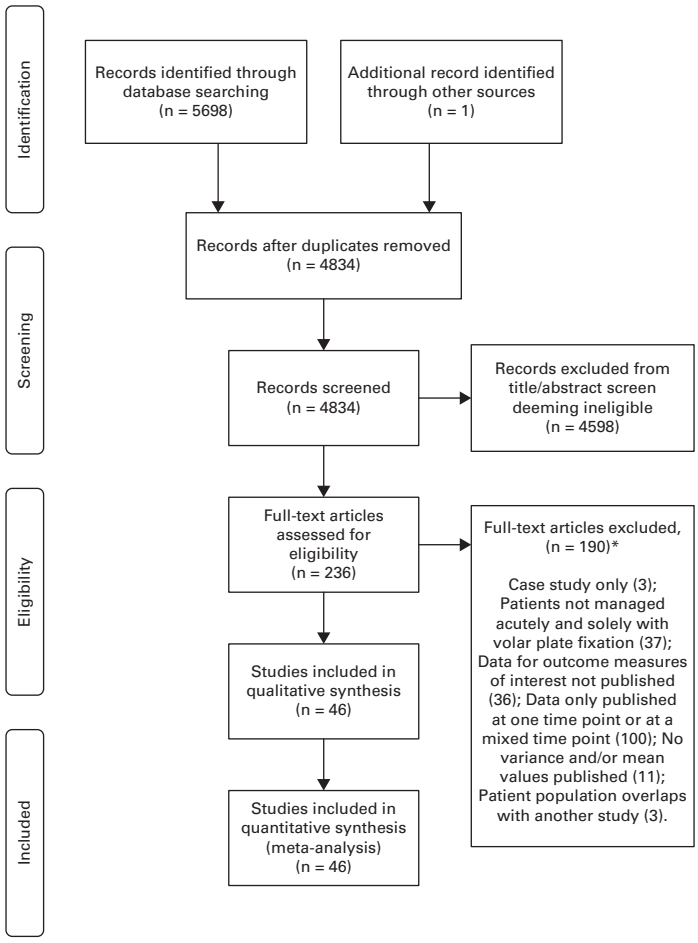

Fig. 1

PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) flowchart for study selection.

model to that described in Ishak et al.[15] A random intercept and random slope were used to account for the correlation induced by the repeated observations made by each study over time. Various models were examined: continuous time with linear change over time; continuous time with polynomial terms, to account for the non-linearity over time; and categorical time, which provides linear fit between available time points. Categorical time had the best fit using the Akaike Information Criterion (AIC) and Bayesian Information Criterion (BIC),[16] and so the results presented are based on using time as a categorical variable.

Mean outcomes at each time point were estimated and presented with 95% confidence intervals (CIs). Pairwise comparisons using contrasts were made to determine the rate of change between subsequent time points. Because multiple comparisons were undertaken for each outcome measure a Bonferroni-type correction was made to provide more robust p-value estimates.

Due to the inclusion of a wide range of study types, some of the studies had two or more groups that fit the inclusion criteria. In these cases, both groups were included as an independent group in the pooled data analysis.

Heterogeneity between studies was assessed using Cochrane's Q-statistic and the estimated between study variability (τ^2) with 95% CI is presented. A p-value of < 0.05 was deemed statistically significant.

Additional analyses. As the DASH and QuickDASH were combined for analysis, sensitivity analysis was performed on each measure separately to ensure combining results for the DASH and QuickDASH scores did not have a significant influence on the results.

To determine if there were any significant moderator effects and to determine if heterogeneity between studies could be explained by moderators, independent variables including mean participant age, percentage of females, percentage of study cohort in each AO fracture classification,[17] immobilisation time, and study quality were included (one at a time only) as a main effect in the meta-analysis model to determine whether they significantly influenced the change in outcome measure after adjusting for change over time.

Results

Study selection. A total of 46 study reports, inclusive of 3258 subjects, were selected for this review and meta-analysis. The selection process is detailed in Figure 1.

Table III. Characteristics for all studies included in the meta-analysis

First author	Year	Study type	Groups in study	Study arms included	Country	Number of subjects	STROBE score
Arora[36]	2011	Randomised controlled trial	2	1	Austria	36	14
Brehmer[37]	2014	Randomised controlled trial	2	2	USA	81	17
Buijze[18]	2010	Retrospective cohort	2	2	USA	36	12
Chung[19]	2006	Prospective case series	1	1	USA	87	21
Costa[38]	2015	Randomised controlled trial	2	1	UK	231	21
Dzaja[20]	2013	Prospective cohort	2	1	UK	24	9
Egol[39]	2008	Randomised controlled trial	2	1	USA	39	14
Ekrol[40]	2014	Randomised controlled trial	2	2	UK	336	20
Fowler [21]	2013	Prospective cohort	1	1	USA	39	13
Galos[41]	2016	Randomised controlled trial	2	2	USA	36	13
Gong[22]	2011	Prospective cohort	2	1	South Korea	26	17
Gradl[42]	2014	Randomised controlled trial	2	1	Germany	72	20
Gradl[43]	2013	Randomised controlled trial	2	1	Germany	52	16
Haberle[44]	2015	Randomised controlled trial	2	2	Germany	60	16
Huber[23]	2006	Prospective case series	1	1	Germany	22	15
Huh[24]	2012	Prospective cohort	1	1	Korea	34	6
Jakubietz[45]	2012	Randomised controlled trial	2	1	Germany	22	16
Karantana[46]	2013	Randomised controlled trial	2	1	UK	66	15
Kasapinova[47]	2009	Prospective randomised study	1	1	Macedonia	42	17
Kim[48]	2011	Randomised controlled trial	2	2	South Korea	48	7
Kim[25]	2013	Retrospective cohort	2	2	South Korea	60	20
Krischak[26]	2009	Randomised controlled cohort study	2	2	Germany	46	20
Loisel[27]	2015	Prospective cohort	1	1	France	52	16
Lozano-Calderon[49]	2008	Randomised controlled trial	2	2	USA	60	18
Marcheix[50]	2010	Randomised controlled trial	2	1	France	50	17
Matschke[28]	2011	Prospective case series	2	1	USA	266	10
McFadyen[51]	2011	Randomised controlled trial	2	1	UK	27	16
Mellstrand[52]	2016	Randomised controlled trial	2	1	Sweden	70	13
Moriya[29]	2011	Prospective case series	1	1	Japan	62	22
Plate[53]	2015	Randomised controlled trial	2	1	USA	30	12
Rikli[30]	2015	Prospective cohort	1	1	Switzerland	249	16
Roh[31]	2014	Prospective cohort	1	1	South Korea	121	18
Rozental[54]	2009	Randomised controlled trial	2	1	USA	23	19
Safi[55]	2013	Randomised controlled trial	2	1	Czech Republic	31	20
Sammer[32]	2008	Prospective cohort	2	1	USA	85	19
Sharma[56]	2014	Randomised controlled trial	2	1	India	32	12
Souer[57]	2011	Randomised controlled trial	2	2	USA	94	9
Tosti[58]	2013	Randomised controlled trial	2	2	USA	60	19
Uchiyama[59]	2013	Randomised controlled trial	2	2	Japan	80	13
Wei[60]	2009	Randomised controlled trial	3	1	USA	12	22
Wilcke[61]	2011	Randomised controlled trial	2	1	Sweden	33	18
Williksen[62]	2015	Randomised controlled trial	2	1	Norway	46	15
Yamazaki[63]	2015	Randomised controlled trial	2	2	Japan	74	19
Yasuda[33]	2009	Prospective cohort	1	1	Japan	26	20
Ydreborg[34]	2015	Prospective cohort	1	1	Sweden	101	11
Zenke[35]	2009	Prospective cohort	3	3	Japan	118	18

Study characteristics. The reports included were of mixed study designs and quality; 18 were observational study designs[18-35] and 28 were randomised controlled trials.[36-63] The study characteristics are detailed in Table III. Of the 46 studies, 14 contained two or more arms within the study that were incorporated into the pooled estimates.

Risk of bias. The quality assessment score details are supplied in the supplementary table. The mean (SD) score was 15.9 (13 to 19). Analysis of the quality of the study showed no significant effect on outcomes, hence all studies were included in the meta-analysis, regardless of the quality score.

Results of individual studies. The individual details of each study are reported in Tables III and IV.

Patient-reported outcomes, DASH/QuickDASH Scores. The mean DASH/Quick DASH from 31 studies indicated a high post-operative disability of 66.0% (95% CI 59.9% to 72.2%) at one week post-surgery (Table V), with rapid subsequent improvement up until three months post-surgery. The pattern of improvement is shown in Figure 2a. The DASH/QuickDASH continued to improve up until one year, when scores were within the normal range[64] (mean 7.8%, 95% CI 4.8% to 10.8%). There was significant

Table IV. Individual study outcome measures and time points

First author	Year	Outcomes measured	Time points included (wks)
Arora[36]	2011	ROM (°), Grip strength (kg), DASH, PRWE	6, 12, 26, 52
Brehmer[37]	2014	ROM (°), Grip strength (kg), DASH	0.5, 2, 3, 4, 6, 8, 12, 26
Buijze[18]	2010	ROM (°), Grip strength (kg, %), DASH	2, 26
Chung[19]	2006	ROM (°), Grip strength (kg)	12, 26, 52
Costa[38]	2014	DASH, PRWE	12, 26, 52
Dzaja[20]	2013	ROM (°), Grip strength (kg), PRWE	6, 12, 26, 52
Egol[39]	2008	ROM (°) (%), Grip strength (%), DASH	12, 26, 52
Ekrol[40]	2014	DASH	6, 12, 26, 52
Fowler[21]	2013	ROM (°), Grip strength (%), DASH	2, 6, 12, 52
Galos[41]	2016	DASH	6, 12
Gong[22]	2011	ROM (%), DASH	0, 2, 6, 12, 24
Gradl[42]	2013	ROM (%), Grip strength (%)	8, 26, 52
Gradl[43]	2014	ROM (°) (%), Grip strength (%)	8, 52, 104
Haberle[44]	2015	ROM (°), QuickDASH	6, 12
Huber[23]	2006	ROM (°)	4, 12, 26, 52
Huh[24]	2012	Grip strength (kg, %), DASH	26, 52
Jakubietz[45]	2012	ROM (°), Grip strength (%)	6, 12, 26, 52
Karantana[46]	2013	ROM (°), Grip strength (%), DASH	6, 12, 52
Kasapinova[47]	2009	PRWE	1, 12, 26
Kim[48]	2011	ROM (°), Grip strength (kg), DASH	12, 52
Kim[25]	2013	ROM (°), Grip strength (kg), DASH	12, 52
Krischak[26]	2009	ROM (°, %), Grip strength (kg), PRWE	1, 6
Loisel[27]	2015	QuickDASH	1, 2, 3, 4, 5, 6
Lozano-Calderon[49]	2008	ROM (°), Grip strength (kg), DASH	12, 26
Marcheix[50]	2010	ROM (°), Grip strength (%), DASH	12, 26
Matschke[28]	2011	ROM (°), Grip strength (kg, %)	26, 52, 104
McFadyen[51]	2011	DASH	12, 26
Mellstrand[52]	2016	DASH, PRWE	12, 52
Moriya[29]	2011	ROM (%), Grip strength (%)	2, 4
Plate[53]	2015	ROM (°), Grip strength (kg), QuickDASH	2, 6, 12, 26, 52, 104
Rikli[30]	2015	Grip strength (kg), PRWE	6, 12, 26, 52
Roh[31]	2014	ROM (°), Grip strength (kg)	4, 12, 24
Rozental[54]	2009	ROM (°), DASH	6, 9, 12, 52
Safi[55]	2013	ROM (°), DASH	6, 12, 52
Sammer[32]	2008	ROM (%), Grip strength (%)	26, 52
Sharma[56]	2014	ROM (°), Grip strength (%)	6, 52, 104
Souer[57]	2011	ROM (°) (%), Grip strength (kg, %), DASH	12, 26
Tosti[58]	2013	ROM (°), Grip strength (kg, %), DASH	2, 6, 12, 52
Uchiyama[59]	2013	ROM (°), Grip strength (kg), QuickDASH	4, 8, 12, 16, 20, 26
Wei[60]	2009	ROM (°), Grip strength (kg), DASH	6, 12, 26, 52
Wilcke[61]	2011	ROM (%), Grip strength (%), DASH, PRWE	12, 26, 52
Williksen[62]	2015	ROM (°), Grip strength (kg), QuickDASH	16, 26, 52
Yamazaki[63]	2015	ROM (%), Grip strength (%), DASH	6, 12, 24, 48
Yasuda[33]	2009	ROM (%), Grip strength (%)	6, 12, 26, 52
Ydreborg[34]	2015	ROM (°), Grip strength (kg) (%), DASH	2, 26, 52, 104
Zenke[35]	2009	ROM (°), Grip strength (%), DASH	1, 2, 3, 4, 6, 8, 12, 24 and 52

% measured as percentage of other (uninjured) side rather than absolute values
ROM, range of movement; DASH, Disability of the Arm, Shoulder and Hand; PRWE, Patient Rated Wrist and Hand Evaluation

change between consecutive time points within the first year, but not between one and two years.

Analysing the DASH and the QuickDASH separately resulted in similar estimated disability scores and differences between scores.

PRWE scores. Only eight studies reported on the PRWE but the pooled results (Table V) were significant. The PRWE has a similar pattern of recovery to the DASH (Fig. 2b), with initial rapid improvements, but reached a plateau earlier than the DASH. There were significant changes occurring between consecutive time points only within the first six months.

Physical measures. Table VI provides all available results and further detail of the outcomes below.

Grip strength. In 19 studies grip strength was reported as an absolute (kg) value and 15 studies reported grip strength as a percentage (%) value (Table VI). Grip strength was approximately half that of the uninjured side at six weeks, with a mean of 13.8 kg (95% CI 10.4 kg to 17.1 kg) or 47.4% (95% CI 40.3% to 54.5%) of the uninjured side. Assuming full grip strength accounts for a 5% to 10% difference between left and right sides, it takes over one year to reach full comparable strength (Fig. 2c), with the one-year measures being a mean of 24.8 kg (95% CI 21.6 kg to

Table V. Patient-reported outcome results

Time (wks)	Mean (95% CI)	Change from previous time	p-value for change
DASH/QuickDASH (n = 31)			
1	66.0 (59.9 to 72.2)	UTA	N/A
6	30.7 (27.5 to 34.0)	-35.3 (-43.2 to -27.3)	< 0.001*†
12	16.3 (13.5 to 19.1)	-14.4 (-17.9 to -10.9)	< 0.001*†
26	11.5 (8.5 to 14.5)	-4.8 (-8.0 to -1.5)	0.001*†
52	7.8 (4.8 to 10.8)	-3.8 (-7.0 to -0.5)	0.017*†
104	6.3 (-0.5 to 13.0)	-1.5 (-10.1 to 7.1)	1.000†
Heterogeneity,τ^2	53.3 (35.5 to 87.3)		0.001*‡
PRWE (n = 8)			
1	68.7 (53.8 to 83.7)	UTA	N/A
6	40.4 (34.1 to 46.7)	-28.3 (-45.6 to -8.0)	0.002*†
12	22.6 (17.5 to 27.8)	-17.8 (-25.9 to -9.6)	< 0.001*†
26	15.4 (10.2 to 20.6)	-7.2 (-13.2 to -1.3)	0.008*†
52	12.2 (7.0 to 17.4)	-3.2 (-9.2 to 2.8)	0.550†
Heterogeneity, τ^2	38.6 (16.4 to 134.9)		<0.001*‡

*Statistically significant
†Bonferroni adjusted simultaneous z-tests
‡Cochrane's Q-test for heterogeneity
DASH, Disability of the Arm, Shoulder and Hand; UTA, unable to analyse due to absence of studies; PRWE, Patient Rated Wrist and Hand Evaluation

28.0 kg) or 88% (95% CI 82.1% to 94.2%) of the healthy side. Grip strength showed significant change between most time points up until two years.

Range of movement (ROM). Range of movement recovery followed a similar pattern of early, rapid improvements, but these mostly plateaued earlier than the other outcomes (Table VI; Figs 2d to 2f). Flexion and extension showed significant improvements between the one-, six-, 12- and 26-week time points, but not thereafter. Supination, pronation, radial deviation, and ulnar deviation showed significant improvements between some consecutive time points only in the first three months.

Additional analysis. Adverse outcomes relating to volar plate fixation were summarised from the 36 studies that reported observed complications. Of the 46 studies in this review, ten studies did not contribute to this summary: one study reported complications of surgery, but it was unclear whether these were related to volar plate fixation; three studies reported no adverse events; and six studies made no reference to complications at all. In total, there were 322 complications recorded. Of these, there were 21 cases of nonunion and 27 of malunion recorded. Out of the remaining 274 additional reported adverse outcomes, the ten most common were: neurological dysfunction, including carpal tunnel syndrome (103 cases); tendon issues, including tendinitis, tenosynovitis and rupture (59 cases); plate and screw issues (36 cases); incision and suture problems, including infections (36 cases); complex regional pain syndrome (15 cases); finger issues, including stiffness and functional loss (four cases); ulnar styloid pain (four cases); delayed healing (two cases); adhesive capsulitis of the ipsilateral shoulder (two cases); and radiocarpal subluxation (two cases). Due to complications, a total of 112 secondary procedures were performed. The three most commonly reported reasons for secondary procedures were plate/screw removal (68 cases), carpal tunnel release (seven cases) and tendon transfer following rupture (two cases). It was unclear whether complications were concomitant or individual cases in all except two studies so the total number of patients with complications could not be calculated.

Each outcome measure was analysed to explore the possible influence of each of the proposed moderators as described earlier. The results are presented in Table VII and VIII and summarised below.

Age, fracture types, and immobilisation time had a significant effect on some outcomes. Studies with a higher mean age had lower mean grip strength ($p = 0.001$), flexion ($p < 0.001$) and extension ($p = 0.001$) values after adjusting for change over time. After adjusting for change over time, study groups with a higher percentage of AO type B fractures had higher flexion ($p = 0.025$), extension ($p < 0.001$), ulnar deviation ($p = 0.011$) and grip strength ($p = 0.001$) values. Studies with longer mean immobilisation time had significantly higher flexion ($p = 0.014$), extension ($p = 0.004$) and ulnar deviation ($p = 0.011$) after adjusting for change over time.

The combined DASH/QuickDASH, supination, pronation, and radial deviation were not significantly influenced by any of these moderators. The PRWE and most outcomes when reported as percentage of the uninjured side were not reported by enough studies to enable analysis of moderator effects.

Discussion

These longitudinal meta-analyses illustrated initial high levels of impairment and disability following a distal radius fracture managed with volar plate fixation, with subsequent rapid improvements for the first three months. Except for ROM outcomes, improvements occur for six or 12 months post-operatively and plateau or approach normal values thereafter. Grip strength continued to change for up to two years post-operatively. This paper provides longitudinal data that may be useful for clinicians to compare patients' progress to the expected outcome means at regular time points throughout their recovery.

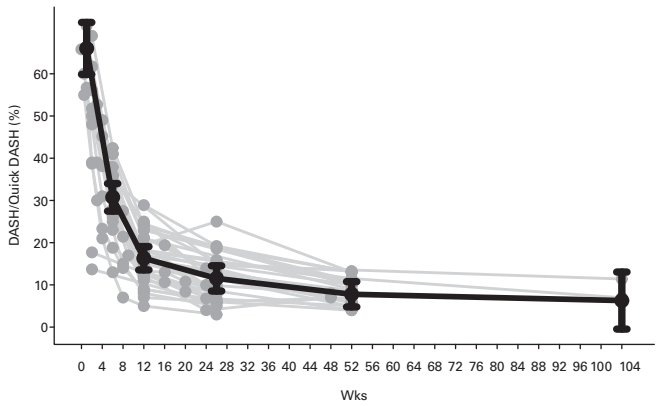

Fig. 2a

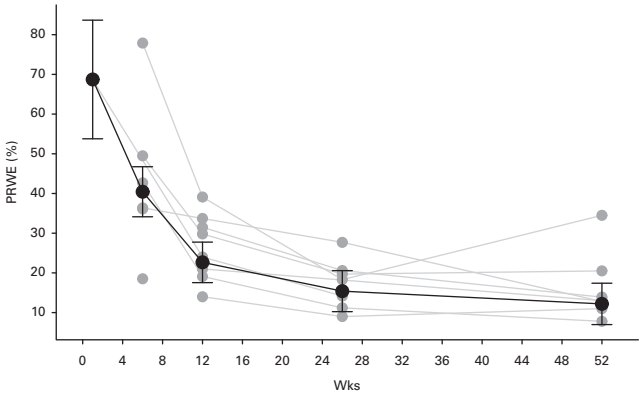

Fig. 2b

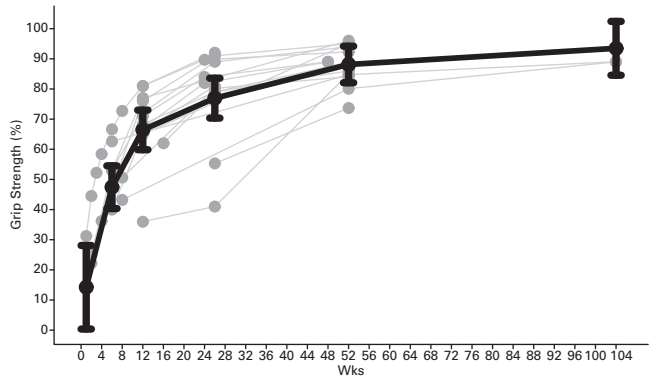

Fig. 2c

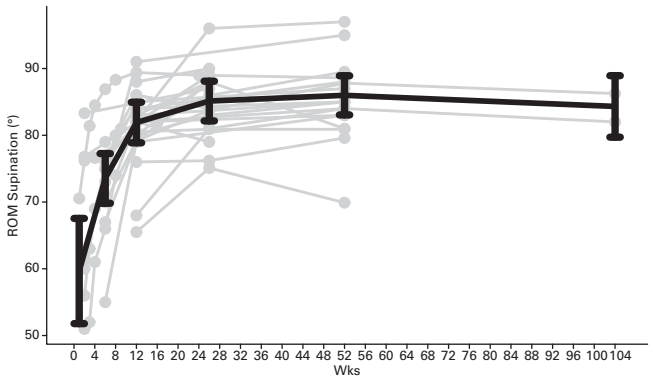

Fig. 2d

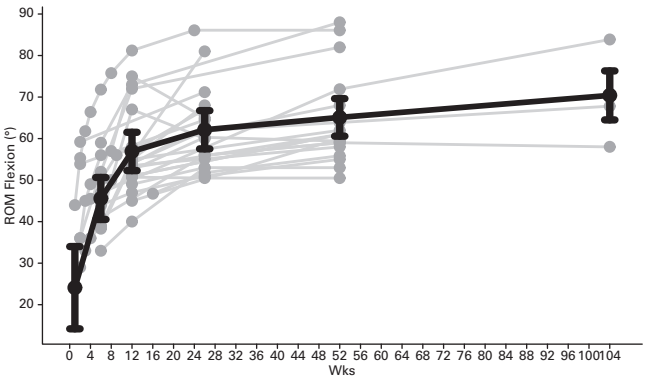

Fig. 2e

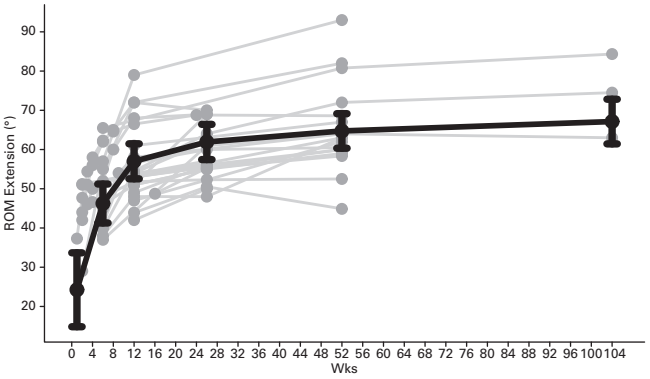

Fig. 2f

a) Disabilities of the arm to shoulder and hand (DASH)/QuickDASH results; b) Patient Rated Wrist and Hand Evaluation (PRWE) results; c) Grip strength (%) results; d) range of movement (ROM) supination (°) results; e) ROM Flexion (°) results; f) ROM Extension (°) results.

This pattern of recovery of initial high levels of impairment and disability, with rapid ubsequent improvement in the early recovery stages, has been reported in conservatively managed DRF,[9] as well as other common hand fractures managed with ORIF.[65] These studies also reported the most rapid improvements occur in the first two to three months following surgery. The initial rapid change in outcomes further reinforces the need for timely and early therapeutic intervention to maximise the period in which the most gains are expected.

Grip strength and DASH scores were the only outcomes to show continued improvement after one year. However, the number of studies reporting outcomes at two years may have been too few to detect any change in other measures. Regardless, with a minimum clinically important difference for the DASH and grip strength being 10% to 15%[66,67] and 6.5 kg[68] respectively, the DASH improved only by 2% in the second year and the grip strength improved by 2.4 kg, suggesting that the improvements occurring after one year are not clinically important for most patients. Other

Table VI. Physical outcome results (Part 1)

Time (wks)	Mean (95% CI)	Change from previous time	p-value for change
Grip strength (kg) (n = 19)			
1	5.0 (-0.7 to 10.7)	UTA	N/A
6	13.8 (10.4 to 17.1)	8.8 (2.5 to 15.1)	0.002*†
12	18.9 (15.9 to 22.0)	5.1 (2.4 to 7.8)	< 0.001*†
26	22.4 (17.9 to 27.3)	3.5 (1.3 to 5.6)	< 0.001*†
52	24.8 (21.6 to 28.0)	2.3 (-6.8 to 11.5)	1.000†
104	27.2 (19.8 to 34.5)	2.5 (0.1 to 4.8)	0.035*†
Heterogeneity, τ^2	41.1 (24.0 to 77.1)	N/A	< 0.001‡
Grip strength (% of uninjured arm) (n = 15)			
1	14.2 (0.4 to 28.1)	UTA	N/A
6	47.4 (40.3 to 54.5)	33.2 (14.9 to 51.5)	< 0.001*†
12	66.4 (59.8 to 73.0)	19.0 (10.4 to 27.5)	< 0.001*†
26	77.0 (70.3 to 83.6)	10.5 (1.9 to 19.1)	0.009*†
52	88.1 (82.1 to 94.2)	11.2 (4.5 to 17.8)	< 0.001*†
104	93.5 (84.6 to 102.4)	5.4 (-4.1 to 14.8)	0.724†
Heterogeneity, τ^2	119.1 (62.6 to 294.5)	N/A	< 0.001‡
Flexion (°) (n = 22)			
1	24.1 (14.2 to 34.0)	UTA	N/A
6	45.6 (40.5 to 50.6)	21.5 (9.2 to 33.8)	< 0.001*†
12	56.9 (52.3 to 61 to5)	11.3 (6.4 to 16.2)	< 0.001*†
26	62.1 (57.5 to 66.7)	5.2 (1.0 to 9..4)	0.007*†
52	65.1 (60.6 to 69.6)	3.0 (-0.3 to 6.3)	0.106†
104	70.4 (64.5 to 76.3)	5.3 (-0.1 to 10.7)	0.062†
Heterogeneity, ?^{2}	107.8 (66.2 to 200.1)	N/A	< 0.001‡
Flexion (%) (n = 7)			
1	UTA	UTA	N/A
6	63.9 (58.22 to 69.6)	UTA	N/A
12	76.4 (71.9 to 80.8)	12.5 (6.9 to 18.0)	< 0.001*†
26	85.4 (81.2 to 89.7)	9.1 (4.7 to 13.4)	< 0.001*†
52	89.6 (85.1 to 94.1)	4.2 (-0.4 to 8.7)	0.084†
104	UTA	UTA	N/A
Heterogeneity, τ^2	20.2 (5.2 to 107.9)	N/A	< 0.001‡
Extension (°) (n = 22)			
1	24.5 (14.8 to 33.7)	UTA	N/A
6	46.2 (41.3 to 51.2)	22.0 (10.4 to 33.6)	< 0.001*†
12	57.0 (52.5 to 61.5)	10.8 (5.9 to 15.6)	< 0.001*†
26	61.9 (57.4 to 66.4)	4.9 (0.8 to 9.0)	0.010*†
52	64.7 (60.3 to 69.1)	2.8 (-0.5 to 6.1)	0.148†
104	67.1 (61.4 to 72.8)	2.4 (-2.8 to 7.6)	1.000†
Heterogeneity, τ^2	101.2 (61.6 to 189.4)	N/A	< 0.001‡
Extension (%) (n = 7)			
1	UTA	UTA	N/A
6	68.3 (61.7 to 75.9)	UTA	N/A
12	81.6 (75.6 to 87.7)	13.3 (5.8 to 20.8)	< 0.001*†
26	91.2 (85.4 to 97.0)	9.6 (2.9 to 16.3)	0.002*†
52	94.6 (88.8 to 100.3)	3.4 (-2.2 to 8.9)	0.449†
104	UTA	UTA	N/A
Heterogeneity, τ^2	38.8 (12.2 to 180.2)	N/A	< 0.001‡
Supination (°) (n = 21)			
1	59.7 (51.8 to 67.5)	UTA	N/A
6	73.5 (69.8 to 77.2)	13.9 (3.7 to 24.1)	0.002*†
12	81.9 (78.9 to 84.9)	8.4 (4.1 to 12.6)	< 0.001*†
26	85.1 (82.1 to 88.1)	3.2 (-0.0 to 6.5)	0.057†
52	86.0 (83.1 to 88.9)	0.9 (-1.7 to 3.4)	1.000†
104	84.3 (79.7 to 88.9)	-1.7 (-6.6 to 3.3)	1.000†

authors have also conferred that any improvements after one year are not clinically or statistically significant.[69]

ROM measures plateaued earlier than other outcomes, and remained below normative values, demonstrating significant change for time points within the first three to six months, but not later in the recovery period. These findings highlight not only the need for early, timely rehabilitation, as the greatest gains and most efficacious time to use techniques to improve ROM is within the initial three months, but also reinforce the need to shift the clinical focus to strength and function after ROM has reached a plateau.

ROM is often the only outcome measure regularly monitored in a clinical setting, especially early in the recovery period. However, our findings suggest that grip strength and the DASH scores are more sensitive to longitudinal change than ROM measures and therefore are important outcome measures to use clinically, and regularly, to detect treatment efficacy over the first year. As in any clinical population, it is important to record outcomes that measure recovery at impairment, activity limitation, and participation levels[70] to give a holistic picture of progress. Importantly, in this population, the use of both physical and

Table VI. Physical outcome results (Part 2)

Time (wks)	Mean (95% CI)	Change from previous time	p-value for change
Heterogeneity, τ^2	41.6 (24.9 to 78.9)	N/A	< 0.001‡
Supination (%) (n = 8)			
1	UTA	UTA	N/A
6	82.8 (76.6 to 88.9)	UTA	N/A
12	92.4 (87.6 to 97.1)	9.6 (4.1 to 15.1)	< 0.001*†
26	95.6 (91.5 to 99.8)	3.2 (-0.7 to 7.3)	0.148†
52	96.5 (92.4 to 100.6)	0.8 (-1.2 to 2.9)	0.995†
104	UTA	UTA	N/A
Heterogeneity, τ^2	28.3 (10.0 to 117.6)	N/A	< 0.001‡
Pronation (°) (n = 21)			
1	69.4 (64.0 to 74.8)	UTA	N/A
6	78.1 (75.2 to 81.0)	8.7 (2.1 to 15.3)	0.003*†
12	83.1 (80.5 to 85.6)	5.0 (2.4 to 7.6)	< 0.001*†
26	84.2 (81.7 to 86.7)	1.1 (-0.7 to 3.0)	0.637†
52	85.5 (83.0 to 88.0)	1.3 (-0.3 to 2.9)	0.161†
104	84.9 (81.6 to 88.2)	-0.6 (-3.5 to 2.3)	1.000†
Heterogeneity, τ^2	31.6 (18.4 to 62.1)	N/A	< 0.001‡
Pronation (%) (n = 8)			
1	UTA	UTA	N/A
6	88.1 (83.5 to 92.8)	UTA	N/A
12	96.7 (94.0 to 99.4)	8.5 (2.0 to 15.0)	0.006*†
26	97.8 (95.4 to 100.1)	1.1 (-3.2 to 5.4)	1.000†
52	100.0 (97.8 to 102.3)	2.3 (-0.5 to 1.4)	0.507†
104	UTA	UTA	N/A
Heterogeneity, τ^2	6.2 (2.5 to 19.3)	N/A	< 0.001‡
Radial deviation (°) (n = 15)			
1	UTA	UTA	N/A
6	14.7 (12.6 to 16.8)	UTA	N/A
12	18.8 (17.0 to 20.6)	4.1 (1.8 to 6.4)	< 0.001*†
26	20.5 (18.8 to 22.3)	1.8 (-0.1 to 3.6)	0.063†
52	21.4 (19.7 to 23.2)	0.9 (-0.5 to 2.4)	0.485†
104	22.1 (19.7 to 24.6)	0.7 (-1.6 to 3.0)	1.000†
Heterogeneity, τ^2	9.7 (4.8 to 24.4)	N/A	< 0.001‡
Radial deviation (%) (n = 6)			
1	UTA	UTA	N/A
6	UTA	UTA	N/A
12	85.6 (78.6 to 92.5)	UTA	N/A
26	92.8 (88.0 to 97.5)	7.2 (-0.6 to 15.0)	0.078†
52	94.4 (90.0 to 98.8)	1.7 (-3.4 to 6.8)	0.928†
104	UTA	UTA	N/A
Heterogeneity, τ^2	14.5 (0 to 138.6)	N/A	0.188‡
Ulnar deviation (°) (n = 15)			
1	UTA	UTA	N/A
6	23.9 (20.8 to 27.0)	UTA	N/A
12	30.2 (27.6 to 32.9)	6.3 (3.0 to 9.6)	< 0.001*†
26	32.0 (29.4 to 34.6)	1.8 (-0.9 to 4.4)	0.386
52	32.3 (29.7 to 34.9)	0.3 (-1.8 to 2.4)	1.000
104	33.3 (29.7 to 36.9)	0.9 (-2.5 to 4.4)	1.000
Heterogeneity, τ^2	22.3 (12.3 to 48.1)	N/A	< 0.001‡
Ulnar deviation (%) (n = 6)			
1	UTA	UTA	N/A
6	UTA	UTA	N/A
12	77.2 (61.1 to 93.2)	UTA	N/A
26	82.4 (69.9 to 95.0)	5.3 (-9.8 to 20.3)	0.872†
52	91.2 (78.6 to 103.8)	8.8 (-0.3 to 17.8)	0.267†
104	UTA	UTA	N/A
Heterogeneity, τ^2	187.5 (62.4 to 1347.8)	N/A	< 0.001‡

*Statistically significant
†Bonferroni adjusted simultaneous z-tests
‡Cochrane's Q-test for heterogeneity
UTA to unable to analyse due to absence of studies

functional outcome measures also ensure longer-term improvements are accounted for.

When compared with the DASH, the PRWE reported higher disability scores and improvements plateaued earlier. This may be because the PRWE has a high focus on pain scores and therefore may be less likely to change. Other studies reporting pain scales at the one-year time point found that more than half of participants still report some pain, though most described their pain as mild.[8,71] This finding of the DASH showing more change compared with the PRWE is in contrast to another study that found that the PRWE had better responsiveness compared with the DASH for wrist injuries.[12] Nevertheless both these measures are considered appropriate for assessing outcome

Table VII. Estimated moderator effects with 95% confidence intervals (CIs) and p-values

Moderator	DASH/QuickDASH	p-value	ROM flexion (°)	p-value	ROM extension (°)	p-value	ROM supination (°)	p-value	ROM pronation (°)	p-value
Mean age (95% CI)	0.07 (-0.12 to 0.26)	0.487	-0.91 (-1.22 to -0.60)	< 0.001*	-0.42 (-0.69 to -0.17)	0.001*	-0.10 (-0.31 to 0.12)	0.388	0.02 (-0.04 to 0.09)	0.506
Mean % of females (95% CI)	0.16 (-0.01 to 0.32)	0.058	-0.20 (-0.53 to 0.13)	0.226	0.02 (-0.29 to 0.33)	0.907	-0.01 (-0.23 to 0.21)	0.934	0.01 (-0.09 to 0.11)	0.799
Mean % of type A fractures (95% CI)	0.04 (-0.04 to 0.11)	0.363	-0.05 (-0.25 to 0.15)	0.621	0.04 (-0.15 to 0.22)	0.746	0.04 (-0.07 to 0.15)	0.494	0.02 (-0.03 to 0.06)	0.399
Mean % of type B fractures (95% CI)	0.12 (-0.04 to 0.28)	0.140	0.24 (0.03 to 0.45)	0.025*	0.34 (0.16 to 0.52)	< 0.001*	0.02 (-0.08 to 0.12)	0.675	0.00 (-0.04 to 0.05)	0.877
Mean % of type C fractures (95% CI)	-0.03 (-0.09 to 0.02)	0.253	-0.11 (-0.22 to -0.01)	0.033*	-0.05 (-0.15 to 0.04)	0.273	-0.02 (-0.08 to 0.04)	0.464	0.01(-0.01 to 0.02)	0.437
Mean immobilisation time (days) (95% CI)	0.06 (-0.07 to 0.19)	0.384	0.20 (0.04 to 0.37)	0.014*	0.20 (0.07 to 0.34)	0.004*	0.01 (-0.05 to 0.08)	0.736	0.00 (-0.03 to 0.03)	0.974
Mean quality score (95% CI)	0.42 (-0.35 to 1.19)	0.283	-0.24 (-1.17 to0.69)	0.618	0.02 (-0.89 to 0.93)	0.959	0.20 (-0.39 to 0.79)	0.515	0.13 (-0.42 to 0.67)	0.643

*Statistically significant
p-values calculated using Wald-type test
DASH, Disability of the Arm, Shoulder and Hand; ROM, range of movement

Table VIII. Estimated moderator effects with 95% confidence intervals (CIs) and p-values

Moderator	ROM radial deviation (°)	p-value	ROM ulnar deviation (°)	p-value	Grip strength (kg)	p-value	Grip strength (%)	p-value
Mean age (95% CI)	-0.03 (-0.22 to 0.16)	0.754	-0.14 (-0.41 to 0.13)	0.313	-0.35 (-0.56 to -0.14)	0.001*	0.94 (0.03 to 1.86)	0.044
Mean % of females (95% CI)	-0.05 (-0.21 to 0.11)	0.571	-0.07 (-0.30 to 0.15)	0.520	0.04 (-0.04 to 0.12)	0.309	0.34 (-0.12 to 0.81)	0.150
Mean % of type A fractures (95% CI)	-0.02 (-0.11 to 0.07)	0.717	-0.00 (-0.14 to 0.13)	0.954	-0.13 (-0.19 to -0.07)	< 0.001*	-0.11 to (-0.29 to 0.07)	0.243
Mean % of type B fractures (95% CI)	0.05 (-0.08 to 0.18)	0.444	0.21 (0.05 to 0.37)	0.011*	0.12 (0.05 to 0.19)	0.001*	0.03 (-0.40 to 0.47)	0.877
Mean % of type C fractures (95% CI)	-0.01 (-0.06 to 0.04)	0.615	-0.05 (-0.12 to 0.02)	0.185	-0.02 (-0.08 to 0.04)	0.559	0.06 (-0.12 to 0.24)	0.522
Mean immobilisation time (days) (95% CI)	0.06 (-0.02 to 0.14)	0.162	0.14 (-0.03 to 0.26)	0.011*	0.06 (-0.04 to 0.16)	0.242	0.08 (-1.17 to 1.33)	0.904
Mean quality score (95% CI)	-0.01 (-0.35 to 0.33)	0.942	0.28 (-0.19 to 0.76)	0.244	-0.59 (-1.49 to 0.30)	0.194	0.08 (-1.80 to 1.96)	0.934

*Statistically significant
p-values calculated using Wald-type test
ROM, range of movement

in radial fractures.[72] It is likely that the lack of significant improvement after six months is due to the small number of studies reporting the PRWE.

The moderator analyses identified that mean cohort age, mean immobilisation time, and fracture classification had significant influence on the pooled outcomes. Older mean age was associated with poorer physical measures including flexion and extension ROM and grip strength. However, there is lack of consensus in the literature, with some studies supporting our finding that older age negatively influences outcomes,[73] but other studies reporting no influence on outcomes.[74] Studies with a higher percentage of AO type B (intra-articular) fractures had better grip strength, flexion, and extension than the other fracture types. Longer mean immobilisation times were associated with better flexion, extension, and ulnar deviation. Except for the quality score, which is a trial level variable, the results of these moderator analyses should be treated with caution, because the variables combine data over patients and may not be a reliable estimate of the true relationships (i.e. the significant results may be due to aggregation bias). The results do help to suggest the need for an individual patient data meta-analysis that would provide more reliable insight into these relationships, and would not be subject to potential aggregation bias.

Methodological considerations and limitations. Besides the clinical implications of our findings, this study also makes an important methodological contribution. Historically, meta-analyses analysed available studies at certain time points only, and inference between time points was not possible. When too few studies reported given time points, it may not have been possible to undertake a meta-analysis for those given time points. This statistical analysis successfully employed a method to estimate the change between time points for each outcome, without requiring all studies to report on outcomes at every time point throughout the recovery period. This analysis provided the unique opportunity to pool data from studies to answer our clinical questions. To our knowledge, this method of longitudinal meta-analysis has not been performed for the wrist fracture population, or for any other musculoskeletal cohort. This type of analysis could be used in future studies to investigate recovery of distal radial fracture managed conservatively or with other operative methods.

Several limitations need to be acknowledged. The heterogeneity between studies was significant for all the outcome measures. This is perhaps reflective of the wide variety of study designsfacility locations, or practices and sample characteristics that were included in our review and meta-analysis. We had no inclusion or exclusion criteria based on design or treatment pathway. We are also aware of recent concerns expressed about the reliability of fracture classification which might have affected our source material.[75,76]

The STROBE tool was for quality assessment; however, it is a questionnaire tailored to observational studies rather than the mixed study types analysed here. It was chosen as it focuses on areas relevant to our longitudinal research question, namely the methods and reporting of outcomes over time however it is possible another tool may have been preferable. Our results indicated no evidence of an impact of quality on summary measures.

Numerous studies have documented recovery following wrist fracture, but most do not detail outcomes across the prolonged recovery period. The results of this review confer that patients and clinicians can expect clinically meaningful improvements for one year post-surgery following DRF, after which progress plateaus for most and reaches normal values. The DASH and grip strength showed significant improvement for at least one year following surgery, with all other outcomes plateauing earlier.

Take home message:

- The period associated with the greatest physical recovery is in the first three months following surgery
- Improvements in outcomes can be expected for 12 months
- After 12 months, progress plateaus and reaches normal values.

Supplementary material

A table showing the Strengthening The Reporting of OBservational Studies in Epidemiology (STROBE) checklist used for our quality assessment for each study in this review is available alongside the online version of this article at www.bjj.boneandjoint.org.uk

Author contributions:
S. B. Stinton: Preparation of paper/study, Methods design, Literature search, Data extraction and cross checking, Quality assessment of papers, Analysis methodology, Write up, Editing of paper.
P. L. Graham: Preparation of paper/study: Methods design, Analysis methodology, Analysis of data, Write up, Editing of paper.
N. A. Moloney: Preparation of paper/study: Methods design, Literature search, Quality assessment of papers, Analysis methodology, Write up, Editing of paper.
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4.3 Published supplementary Material

Supplementary Figure 1: STROBE checklist of the included papers

Author	Year	STROBE component score																					Total
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	
Arora	2011	1	1	1	1	1	1	0	0	1	1	1	0	0	1	1	0	1	1	0	0	0	1	14
Brehmer	2014	1	1	1	1	1	1	1	0	1	1	0	0	1	1	1	0	1	1	1	1	0	1	17
Buijze	2010	0	1	1	1	0	1	0	0	0	0	1	0	0	1	1	0	0	1	1	1	1	1	12
Chung	2006	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	21
Costa	2014	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	21
Dzaja	2013	0	1	1	1	1	1	0	0	0	0	1	0	0	0	0	0	0	1	1	1	0	0	9
Egol	2008	1	1	1	1	0	1	0	0	0	1	0	0	1	1	1	1	1	1	1	1	0	0	14
Ekrol	2014	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	0	1	1	1	20
Fowler	2013	1	1	1	1	0	1	1	0	1	0	0	0	1	1	1	0	0	1	0	1	0	1	13
Galos	2016	1	1	1	1	1	1	1	0	0	1	1	1	1	0	1	1	1	1	0	0	1	1	17
Gong	2011	0	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	20
Gradl	2013	1	1	1	1	0	1	1	1	0	1	1	0	1	0	1	0	1	1	1	1	0	1	16
Gradl	2014	1	1	1	1	1	1	0	1	0	1	1	0	1	0	1	1	0	1	1	1	1	0	16
Haberle	2015	1	1	1	1	1	1	1	1	0	0	1	0	1	1	1	0	0	1	1	0	0	1	15
Huber	2006	0	0	1	1	1	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	1	6
Huh	2012	0	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	1	1	1	1	1	0	16
Jakubietz	2012	1	1	1	1	0	1	1	0	0	1	0	0	1	0	1	0	1	1	1	1	1	1	15
Karantan	2013	0	1	1	1	1	0	1	0	1	1	1	1	1	0	1	0	1	1	1	1	1	1	17
Kasapino	2009	0	1	1	1	0	1	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	7
Kim	2011	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	0	1	1	1	1	1	1	20
Kim	2013	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	0	1	1	1	1	0	1	20
Krischak	2009	1	1	1	1	1	1	1	1	0	0	1	1	0	1	1	0	1	1	1	1	0	0	16
Loisel	2015	1	1	1	1	0	1	1	1	1	0	1	0	1	1	1	1	1	1	1	1	1	0	18
Lozano-	2008	0	1	1	0	1	1	1	0	1	1	1	1	0	1	1	0	1	1	1	1	1	1	17
Marcheix	2010	0	1	1	1	0	1	0	0	0	1	1	0	1	1	1	0	0	1	0	0	0	0	10
Matschk	2011	1	1	1	1	0	1	1	1	1	0	0	1	0	0	1	1	0	1	1	1	1	1	16
McFadye	2011	1	1	1	1	0	1	0	0	1	1	1	0	0	1	1	0	0	1	1	1	0	0	13
Mellstran	2016	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	22
Moriya	2011	1	1	1	1	1	1	0	0	0	0	0	0	0	1	0	1	0	1	1	1	1	0	12
Plate	2015	1	1	1	1	0	1	1	0	0	0	1	1	1	0	1	0	1	1	1	1	1	1	16
Rikli	2015	1	1	1	1	1	1	1	1	0	1	1	1	1	1	0	0	0	1	1	1	1	1	18
Roh	2014	1	1	1	1	1	1	1	1	0	1	1	1	0	1	1	1	0	1	1	1	1	1	19
Rozental	2009	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	0	1	1	1	1	1	1	20

Safi	2013	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	0	1	1	1	1	0	1	19
Sammer	2008	0	1	1	1	1	1	1	1	0	0	1	0	0	0	0	0	1	0	1	1	0	1	12
Sharma	2014	1	1	1	1	0	1	1	1	0	0	0	0	0	1	1	0	0	0	0	0	0	0	9
Souer	2011	1	1	1	1	0	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	0	1	19
Tosti	2013	1	1	1	1	0	0	0	1	1	0	1	0	0	1	1	0	0	1	1	1	0	1	13
Uchiyam	2013	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	22
Wei	2009	1	1	1	1	0	1	1	1	1	1	0	1	1	1	1	1	0	1	1	1	0	1	18
Wilcke	2011	1	1	1	1	1	1	1	1	0	1	0	0	0	0	1	1	0	1	1	1	1	0	15
Williksen	2015	1	1	1	1	1	1	0	0	1	1	1	0	1	1	1	1	1	1	1	1	1	1	19
Yamazaki	2015	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	1	1	1	1	1	20
Yasuda	2009	0	1	1	1	1	1	0	0	0	0	0	0	0	1	1	1	0	0	1	1	1	0	11
Ydreborg	2015	1	1	1	1	1	1	1	1	0	0	1	1	1	1	1	0	1	1	1	1	1	0	18
Zenke	2009	0	1	1	1	0	1	1	1	0	0	0	0	1	1	1	0	1	1	1	1	0	1	14

Additional supplementary material relating to this study is provided at the end of this thesis in Appendix 3.

CHAPTER FIVE

Driving performance following a wrist fracture:

A pilot study using a driving simulator

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5.1 Authorship statement

The authors of the paper "**Stinton SB**, Pappas E, Edgar DW, Moloney NA. Driving performance following a wrist fracture: A pilot study using a driving simulator. Hand therapy. 2019; 25(1): 26-36." confirm that Susan Belinda Stinton has provided the following contributions to the study:

- Conception and design of the research
- Data acquisition
- Interpretation of the findings
- Writing the manuscript and critical appraisal of the content.

Susan Stinton

_____

Date: 6th February 2023

As the primary supervisor for the candidature upon which this thesis is based, I can confirm that the authorship attribution statements above are correct.

Evangelos Pappas

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Driving performance following a wrist fracture: A pilot study using a driving simulator

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Abstract

Introduction: Driving performance, as assessed using a driving simulator, after distal radius fracture has not been previously studied. Our aims were to undertake a pilot study to assess feasibility via: (i) acceptability of driving simulation for this assessment purpose, (ii) recruitment and retention, (iii) sample size calculation. Preliminary evaluations of differences in driving performance between individuals recovering from distal radius fracture and controls were conducted to confirm if the methodology provided meaningful results to aid in justification for future studies.

Methods: Driving performance of 22 current drivers (aged 21–81 years), recruited by convenience sampling, was assessed using a driving simulator. The fracture group included those recovering from distal radius fracture managed with open reduction and internal fixation using a volar plate. The control group were uninjured individuals. Assessment was performed approximately five weeks post-surgery and follow-up assessment two weeks later. Acceptability outcome measures included pain and simulator sickness scores, feasibility measures included retention rates and measures of driving performance included time spent speeding, time spent out of the lane, standard deviation of lateral position and hazard reactions.

Results: The assessment was completed by 91% of participants; two participants dropped out secondary to simulator sickness. Retention rates were 83%. Preliminary results suggest those with distal radius fracture spent more time out of the lane and less time speeding.

Conclusion: This method was sensitive, acceptable and feasible according to the parameters of this pilot study. The results from this small sample suggest that between-group differences in driving performance are measurable using driving simulation five weeks following distal radius fracture.

Keywords

Distal radius fracture, driving performance, driving simulator, orthopaedics, wrist fracture

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Introduction

Distal radius fractures (DRFs) are among the most common fractures across all ages,[1] accounting for around 20% of all fractures[2] and show trends of increasing incidence.[1] As 73–87% of the driving age population in developed countries including Australia and the US are licensed drivers;[3,4] it follows that many individuals who sustain a DRF are current drivers. The direct and indirect costs relating to wrist fractures (including DRF) are significant, with treatment, rehabilitation and productivity costs in Australia in excess of $131 million in 2016.[5] Open reduction and internal

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fixation (ORIF) with volar plate fixation are an increasingly common intervention for DRF.[6,7] A lengthy recovery period follows ORIF and is associated with high initial disability, but with the majority of recovery occurring within three months post-operatively.[8] Given the functional limitations during early recovery,[8] driving performance for individuals recovering from a DRF may be impaired. However, consensus is lacking among medical professionals regarding when, and by what criteria individuals are deemed to have adequate driving fitness following DRF.[9]

Many patients' seek advice from clinicians regarding return to driving timeframes following their DRF.[10–13] Driving is a complex task that requires adequate cognitive and physical function, and is also influenced by behavioural factors.[14] Driving is required for independence, social and work-related activities and poses significant consequences, including reduced work-related productivity, social isolation and burden on family members if individuals are unable to drive.[11] Conversely, driving with restricted capacity poses safety risks to individuals and others.

Formal driving assessment for licensing purposes of people with disabilities is a specialised field. The Australian national guidelines require people with permanent disabilities to have a driving assessment by a specialist occupational therapist prior to resumption of driving.[14] With temporary injuries including DRF, in Australia these assessments are not a legislated requirement and usually not routinely performed, due to the specialist service required, financial expense and time-consuming nature.[14] Fitness to drive recommendations are usually given by the treating doctor, with medico-legal, insurance, and safety-related implications if the individual is given inaccurate advice.[14]

Most studies investigating potential impacts of DRF on fitness to drive have been performed on healthy participants using immobilisation orthoses, but not on actual patients.[10,12,13,15,16] These provide low level evidence that driving when the wrist is immobilised results in worsened driving performance in healthy participants,[9] but potential confounding factors relating to DRF pathology remain poorly understood. There is only one other known study which assessed driving performance in participants with DRF.[17] Jones et al.[17] assessed the driving performance of 23 individuals with DRF managed with ORIF, using an on-road, closed course driving examination. They showed that 70% of participants passed the driving assessment at three weeks post-operatively.[17] This study reported no significant correlation between the driving assessment and clinical factors including age, laterality of the fracture, orthosis use when driving, strength, range of motion, pain or patient-reported confidence.[17] Despite the majority passing the assessment three weeks post-operatively, the corollary, however, is that 30% did not pass the driving assessment and could be dangerous, should they return to driving with restricted capacity. Further, the implication of this result in a real-world context may imply that one in three DRF patients should be advised to refrain from driving in the early recovery stage, but in Australia, there are no guidelines or legislation to enforce that requirement.

Driving simulation is a valid method of assessing driving performance in research settings for other populations[18,19] and has been used previously to assess driving performance of those with upper limb immobilisation.[13,20] To our knowledge, research-based assessment procedures for driving performance as measured by a driving simulator have not been previously described for individuals with any wrist trauma, including DRF managed with volar plate fixation. Although driving simulators are not practical for use in a clinical setting, the understanding gained from driving simulator research-based assessments will help guide clinical practice and fitness to drive recommendations.

Potential methodological considerations relating to driving simulation include simulator sickness, a type of motion sickness,[21] and provocation of fracture-related pain. In light of these adverse effects, the acceptability of the assessment procedures in a population with DRF needs to be established. While not a replacement for formal on-road driving assessments, the limitations of driving simulator use for research purposes were outweighed by the advantages of being able to standardise the driving assessment (including vehicle related factors, road and weather conditions) and the opportunity to record reactions to low frequency hazards, unplanned or more demanding tasks, as well as doing this without safety implications posed in assessing these driving components on-road.

There is a clear gap in our understanding of the fitness to drive for individuals with DRF, particularly in the immediate period following immobilisation. Assessing for differences in driving performance between healthy participants and those with a DRF, using standardised conditions within a driving simulator, will inform objective guidelines and aid clinical decision making in determining a patient's fitness to drive. However, as this is a new research area, a pilot study to establish the feasibility of the proposed methodology was needed to aid planning of future, larger scale studies. Key reasons for conducting a pilot study are to test the methodology, confirm the processes that are key to success of a future study (as identified through recruitment and retention rates), as well as ensuring the acceptability of assessments to ensure procedures are well tolerated.[22,23]

The primary aim of this pilot study was to assess feasibility. Specific objectives were to (i) evaluate the

acceptability of using a driving simulator for this population; (ii) obtain data on recruitment and retention; and (iii) generate data required to calculate the sample size for a larger study. The secondary aim was to perform a preliminary evaluation of differences in driving performance between individuals recovering from DRF and controls, as well as examine longitudinal changes in driving performance within the fracture group, to confirm if the methodology provided meaningful results to aid in justification for further future studies.

Methods

This pilot study used case-controlled cohort methodology to compare the driving performance of those with a DRF to an uninjured control group. It is reported in accordance with the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines for cohort studies.[24]

Ethical approval was granted by the Western Sydney Local Health District Ethics Committee (4220 AU RED HREC/15/WMEAD/52) prior to commencing recruitment.

Two groups of participants were recruited; a fracture group recovering from a DRF and uninjured controls. Individuals from both groups were recruited between May 2015 and February 2017, from four private physiotherapy practices in a large metropolitan area in Australia and their affiliated medical groups, with the control group also being recruited from a local university, using advertising posters and pamphlets. All individuals who met the inclusion criteria (Table 1) were invited to participate and informed consent was obtained. Those in the fracture group were also required to obtain written approval for participation in the study from their treating orthopaedic surgeon.

Procedure

Both groups undertook clinical and driving assessments. The fracture group had a baseline assessment within week one following cessation of full-time cast or splint use, the earliest feasible timepoint the assessments could be completed without wrist immobilisation. A single follow-up was performed two to four weeks later. Based on results from a large meta-analysis,[8] it was assumed that participants recovering from a DRF would have improvements in their physical status within this timeframe, but it was unknown if their driving performance would also change. The immobilisation prescription was at the discretion of the referring orthopedic surgeons which subsequently dictated the time point of the baseline assessment. The control group completed a single assessment.

Fracture participants received usual postoperative therapy provided by a physiotherapist/certified hand therapist, which included weekly or fortnightly appointments for approximately 12 weeks following surgery, consistent with routine practices reported in the literature.[25]

The assessment consisted of a clinical examination and driving assessment, performed by the same researcher on the same day at a university laboratory, lasting approximately 60 min. The clinical examination was performed prior to the driving assessment. The driving assessment was performed in a driving simulator consisting of a right-hand drive, automatic *SmartCar* equipped with *Stisim Drive*^{TM} software (Training Simulator—M400) which is in a specialised university laboratory setting (Figure 1). This simulator has a fixed base with no real motion, consisting of a full

Table 1. Inclusion and exclusion criteria for the fracture and control groups.

Inclusion criteria	Exclusion criteria
Distal radius fracture (intra or extra articular) managed with open reduction and internal fixation (ORIF) using a single volar plate[a]	Wrist fractures that had been managed conservatively, or with an alternative operative procedure to an ORIF using volar plate fixation[a]
A valid Australian driver's license[b]	Drivers with learner or probationary licenses[b]
A current driver who has driven a car within the last 6 months[b]	Concurrent neural injury to the upper limb[a]
Over 18 years of age[b]	Concurrent musculoskeletal injury sustained at the time of the wrist fracture[a]
	Current pain medication use other than over the counter analgesia such as paracetamol or nurofen, or medication use where driving is not recommended[b]
	Bilateral wrist fracture[a]
	Unable to understand and speak English[b]

[a]Criteria for wrist fracture group only.
[b]Criteria for both the fracture and control group.

Figure 1. Driving simulator set-up.

car body, with steering wheel, accelerator and brake pedals, dashboard and speedometer. Projector screens give a 260° field of view. The same researcher performed both the clinical and driving assessment, and thus was not blinded to the group of the participants; however, the driving performance measurements were automatically recorded by the simulator software, which minimized the possibility of assessor bias.

The driving assessment consisted of two scenarios, each 10 km long and lasting approximately 10 min. Each scenario and the total drive time was kept short, which is in line with recommendations to minimize simulation exposure to reduce rates and severity of simulator sickness.[26] A 10-min break between the two driving scenarios was included to minimize simulator sickness. Prior to commencing the driving assessment, participants were given a practice run to account for potential learning effect. Participants were instructed to start the driving scenario, with the same script for each participant (Appendix 1). The driving simulator procedures were similar to those used in previous studies in individuals with upper limb conditions[13] and were based on a scenario from a previous study.[27] Scenario one focused on control and maneuvering the car. Scenario two also required participants to respond to potential hazards.

Feasibility outcomes

Measures of recruitment, retention and simulator testing acceptance were assessed, in-line with previously reported key measures of feasibility reporting.[22,23]

Recruitment. Recruitment issues were identified from informal patient reports.

Retention rates. Retention was assessed by both the number of participants completing each assessment attended and the number of participants in the fracture group returning for the follow-up assessment, with the aim of over 80% completion of procedures and under 20% drop out, keeping with the Newcastle-Ottawa Scale for quality assessment of cohort studies where points are lost where retention percentages are less than 80%.[28]

Acceptance of procedures. To assess tolerance of procedures, potential adverse effects of pain and simulator sickness were recorded. Pain intensity rating on a numerical rating scale (NRS 0–10)[29] was recorded before, during and after the assessments. If participants reported an increase in pain, they were reminded they could cease the assessment. Simulator sickness was recorded after each scenario in the driving assessment using subjective reports of none, mild, moderate or severe.

Clinical outcomes

The clinical outcome measures included those commonly used when detailing recovery following DRF.[8]

Range of motion. A goniometer was used according to the standardized guidelines to record active composite finger flexion,[30] wrist flexion, wrist extension, forearm supination and pronation.[31]

Grip strength. Pain-free grip strength (kg) was measured using a hand-held dynamometer according to the standardized guidelines[31] with the best of three attempts recorded.[32]

Patient-reported functional measures. Participants completed the Disability of the Arm, Shoulder and Hand (DASH) questionnaire and Patient-rated wrist evaluation (PRWE); both are valid and reliable indicators of change in functional ability following a DRF.[33]

Laterality assessment. Hand laterality was assessed using the *Recognise* app to record accuracy and time taken to discriminate left- and right-hand images. This has been used previously in studies investigating prognostic factors following a DRF,[34] with normative reaction times available.[35]

Driving assessment

Outcomes were chosen to reflect participants' control of the car and their driving behavior. These included

- Average car speed (kph).
- Percentage of total drive time spent over the speed limit.

- Standard deviation of lateral position (SDLP)(m): a measure of the 'weaving' or lateral movement of the vehicle. As increased SDLP results in lane crossings into the adjacent traffic lane or off the road, it is considered an index of driving safety.[36]
- Percentage of total drive time the vehicle spent out of lane.

Hazard reaction. Two events representing potential hazards were evaluated.

Event 1: A truck pulled out into the lane in a section of road undergoing roadworks, requiring sudden braking to avoid a collision (stopping short of the hazard). Driving performance during this task was analysed using driving speed, maximum brake input, and the final car to truck distance in the final stationary position.

Event 2: The driver was required to make a right turn against a line of oncoming vehicles that were spaced at consecutively longer intervals. Driving performance during this task was analysed using driving speed, SDLP during the turn and the distance between cars (m) at which the participant decided to take the turn. Very short distances are reflective of riskier driving behaviour, and very long distances reflective of overly cautious driving.

Statistical analyses

Demographics, retention rates, simulator sickness and pain were reported using descriptive statistics.

Clinical and driving assessment data were assessed for normality using skewness and kurtosis scores and Kolmogorov–Smirnov and Shapiro–Wilk tests of normality for driving performance variables. As expected with the sample size ($n = 22$), data were not all normally distributed and non-parametric procedures were used. As fitting for non-parametric procedures, median values are reported.

Mann–Whitney U tests were used to compare the control group with both the fracture group baseline and follow-up results. Repeated-measures Wilcoxon signed rank tests were used to compare variables from the fracture group between baseline and follow-up. Participants who did not complete the assessments were not included in analyses.

Sample size calculations for future studies were conducted using the significant driving performance variables that appeared most sensitive to change.[37]

Results

There were 16 control and 6 fracture group participants. Demographics are detailed in Table 2. There were no significant differences between the groups in age ($p = 0.97$), gender ($p = 0.86$) or hand dominance ($p = 0.55$). The first assessment was completed at a median time post-surgery of 34 (range 14–43) days and follow-up assessment at median of 48 days (range 31–63).

Table 2. Demographics of the control and fracture groups.

	Control (n=16)	Fracture (n=6)
Age (in years)		
Median (SD)	47 (17.5)	54 (19.9)
Range	22–81	21–71
Gender		
Female (% of group)	10 (62.5%)	4 (66.7%)
Male (% of group)	6 (37.5%)	2 (33.3%)
Hand dominance		
Right (% of group)	15 (93.8%)	6 (100%)
Left (% of group)	1 (6.2%)	0 (100%)
Injured side		
Right (% of group)		1 (16.7%)
Left (% of group)		5 (83.3%)
Dominant side injured		1 (16.7%)

Acceptability

Simulator sickness was reported during nine baseline driving assessments (41%), and at two follow-up assessments (40%), affecting 50% of the fracture group and 37% of the control group. However, in the majority, simulator sickness was mild and resolved within 15 min of completing the assessment procedures. Participants rated their simulator sickness as none ($n = 11$), mild ($n = 7$), moderate ($n = 2$) or severe ($n = 2$).

Recruitment

Recruitment rates were slower than anticipated, primarily due to difficultly for fracture participants to travel to the driving simulator location, which was a 30–60-min drive from each of the physiotherapy practices. Funding provided vouchers for participants to compensate for travel costs, but the logistics of travel for individuals who had not returned to driving independently was an identified recruitment barrier.

Retention rates

One participant (in the control group) did not complete the driving assessment due to simulator sickness, equating to 95% completion of the assessment procedures. An additional participant from the fracture group did not return for the follow-up due to simulator sickness at the baseline assessment, equating to 83% of follow-up assessment retention. There were no other drop-outs.

Pain was reported prior to the assessment procedures in two participants (1–6/10 NRS). An increase in pain by two to five points on the NRS was reported by two participants, who reported an increase in pain at both the baseline and follow-up driving assessments. These participants reported their pain resolved or returned to the baseline level within 15 min of completing the assessment. No participants opted to cease testing because of pain.

Sample size estimation

Power analyses[37] were conducted using the mean (SD) of both the time spent over the speed limit and the time spent out of the lane. A minimum sample size of four per group would be required for 0.8 power to detect significance (<0.05) using effect sizes from this study of 2.8 and 2.5, respectively. To be more conservative and to improve the generalizability of the results, if effect sizes remain moderate to large (0.7–1.0), 17–34 participants per group will be required. Also to be considered is the timing of the assessments and the sample size; as the effect sizes reduces after five weeks post-surgery, more modest effect sizes estimations such as the example above will be required if the assessments are being performed after this time point.

The drop-out rate was 17%, but two further people experienced severe simulator sickness and two experienced an increase in pain, although they did not drop out. To allow for future participants dropping out because of pain and simulator sickness, it would appear prudent to allow for a drop-out rate of 25%. Therefore, the results suggest a minimum sample size of 22 participants for earlier assessment timepoints and up to 43 participants per group for later assessment timepoints.

Clinical assessment

There was greater range of motion and grip strength, faster left/right discrimination times and lower disability scores in the controls compared to the fracture group at both timepoints, but the size of the differences was smaller by follow-up as the fracture group improved between assessments (Table 3).

Driving assessment

During scenario one (Table 4), there were differences between the fracture and control groups, with the fracture group spending a higher percent of time spent out of the lane (13.04% vs. 0.21%, $p < 0.001$) and a lower percent of time over the speed limit (3.00% vs. 15.57%, $p < 0.001$), with these differences no longer apparent by the follow-up assessment.

During scenario two (Table 5), there were also differences between the groups at the baseline assessment, with the fracture group driving at lower speed during the first hazard event (35.32 vs. 30.97 km/h, $p = 0.04$), and consequently able to stop further away from the truck hazard (15.36 m vs. 12.66 m, $p = 0.002$). These differences remained significant at the follow-up assessment. In the second hazard, the fracture group waited for a greater gap between oncoming cars prior to attempting to turn into the oncoming traffic (99.39 m vs. 65.02 m, $p = 0.03$); this difference was no longer significant at follow-up (102.91 m vs. 65.02, $p = 0.5$).

Discussion

The methodology was effective in highlighting differences in driving performance as assessed on a driving simulator, between individuals recovering from DRF and controls. Retention rates were relatively high (83%) despite pain and simulator sickness. One-third of the fracture group reported an increase in pain during the driving assessment; however, no participants opted to cease the assessment. Recruitment rates were lower than anticipated and we recommend future similar studies account for the travel difficulties faced by participants who may not be able to drive to an external driving simulator assessment site, and/or engage the assistance of a patient representative to flag potential recruitment issues.

Acceptability was limited primarily by simulator sickness, affecting 41% of participants, but most cases were mild. Despite being a common complaint associated with driving simulation,[38] we hypothesize that our rates were high due to the number of corners and turns included[38] to assess steering wheel control specifically challenging our patient population, despite implementing appropriate management strategies. Simulator sickness needs to be considered as a potential risk when obtaining ethics and participant consent, and the related drop-out rate needs to be accounted for when planning future studies. Warning patients during the consent process and explaining that they might experience simulator sickness during the driving assessment, but this is likely to settle within 15 minutes, may aid participant retention.

Even though this study was not statistically powered to fully evaluate group or longitudinal differences, the identification of the variables that were different between group or time points may assist with design of future studies. There were significant differences in clinical and driving assessment between the fracture group and controls, and within the fracture group across time. Despite the small sample size, it is likely the significant findings resulted from moderate to large effect sizes. Regardless, these findings support the

Table 3. Clinical assessment results, between group and repeated measures analyses.

	Control group (n=16)		Fracture group baseline assessment (n=6)		Fracture group follow-up assessment (n=5)		p value (effect size)		
	Median	(95% CI)	Median	(95% CI)	Median	(95% CI)	Between-group comparison (baseline)	Between-group comparison (follow-up)	Repeated measures comparison Fracture group
Questionnaires									
DASH	2.00	(0.89–11.23)	32.05	(5.28–61.98)	12.93	(0–43.63)	0.006* (1.36***)	0.05* (0.87***)	0.138 (0.60)
PRWE	0.00	(0–3.72)	60.25	(15.58–86.09)	20.50	(0–60.05)	<0.001* (2.05***)	0.008* (1.44***)	0.043 (0.76**)
Range of movement									
Composite finger flexion (mean finger cm from pulp to distal palmar crease)	0.00	(0–0.54)	0.00	(0–2.34)	1.0	(0–2.17)	0.449 (2.05***)	0.153 (0.85**)	0.785 (0.08)
Wrist extension (degrees)	67.50	(63.41–73.47)	47.50	(24.96–61.71)	50.00	(29.07–66.93)	0.001* (2.10***)	0.011* (1.61***)	0.197 (0.29)
Wrist flexion (degrees)	75.00	(63.50–75.88)	27.50	(13.87–54.47)	35.00	(14.36–59.64)	0.001* (2.29***)	0.002* (2.14***)	0.109 (0.15)
Forearm supination (degrees)	80.00	(75.62–83.75)	37.50	(21.84–63.16)	50.00	(31.02–76.98)	0.002* (2.5***)	0.019* (1.82***)	0.066 (0.60)
Forearm pronation (degrees)	85.00	(82.41–86.96)	75.00	(51.47–86.85	80.00	(72.40–87–60)	0.01* (1.25***)	0.179 (0.94**)	0.109 (1.63***)
Pain-free grip strength									
Percent of injured side (or percent of dominant side in control group)	93.95	(84.42–96.21)	47.71	(18.40–78.47)	72.14	(29.46–102.33)	0.003* (0.60)	0.091 (1.24***)	0.043 (0.60)
Left/right discrimination									
Left time (s)	2.10	(1.95–2.34)	2.70	(2.13–2.97)	2.60	(2.14–3.34)	0.033* (1.25***)	0.019* (1.32***)	0.785 (0.31)
Right time (s)	2.05	(1.81–2.34)	2.30	(1.80–3.29)	2.60	(2.34–2.77)	0.018* (0.82**)	0.003* (1.54***)	0.686 (0.32)

*P values significant at ($p < 0.05$), **effect sizes medium $> 0.7 <$ 1.0 and ***large $>$1.0.

Table 4. Driving performance during scenario 1: Results, between group and repeated measures analyses.

	Control group (n=15)		Fracture group Baseline assessment (n=6)		Fracture group Follow-up assessment (n=5)		p value (effect size)		
	Median	(95% CI)	Median	(95% CI)	Median	(95% CI)	Between group comparison (Baseline)	Between group comparison (Follow-up)	Repeated measures Fracture group
Average speed (km/h)	61.68	(60.28–64.46)	58.78	(54.14–63.84)	62.11	(58.00–64.86)	0.154(0.76**)	0.933 (<0.001)	0.138(0.80**)
SDLP (m)	0.99	(0.98–1.04)	1.04	(1.01–1.09)	1.03	(0.98–1.08)	0.132(0.70**)	0.612(0.32)	0.273(0.46)
Time over speed limit (%)	15.57	(14.35–22.35)	3.00	(0.36–3.97)	17.50	(13.02–22.85)	<0.001*(2.82***)	0.823(0.25)	0.043*(2.74***)
Time out of lane (%)	0.21	(0.05–1.91)	13.04	(6.19–20.80)	0.00	(0–0.13)	<0.001*(2.48***)	0.117(0.42)	0.043*(1.23***)

*P values significant at ($p < 0.05$), **effect sizes medium $> 0.7 <$ 1.0 and ***large $>$1.0.
SDLP: standard deviation of lateral position, measured in metres.

Table 5. Driving performance during scenario 2: Results for between group and repeated measures analyses.

	Control group (n=15)		Fracture group Baseline assessment (n=6)		Fracture group Follow-up assessment (n=5)		p value (effect size)	
	Median	(95%CI)	Median	(95%CI)	Median	(95%CI)	Between-group comparison (baseline)	Between-group comparison (follow-up)
Event 1								
Speed at start of event	50.90	(47.39–60.03)	49.89	(47.63–51.01)	43.02	(37.42–57.74)	0.381 (0.75**)	0.381 (0.28)
Mean event speed (kph)	35.32	(32.33–39.07)	30.97	(24.06–34.80)	23.58	(18.91–29.83)	0.045* (1.07***)	0.001* (1.84***)
Maximum braking input	80.00	(75.44–83.36)	77.50	(73.94–82.72)	71.00	(59.79–82.21)	0.569 (0.18)	0.205 (0.76**)
Minimum distance to truck	12.66	(10.47–13.46)	15.36	(14.25–16.14)	14.35	(13.45–15.82)	0.002* (1.61***)	0.005* (1.30***)
Event 2								
Mean speed (kph)	44.38	(38.34–48.70)	42.64	(27.32–50.96)	40.03	(35.75–47.05)	0.353 (0.40)	0.225 (0.42)
SDLP (m)	3.00	(2.82–3.06)	2.76	(2.5–2.99)	2.87	(2.64–3.03)	0.062 (0.79**)	0.686 (0.79**)
Gap distance between cars (m)	65.02	(60.62–85.51)	99.39	(80.48–111.05)	102.91	(49.66–126.65)	0.027* (1.36***)	0.50 (0.56)

*P values significant at ($p < 0.05$), **effect sizes medium $> 0.7 <$ 1.0 and ***large $>$1.0.
SDLP: Standard deviation of lateral position, measured in metres.

sensitivity of the methodology and suitability of using a driving simulator for this assessment purpose. Two of the driving variables; percent of time out of lane and percent of time over the speed limit were the most sensitive and would be useful outcomes for use in future studies. These findings also need to be interpreted with caution, as the driving performance measures as assessed on a driving simulator, do not necessarily equate to on-road or real-life driving 'safety'.

Driving speed and time spent over the speed limit have been used in prior studies to reflect 'risky' driving behavior and confidence.[27] Our findings show that the fracture group was less likely to speed compared to controls. This was less apparent by the follow-up, for between-group and repeated-measures comparisons, arguably as those recovering from DRF gained confidence in their driving ability. These findings are consistent with the more cautious driving behaviour previously described in studies[13,20] analyzing the effect of wrist immobilisation on driving performance.

The SDLP and the time spent out of the lane were used to reflect maneuverability and control of the vehicle. Despite the trends of slower speeds, the fracture group spent significantly more time out of their lane at the baseline assessment when compared to controls, with consistent trends for higher SDLP. The fracture group spent significantly less time out of their lane at follow-up, and showed trends of lower SDLP at follow-up compared to at the baseline assessment. These findings likely reflect improving steering wheel control and are consistent with clinical measurements which improved over time. In this study, percent of time out of the lane appears to be more sensitive to change than SDLP.

Our findings may have been confounded by learning effects associated with repeated driving assessments undertaken by the fracture group. Anticipatory driving behaviour was noted in the follow-up driving assessment, e.g. some participants started to brake before the truck pulled out in Event One, resulting in a larger final distance from the car to the truck. A previous study using repeated measures methodology for driving simulator assessments reported no significant learning effect.[39] However, given the assessment of the potential hazards used in our methods, we recommend having two randomly occurring scenario configurations for the baseline and follow-up assessments and assessing the control group on two occasions to account for potential learning effects.

Another limitation in applying the results of this study relates to the wide age range. Older drivers are more likely to have medical conditions that can impact their fitness to drive.[14] There was also a lack of exclusion based on other possible medical conditions that may change driving performance. The assumption that inclusion requirement of a valid driver's license and having driven in six months prior to assessment, implies that no other medical conditions were prohibiting driving; however, there is still a possibility that potential between group differences were not controlled for.

This study has limitations relating to the external validity. The driving simulation was performed in a right-hand drive car with automatic transmission. There may be differences in driving performance in other simulator/car types and vehicle specifics.

The between-group differences in clinical outcomes were expected, given the known levels of physical impairments following DRF managed with ORIF.[8] The above-mentioned differences in driving performance were not obvious at the follow-up assessment, despite significant differences persisting between the fracture and control group clinical outcomes. Future research should evaluate which clinical variables have the highest correlation or prediction of driving performance, as this could guide clinical assessments for fitness to drive in the absence of driving simulation or on-road assessments. It is also unclear what minimum requirements (from either clinical or driving simulator assessments) equate to safe return to driving.

Conclusions

This methodology was largely successful in terms of acceptance and feasibility. Despite the small sample size and associated limitations of this pilot study, the results suggest significant differences in driving performance between healthy individuals and those recovering from a DRF at five weeks post-surgery, but not by the follow-up assessment at seven weeks post-surgery. These differences are apparent in both steering control and driving behaviour, which leads to the recommendation of cautionary advice to patients if they wish to return to driving in the first week after their cast or splint is removed. These results further confirm the sensitivity of driving simulator assessments and application of the study method in future research.

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Ethical approval

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Informed consent

Written informed consent was obtained from all subjects before the study.

Guarantor

SS.

Contributorship

All authors were involved in the protocol development, gaining ethical approval, data analysis, reviewing the manuscript and approved the final version of the manuscript. SS and EP were involved in participant recruitment. SS performed the assessment procedures and wrote the first draft of the manuscript.

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Appendix 1. Driving assessment script prior to commencing each scenario

Instructions prior to entering the car:

"This driving simulator will be used to test your driving performance. Please sit in the car and adjust the seat so that you can comfortably reach the pedals and steering wheel.

Can you see all of the 3 screens and the rear view mirror?

The car operates as a normal on-road car does. The steering wheel, accelerator, brakes and indicators all work as they would in a normal car. You can have a practice driving the car so that you can get used to driving in the simulator. You have 2 minutes to get used to driving in the car"

Scenario 1 instructions:

"The first scenario is about to start. The normal Australian Road Rules such as speed limits, intersection rules and usual road signs apply. Remember, if you get pain in your injured wrist, or if you are feeling any motion sickness like symptoms, or if you wish to stop the test at any time you may do so. You need to drive to Kings Town. Follow the green signs to get there. Try to drive there promptly, as you are meeting a friend in 15 minutes.

Do you have any questions? You may start now"

At end of scenario one:

(fracture group) – "Do you have any pain at this point in your injured wrist?" If yes, "What is your pain out of 10?"

(All participants) – "Do you have any motion sickness like symptoms? If yes, "are these mild, moderate or severe?"

Scenario 2 instructions:

"The next driving scenario is the final part to your assessment.

You need to drive to Kings Town again. Follow the green signs to get there. It may be a different route to the last scenario. Try to drive there promptly, as you have an appointment in 15 minutes.

Do you have any questions? You may start now"

At end of scenario two:

(fracture group) – "Do you have any pain at this point in your injured wrist?" If yes, "What is your pain out of 10?"

(All participants) – "Do you have any motion sickness like symptoms? If yes, "are these mild, moderate or severe?"

Additional unpublished material relating to this study is provided at the end of this thesis in Appendix 4

CHAPTER SIX

Who crashes their car after wrist fracture?

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Authorship statement

The authors of the paper "**Stinton SB**, Pappas E, Nettel-Aguirre A, Moloney NA, Refshauge K, Edgar DW. Who crashes their car following wrist fracture? *The Journal of Hand Therapy.* 2023; in-print." confirm that Susan Belinda Stinton has provided the following contributions to the study:

- Conception and design of the research
- Data acquisition
- Interpretation of the findings
- Writing the manuscript and critical appraisal of the content.

Susan Stinton

_____

Date: 6th February 2023

As the primary supervisor for the candidature upon which this thesis is based, I can confirm that the authorship attribution statements above are correct.

Evangelos Pappas

_____

Date: 6th February 2023

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Who crashes their car following wrist fracture?

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ABSTRACT

Background: Wrist fractures are common injuries associated with high disability in the early recovery period. The impact of wrist fractures on safe return to drive is not understood.
Purpose: (1) To compare the proportion of adults who were drivers in car crashes before and after wrist fracture; (2) To examine potential factors (demographic and/or clinical) associated with increased odds of being a driver in a car crash following wrist fracture.
Study Design: Retrospective cohort study.
Methods: Three state-wide government datasets (MainRoads Western Australia [WA], Hospital Morbidity Data Collection and the Emergency Department Data Collection) were used to obtain and link demographic, clinical and car crash information relating to adults with a wrist fracture sustained between 2008 and 2017. McNemar's tests were used to compare the proportion of drivers in a car crash within the 2 years prior to and following the fracture date. Multivariable logistic regressions were used to identify if any variables were associated with increased odds of crashing in the post-fracture period.
Results: Data relating to 37,107 adults revealed a 3.3% (95% CI 3.0%–3.6%, $p < 0.05$) decrease in the proportion of drivers in a car crash following wrist fracture, persisting for the entire 2 years post-fracture, when compared to the proportion who crashed before their fracture. Those with more severe wrist fracture injury patterns had 79%(95% CI 1.07–3.0, $p = 0.03$) higher odds of having a crash in the first 3 months following their injury, compared to those with isolated wrist fracture injuries.
Conclusions: These results inform and update return to drive recommendations. The reduced proportion of drivers involved in crashes following wrist fracture persisted for 2 years; longer than the expected physical recovery timeframe. It is important that hand therapists actively educate the sub-group of adults with more severe wrist fracture injury patterns of the increased likelihood of car crash for the 3 months following their fracture.

Introduction

Driving is a complex task that requires co-ordination of physical, behavioral and cognitive processes and is important for independence in social and work-related activities.[1] Individuals commonly ask "when is it safe to return to drive?" following upper limb fracture. There are associated safety and medicolegal risks if individuals with restricted driving capacity are given inaccurate advice, especially if they are involved in a subsequent car crash. Conversely, delaying return to drive has financial and social consequences, results in reduced independence and increased work absences.[1] The ultimate medical fitness to drive is often given by the treating doctor.[2,3] However, the skill set of hand therapists entailing assessments and understanding of functional capacity of patients is uniquely placed within the multidisciplinary team to inform this complex decision.[2]

Wrist fractures account for approximately 20% of all adult fractures and are among the most common fractures across all ages, affecting both young and older drivers.[4] The mechanism of injury is often low impact trauma in post-menopausal women, while wrist fractures in young adults are often sustained during high impact trauma for example, car crash or sporting injuries.[5] Wrist fractures

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are associated with disabling functional limitations, especially in the first six weeks of recovery.[6] Most improvement in physical and functional status occurs in the first three months of recovery, with subsequent smaller, consistent improvements for at least 1 year post-fracture.[6]

Given the overall difficulty in performing activities of daily living following wrist fracture,[6] fitness to drive may also be affected. Previous literature investigating return to drive following any upper limb trauma is exceedingly scarce.[2,7,8] However, there is a small body of evidence to suggest that driving performance is impaired in uninjured participants when using an immobilization cast.[7] In addition, results from clinical studies that assessed driving performance among those recovering from wrist fracture showed that steering wheel control is reduced when compared to uninjured controls.[8] Additionally, 30% (7/23) of participants failed a driving test when assessed within 18 days of distal radius fracture surgery.[9] Despite these reports of reduced driving capacity following wrist fracture, it is not known if this increases the likelihood of car crash.

Internationally, there are no practice guidelines or objective evidence to assist clinicians in deciding on the timepoint that individuals are able to return to drive following wrist fracture.[3,10] It is plausible that this has resulted in inconsistencies in return to drive recommendations; advice from health professionals varies from no requirement to abstain from driving, to restrictions for 12 weeks post-fracture.[7] In addition, patient behavior does not always follow recommendations from health professionals. One study reported that many patients admit to returning to drive while still on narcotic pain medications, despite contrary recommendations from their doctor, family or friends, and/or feeling unsafe when driving following their injury. Another study reported the average timeframe taken to return to drive following distal radius fractures was 16 days post fracture fixation surgery.[11] Both medical recommendations and self-reported patient behavior correspond with most individuals returning to drive well within three months following wrist fracture.[9,11] However, the overall safely of this behavior is not well understood as the crash risk encountered when returning to drive following wrist fracture has not yet been investigated.

Given that upper limb disability and persistent impairments are highest during the first 3 months post-fracture, car crash occurrence during this period should be of particular interest. Previous research suggests the majority of individuals return to drive early in their recovery while impairments and functional restrictions are ongoing. However, studying the frequency of car crashes over a longer 1-to-2-year period may provide a better understanding of change in crash frequency over time, especially as a proportion of individuals may take longer to return to drive and impairments can extend beyond 3 months.

Purpose of study

To our knowledge, the occurrence and risk factors relating to car crashes following wrist fracture have not previously been reported. A better understanding in this area will assist patients, hand therapists and other health practitioners to make informed recommendations or decisions on returning to drive following wrist fracture. We hypothesize that car crashes are most likely to occur in the first three months following wrist fracture when the physical impairments are the greatest. Therefore, our primary aims were to:

1) Compare the proportion of individuals who have a car crash within 2 years following wrist fracture with the proportion of individuals who crashed during the 2 years prior to the fracture.
2) Determine if any factors (demographic, clinical/injury-related) are associated with increased odds of being a driver in a car crash following wrist fracture.

Methods

This paper is written in accordance with the RECORD reporting checklist for studies reporting on routinely collected health data, including those from administrative data sets. Ethics was granted from the Department of Health WA Human Research Ethics Committee.

Procedures in brief

Three state-wide datasets were used to obtain car crash information relating to a cohort of adults with a wrist fracture managed at a hospital in Western Australia (WA) over a 10-year period: The Emergency Department Data Collection (EDDC), the Hospital Morbidity Data Collection (HMDC) and the MainRoads WA. Western Australia covers approximately a third of Australia's total landmass (2.5 million square kilometers) and is populated by 2.6 million people.[12]

The WA Data Linkage Branch was employed to extract and assimilate the data from the above data collections to ensure quality matching and confidentiality, using person-level linkage, before transfer for analysis to the authors via a secure online transfer. The linkage procedures and quality checking are reported in detail by this group.[13]

Two government health-based data collections EDDC and HMDC identified the retrospective population-based cohort. These datasets contain health-related information representative of public and private hospitals in city and rural locations across WA. The third government data collection, Main Roads WA, was used to obtain car crash data relating to the cohort. Car crash data were obtained for the 2-year period prior to and the 2 years following each individual's fracture date. The MainRoads WA dataset contains information relating to reported car crashes in WA including crash dates, demographics of individuals in each crash and the seating position of involved individuals.

Inclusion criteria comprised all adults (> 18 years old) with a hospital presentation date between 01/01/2008-31/12/2017 and a diagnosis of wrist/forearm fracture, as defined by International Classification of Diseases, Tenth Revision, Australian Modification (ICD-10AM) diagnostic codes. Types of wrist fracture included the distal radius and/or ulna (S52.50-S52.59, S52.6), carpal bones (S62.0-S62.19) and/or midshaft radius and/or ulna (S52.20, S52.30, S52.4) The car crash information was sourced for the corresponding 2-year period before and after the fracture date within the 01/01/2006-31/12/2019 time period.

Design

We conducted a retrospective, cohort study using linked data from administrative government datasets. Each individual served as their own control for the comparison of a car crash incident before and after their wrist fracture. This methodology is often used in car crash studies,[14] as it reduces confounding due to individual personalities and risk-taking behavior, demographics and other comorbidities which potentially influence car crash risk.

The following data were extracted:

Demographics

Sex, age, employment status.

Wrist fracture date

To account for those with a history of more than one wrist fracture (and potential multiple admissions relating to the wrist fracture), a new wrist fracture was recorded if any fracture related

hospital/ED admission occurred more than 18 months following any previous wrist/forearm fracture related admission.

Acute fracture management

Conservative (immobilization +/− closed reduction) or surgical management (open or closed reduction with internal or external fixation). Acute fracture fixation procedures were grouped according to the Australian Classification of Health Interventions, 8th Edition (ACHI) codes in Supplementary Table 1. It was assumed that those with no recorded acute surgical procedure codes were managed conservatively.

Concurrent injury(ies)

Diagnosed at the same hospital presentation as the wrist fracture. These include concurrent injury to the wrist/forearm (including injury or laceration to the skin, muscle, tendon, nerve[s] or vessel[s]), concurrent injury elsewhere in the body (other fracture, organ injury, or injury or laceration to the skin, muscle, tendon, nerve[s] or vessel[s] elsewhere to the wrist/forearm). Diagnostic codes for concurrent injury are described in Supplementary Table 2.

Complications

Were defined according to predefined ICD-10AM codes (Supplementary Table 3). Early complications were those requiring hospital/ED (re)admission within 30 days post-fracture. Requirement for secondary wrist/forearm surgery was recorded (detailed in Supplementary Table 4), occurring > 30 days but within 2 years of the fracture.

Comorbidities

The Elixhauser Index (EI) was calculated by using diagnostic codes relating to hospital/ED admissions in the 2 years before and after the fracture date (with resultant health data from 01/01/2006-31/12/2019). The EI uses 30 co-morbidities with a final score of −7 to +12. Lower scores reflect better health.

Car crash recording

The Main Road WA database includes the seating position data of the involved person(s). Only car crashes where the individual was listed as the driver were included. If the seating position data was missing, these were excluded from analyses. The car crash timing was defined as either 'before fracture or 'after fracture. Those with the date of the car crash falling on the same date (or up to and including 3 days before) as the wrist fracture were in the pre-injury group to ensure any delays in presentation to hospital and/or delays in fracture diagnoses were accounted for.

Analysis

Data cleaning and analyses were performed using Stata (16.1, StataCorp LLC, College Station, TX). A significance level a of 0.05 was used for statistical tests, including the final logistic regression models.

Descriptive statistics, mean (standard deviation) of demographic, clinical and fracture related variables were reported for those who were a driver in a car crash following the wrist fracture date and those with no reported crashes. Where necessary in reporting, small cell counts ($n < 5$) were suppressed.

McNemar's tests were used to determine if the proportion of individuals who were drivers in a car crash was higher among those recovering from wrist fractures compared to the proportion of those who had a crash history in the pre-injury timeframes. The McNemar's tests were completed for 3-month, 6-month, 1- and 2-year time points separately.

To determine if any variables were associated with the odds of car crash, logistic regression was first performed for association with car crash during the first 3 months and then the regression was repeated for the remaining time up until 2 years (3–24 months) following the wrist fracture. The variables of interest included age, sex, health status, wrist/forearm fracture type, acute surgical management, compensable funding status, reported complications and/or concurrent multi-trauma sustained at the time of the fracture. The relationship between continuous variables and car crashes were checked for linearity and transformed if non-linear.

Starting with a full model, backwards elimination methods were used. Prior to elimination of a candidate variable the change in the remaining coefficients were checked to ensure no more than 15% change with each step. A likelihood ratio was calculated and the Akaike information criterion was checked to ensure goodness of fit was not reduced with the elimination steps. Finally, the model was checked for multicollinearity. The logistic regression results are presented as odds ratios (OR) and 95% CI.

Results

Data were derived from 37,107 individuals who had a wrist fracture. Among these, 3071 (8.3% of 37,107) individuals were drivers in (at least) one car crash during the 2 years before and/or the 2 years after their fracture date. Of interest, there were 796 individuals with the crash and fracture date occurring on the same day (i.e., the mechanism of injury for the wrist fracture was a car crash). These individuals are included in the "pre-injury" crash group.

The demographics of the individuals who were a driver in a car crash differ from those with no crash following their wrist fracture. Those who had at least one crash following their wrist fracture were, on average, younger, a greater proportion were male, currently employed and/or had compensable funding and fewer had acute surgical management of their wrist fracture (Table 1).

At all intervals within the 2-year pre- and post- time period, we found that the proportion of drivers involved in at least one car crash after wrist fracture was less than those involved in at least one car crash before wrist fracture (Table 2). This equated to 1006 drivers (2.7% of 37107) who crashed at least once during the 2 years following the fracture date, compared to 2234 drivers (6.0% of 37,107) who were in at least one car crash during the 2 years prior to the fracture date. This corresponds to a 3.3% (95% CI = 3.0%–3.6%, $p < 0.05$) reduction in the proportion of drivers in a car crash in the 2 years. The frequency and proportion of drivers in a car crash in the 3-, 6- and 12- month periods before and after the wrist crashes are detailed in Table 2.

Considering all months during the 2 years prior to the wrist fracture, there was a mean of 200 (SD 13.5) crashes per quarter. In the 2 years following the wrist fracture, the mean number of crashes was 135 (SD 10.5) per quarter (detailed in Supplementary Table 5). When crashes occur in the first 3 months following fracture there was a bimodal distribution with a small peak at 20 days and a larger peak at 10 weeks following fracture (shown in Supplementary Fig. 1).

For the post fracture period, the final multivariable logistic regression showed that a number of variables were associated with odds of car crash. After accounting for associations between age and sex on likelihood of car crash, those with concurrent injury(ies) to wrist (in addition to the wrist fracture) had 79% higher odds (OR 1.79, $p = 0.03$, 95% CI 1.1–3.0) of being a driver in a car crash in the first 3 months following their fracture than those with isolated wrist fracture injury patterns (Table 3 and Fig. 1). Those who were currently employed had higher odds of crash (OR 1.59, $p = 0.01$, 0. 95% CI 1.1–2.3) than those unemployed.

In the time period later than 3 months following the fracture date, the only variables associated with increased likelihood of crash

Table 1
Demographics and clinical profile of those with no reported car crash(es) compared to those with reported crash in the 3 months after the wrist fracture date

	No crash *n* = 36,969	At least one crash *n* = 138
Age in years		
mean (SD)	48.6 (21.1)	31.9 (14.3)
Female		
n (% of group)	21,054 (56.9%)	41 (29.7%)
Type of wrist fracture *n* (% of group)		
Midshaft	8437 (22.8%)	43 (31.2%)
Distal radius	21,282 (57.6%)	54 (39.1%)
Carpal	6761 (18.3%)	39 (28.3%)
Multiple	489 (1.3%)	2 (1.4%)
Acute surgical fracture management		
n (% of group)	4377 (11.4%)	7 (5.1%)
Concurrent injury *n* (% of group):		
Wrist/forearm	2336 (6.3%)	17 (12.3%)
Elsewhere in body	4625 (12.5%)	24 (17.4%)
Any of the above	5809 (15.7%)	32 (23.2%)_
Early complication *n* (% of group)	1328 (3.6%)	9 (6.5%)
Secondary surgical procedure *n* (% of group)	3629 (9.8%)	15 (10.9%)
Employed		
n (% of group)	21,033 (56.9%)	89 (64.5%)
Health status: Elixhauser index		
mean (SD)	0.52 (1.2)	0.34 (0.8)

Table 2
Frequency (%) of drivers with (at least one) car crash in the 3 months, 6 months, 1 year and 2 years before and after wrist fracture*

Timepoint	Crash after?	Crash before?		Total
		Yes	No	
3 months*				
	Yes	12 (< 0.1%)	126 (0.3%)	138 (0.4%)
	No	984 (2.7%)	35,985 (97.0%)	36,969 (99.6%)
	Total	996 (2.7%)†	36,111 (97.3%)	37,107
6 months*				
	Yes	26 (0.01%)	235 (0.6%)	261 (0.7%)
	No	1139 (3.1%)	35,707 (96.3%)	36,846 (99.3%)
	Total	1165 (3.1%)†	35,942 (96.9%)	37,107
1 y*				
	Yes	60 (0.2%)	475 (1.3%)	535 (1.4%)
	No	1473 (4.0%)	35,099 (94.6%)	36,572 (98.6%)
	Total	1533 (4.2%)†	35,574 (95.9%)	37,107
2 y*				
	Yes	169 (0.5%)	837 (2.3%)	1006 (2.7%)
	No	2065 (5.6%)	34,036 (91.7%)	36,101 (97.3)
	Total	2234 (6.0%)†	34,873 (94.0%)	37,107

* McNemars *p*-value < 0.001 for all time comparisons.
† Includes 796 individuals (1.9% of 37107) with the car crash and wrist fracture occurring on the same day.

Table 3
Final logistic regression model of variables associated with increased likelihood of car crash in the first 3 months following wrist fracture

	Odds ratio	*p*-value	95% CI	
			(Lower)	(Upper)
Age (years)	0.96	< 0.001	0.9	0.97
Males	1.52	0.03	1.0	2.2
Workers	1.59	0.01	1.1	2.3
Concurrent wrist injury	1.79	0.03	1.1	3.0

were younger age, male sex and being employed. We did not find association between car crash occurrence and general health status, compensable funding status, acute fracture management pathway, concurrent multi-trauma injuries or the presence of complications at any time period. There were no significant interactions between predictors.

Secondary analysis of car crashes distribution among those with isolated wrist fracture, compared to those with concurrent injury to the wrist or elsewhere in the body (i.e., multi-trauma injury patterns) is described in Supplementary Table 6.

Discussion

This paper identified several novel findings regarding car crashes following wrist fracture. Firstly, we identified a 3.3% reduction in the proportion of individuals who were in a car crash in the 2 years following their wrist fracture, compared to the proportion of individuals in a car crash in the 2 years before their wrist fracture. Further to this finding, factors associated with likelihood of car crash were identified. As well as known relationships between younger males and with increased likelihood of car crash, those with more severe wrist injury patterns were 79% more likely to be in a car crash in the first 3 months following fracture, compared to those with isolated wrist fractures. In addition, workers were more likely to be in a crash compared to those who were not employed.

The reduced occurrence of car crashes persisted across the entire 2-year study period following wrist fracture. This was surprising and contrary to our hypothesis that an increased number of crashes would be apparent within the first 3 months post fracture when impairments are most pronounced. One possibility is that the rate of car crashes (i.e., the crash rate per person per exposure time) is under-represented due to reduced exposure to driving. Reduced driving exposure is expected up to 3 months post-fracture, when those with fractures drive less than usual, but it is also expected that driving exposure reaches normal levels after that timeframe.[9] Without driving exposure data, we cannot establish whether this is the case, which merits further investigation. A further explanation is that this finding reflects more cautious driving over an extended period. Evidence suggests some drivers may be more cautious after wrist fracture for example, less likely to speed or overtake at speed.[8,15] Given that the mechanism of injury for the wrist fracture was a car crash for a large portion of the cohort (25.9%, 796/3071 individuals), it would be expected that many drivers would exhibit cautious driving practices upon returning to drive. Additionally, there was an increased likelihood of car crash among workers when compared to those who were not employed (including retirees). This relationship was observed for the whole 2-year period and perhaps suggest that those who work may have a higher crash risk because of their driving exposure rather than factors relating to their wrist fracture. There were no significant interactions between workers and age and/or sex.

Despite the overall reduced number of car crashes following wrist fracture, it is important to recognize the relationship between car crash occurrence and those with more severe wrist fracture injury patterns. After accounting for the known influence of age and sex on car crash risk, the likelihood of being in a car crash within 3 months following wrist fracture was significantly higher with more severe wrist injury (e.g., those with concurrent additional injury to the wrist) and among those who were currently employed. There was no association found between wrist fracture severity and car crash occurrence after 3 months post-fracture, which is understandable as most functional impairments resolve during this timeframe. In our cohort, almost 10% of individuals had a concurrent wrist injury, therefore approximately one in 10 individuals (those with more severe injury patterns) should be actively educated on their increased likelihood of car crash in the first 3 months following their fracture. It is recommended that this patient sub-group is cautioned about returning to drive within this time period.

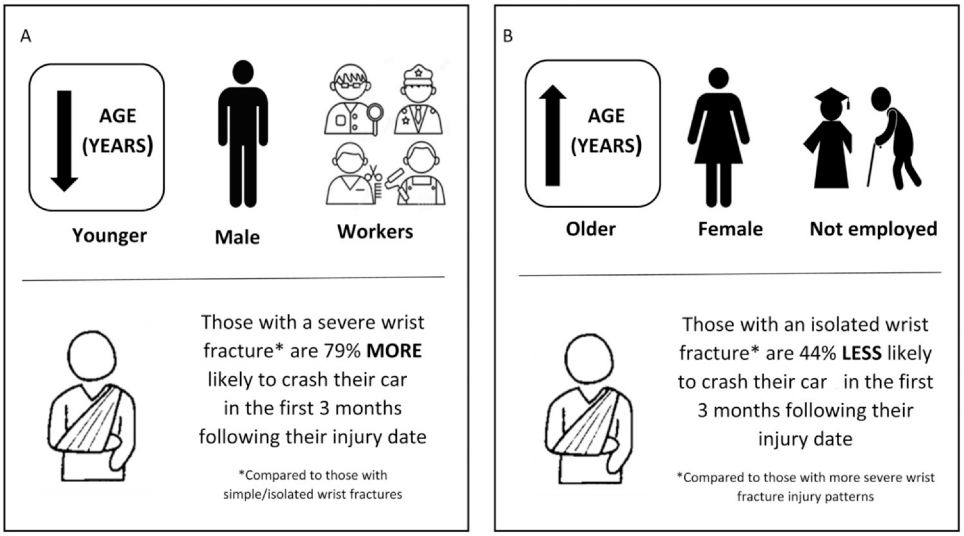

Fig. 1. Infographic showing patient profiles associated with (**A**) higher odds of being in a car crash within 3 months of wrist fracture (**B**) lower odds of being in a car crash within three months of wrist fracture.

When crashes do occur in the first 3 months following fracture, they most often take place around week 3 and week 10 after fracture. It is possible that these peaks correlate with the times when many individuals return to drive following their wrist fracture. It is expected that some individuals return to drive early in their recovery once acute pain settles, while other drivers wait until the plaster cast or orthoses is removed and they are able to use their injured limb more fully. Other research indicates that individuals return to drive on average 15.8 days post-fracture,[11] with 77% of adults driving by week 3 and all by 3 months.[9] Given that scores on the self-reported "Disability of the arm, shoulder and hand" questionnaire at 3 weeks following a distal radius fracture are approximately 50 out of a 100[6] (best score of 0% reflecting no upper limb functional concern), it is possible that this crash distribution reflects increased risk of car crashes when returning to drive with marked physical impairments and functional limitations.

Research regarding driving capacity following upper limb trauma is scarce,[2,7] however, some preliminary evidence is worth noting. One study indicated that 29% (7/23) of those recovering from wrist fracture did not pass a driving examination performed in the first month following wrist fracture surgery.[9] The assessment was undertaken on-road, on a closed course with evaluation of many aspects of driving, but not testing scenarios requiring reaction to potential hazards. Similarly, pilot data demonstrates measurable differences in driving performance in those recovering from wrist fracture when assessed using a driving simulator at five weeks following injury, but not in the follow-up assessment 2 weeks later. These two studies form early evidence to suggest that some individuals demonstrate impaired driving capacity up to 2 months following wrist fracture. Combined with our finding that those with concurrent wrist injuries are more likely to be involved in a subsequent car crash, the emerging evidence suggests that a sub-group of individuals with wrist fracture have a greater risk of car-crash; likely those with more complex injury profiles, higher levels of physical impairments and resultant reduced driving capacity. Additional research is justified to explore links between more detailed clinical profiles (e.g., physical impairments, functional limitations, pain) and return to drive timeframes, driving capacity and risk of car crash.

Limitations of this paper not previously mentioned include possible omission of data from police reports or under reporting of car crashes, and no record of minor/non-reported crashes such as those occurring in car parks or low speed crashes involving no injuries or only minor property damage. However, arguably the most important car crashes are those resulting in injuries that require hospital treatment and/or large property damage, which were included through the mandatory reporting of car crashes in WA.

There are limitations relating to the use of administrative data that was not created to answer the specific research questions. Resultingly, we were limited in the pre-recorded variables and as there are no clinical assessment measures within the datasets, variables such as pain and other clinical variables could not be included in the regression. Although the Data Linkage Service of WA reports quality checking protocols to ensure linkages are of a high quality, it is possible that there was missing data or missing linkage not known to the authors. Finally, this study is only relevant to wrist and forearm fractures; the relationship between other upper limb injuries and car crash rates in other jurisdictions warrants investigation.

Conclusion

There was a 3.3% reduction in the proportion of drivers involved in a car crash in the 2 years following wrist fracture, when compared to the same time period prior to the injury. After wrist fracture those with concurrent injury to the wrist or forearm had 79% higher odds of having a car crash within the first 3 months after injury, compared to those with an isolated wrist fracture. In addition, those employed are at higher risk of crash than those who are not employed. It is important that hand therapists actively educate patients of these risks and caution those with more severe injury patterns of their increased likelihood of car crashes for the three months following the fracture date.

CRediT statement of author contributions

Susan Stinton: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Validation, Visualisation,

Writing (original draft, review and edition). Evangelos Pappas: Conceptualization, Data curation, Funding acquisition, Investigation, Methodology, Validation, Visualisation, Formal analysis, Writing (review and edition), Supervision. Alberto Nettel-Aguirre: Methodology, Validation, Visualization, Writing (review and editing). Niamh Moloney: Conceptualization, Data curation, Funding acquisition, Investigation, Methodology, Validation, Visualisation, Writing (review and edition), Supervision. Kathryn Refshauge: Interpretation of data, Supervision, Writing (review and editing). Dale Edgar: Conceptualization, Data curation, Funding acquisition, Investigation, Methodology, Validation, Visualisation, Writing (review and edition), Supervision.

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Data availability statement

We are unable to provide the full data set. As the data contains confidential health information, as a requirement to gain access, we signed a data transfer agreement confirming we will not disclose the data to any third party. However, individuals are able data is available via request to the data custodians within the WA Department of Health.

Declaration of Competing Interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Susan Stinton reports financial support was provided by Physiotherapy Research Foundation.

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Statement of informed consent

As this was secondary analysis of de-identified data, we were granted a waiver of consent from the Department of Health WA Human Research Ethics Committee: according to the National Statement on Ethical Conduct in Human Research 2.3.10 this study met the required criteria.

Supporting material

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.jht.2023.09.002.

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The RECORD statement – checklist of items, extended from the STROBE statement, that should be reported in observational studies using routinely collected health data.

	Item No.	STROBE items	Location in manuscript where items are reported	RECORD items	Location in manuscript where items are reported
Title and abstract					
	1	(a) Indicate the study's design with a commonly used term in the title or the abstract (b) Provide in the abstract an informative and balanced summary of what was done and what was found	Listed in page 1, abstract	RECORD 1.1: The type of data used should be specified in the title or abstract. When possible, the name of the databases used should be included. RECORD 1.2: If applicable, the geographic region and timeframe within which the study took place should be reported in the title or abstract. RECORD 1.3: If linkage between databases was conducted for the study, this should be clearly stated in the title or abstract.	Type and names of data sets are listed in the methods section of abstract Region and timeframe listed in the methods section of abstract This is stated in the methods section of the abstract
Introduction					
Background rationale	2	Explain the scientific background and rationale for the investigation being reported			Pages 1-2
Objectives	3	State specific objectives, including any prespecified hypotheses			Pages 2-3
Methods					
Study Design	4	Present key elements of study design early in the paper			Pages 3-4
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection			Pages 3-4
Participants	6	*(a) Cohort study* - Give the		RECORD 6.1: The methods of study	Page 3-4

		eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up *Case-control study* - Give the eligibility criteria, and the sources and methods of case ascertainment and control selection. Give the rationale for the choice of cases and controls *Cross-sectional study* - Give the eligibility criteria, and the sources and methods of selection of participants *(b) Cohort study* - For matched studies, give matching criteria and number of exposed and unexposed *Case-control study* - For matched studies, give matching criteria and the number of controls per case		population selection (such as codes or algorithms used to identify subjects) should be listed in detail. If this is not possible, an explanation should be provided. RECORD 6.2: Any validation studies of the codes or algorithms used to select the population should be referenced. If validation was conducted for this study and not published elsewhere, detailed methods and results should be provided. RECORD 6.3: If the study involved linkage of databases, consider use of a flow diagram or other graphical display to demonstrate the data linkage process, including the number of individuals with linked data at each stage.	Pages 3-5 and supplementary Tables 1-4 As the linkage was performed by a third party, the specific methods used (and linkage numbers) are not supplied with the extract, however, linkage methods are referenced in the methods section, refs 13-14.
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable.		RECORD 7.1: A complete list of codes and algorithms used to classify exposures, outcomes, confounders, and effect modifiers should be provided. If these cannot be reported, an explanation should be provided.	Detailed in pages 3-5 and Supplementary tables 1-4

Data sources/ measurement	8	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group			Detailed in pages 3-5 and Supplementary tables 1-4
Bias	9	Describe any efforts to address potential sources of bias			Page 5
Study size	10	Explain how the study size was arrived at			Page 3
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen, and why			Pages 4-5 and Supplementary Tables 1-4
Statistical methods	12	(a) Describe all statistical methods, including those used to control for confounding (b) Describe any methods used to examine subgroups and interactions (c) Explain how missing data were addressed (d) *Cohort study* - If applicable, explain how loss to follow-up was addressed *Case-control study* - If applicable, explain how matching of cases and controls was addressed *Cross-sectional study* - If applicable, describe analytical methods taking account of sampling strategy Describe any sensitivity analyses			Pages 5-6 Page 6 Page 5 N/A

Data access and cleaning methods		..		RECORD 12.1: Authors should describe the extent to which the investigators had access to the database population used to create the study population. RECORD 12.2: Authors should provide information on the data cleaning methods used in the study.	Page 3 Page 5
Linkage		..		RECORD 12.3: State whether the study included person-level, institutional-level, or other data linkage across two or more databases. The methods of linkage and methods of linkage quality evaluation should be provided.	Page 3
Results					
Participants	13	(a) Report the numbers of individuals at each stage of the study (*e.g.*, numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed) (b) Give reasons for non-participation at each stage. Consider use of a flow diagram		RECORD 13.1: Describe in detail the selection of the persons included in the study (*i.e.,* study population selection) including filtering based on data quality, data availability and linkage. The selection of included persons can be described in the text and/or by means of the study flow diagram.	Page 3, 6 and Table 1
Descriptive data	14	(a) Give characteristics of study participants (*e.g.*, demographic, clinical, social) and information on exposures and potential confounders (b) Indicate the number of participants with missing data for each variable of interest *Cohort study* - summarise follow-			Page 6 and Table 1 Page 6 Page 6

		up time (*e.g.*, average and total amount)			
Outcome data	15	*Cohort study* - Report numbers of outcome events or summary measures over time *Case-control study* - Report numbers in each exposure category, or summary measures of exposure *Cross-sectional study* - Report numbers of outcome events or summary measures			Page 6-7, Table 2, Supplementary Table 5 and Figure 1
Main results	16	(a) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (e.g., 95% confidence interval). Make clear which confounders were adjusted for and why they were included (b) Report category boundaries when continuous variables were categorized If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period			Page 7-8, Table 2 and 3
Other analyses	17	Report other analyses done—e.g., analyses of subgroups and interactions, and sensitivity analyses			Page 9 and Supplementary Section 6
Discussion					
Key results	18	Summarise key results with reference to study objectives			Page 9
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision.		RECORD 19.1: Discuss the implications of using data that were not created or collected to answer the specific research	Page 11

		Discuss both direction and magnitude of any potential bias		question(s). Include discussion of misclassification bias, unmeasured confounding, missing data, and changing eligibility over time, as they pertain to the study being reported.	
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence			Page 12
Generalisability	21	Discuss the generalisability (external validity) of the study results			Page 11
Other Information					
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based			Page 13
Accessibility of protocol, raw data, and programming code		..		RECORD 22.1: Authors should provide information on how to access any supplemental information such as the study protocol, raw data, or programming code.	Data availability statement, page 13

Additional supplementary material relating to this study is provided at the end of this thesis in Appendix 5.

CHAPTER SEVEN

CONCLUSION

7.1 THE IMPACT OF THIS THESIS

The broad aim of this thesis was to develop a deeper understanding of wrist and forearm fractures, including the expected recovery, contemporary management pathways, associated complications, and the impact of these on the return to driving. It has been difficult to give evidence-based clinical recommendations regarding the optimal timeframe to return to driving following wrist and forearm fractures. This is related to lack of research, the lengthy rehabilitation journey, as well as the multifaceted interactions between physical capacity and the influence of individual behaviour on the driving task. This thesis provides tangible contributions to the understanding of epidemiology including wrist and forearm fracture incidence and management, as well as new recommendations regarding return to driving following wrist and forearm fractures. However, many uncertainties remain which provide opportunity for future research. The main findings and conclusions relating to the original aims are summarised in the sections below.

7.2 CONSIDERATIONS REGARDING RETURN TO DRIVING FOLLOWING WRIST AND FOREARM FRACTURES

7.2.1 The pronounced evidence gap

Current recommendations and indicators of safe return to driving following wrist and forearm fracture lack a high-quality evidence base and almost entirely arise from expert opinion, as described in Chapter Two. The available evidence at the time of publication of the study in Chapter Two (July 2015) was limited to survey-based studies investigating patient's behaviour when returning to driving following wrist trauma and health-practitioners' expert advice given to this patient group. The rare published clinical studies assessing driving performance were based on uninjured participants using various types of wrist immobilisation. The most obvious evidence gap was research investigating the driving performance of individuals with diagnosed wrist pathologies or trauma.

A main finding *in Chapter Two* was the reduced influence of isolated wrist immobilisation on the driving performance of uninjured drivers, when compared to a more pronounced impact of immobilisation that also includes the thumb and/or elbow. Other authors have since

completed additional studies that concur with this finding.[1-3] Recent papers from Jones et al.[2] and Mansour et al.[3] also report a negative effect of combined wrist and thumb immobilisation and minimal effect of isolated wrist immobilisation on the driving performance of uninjured participants. However, the driving assessment methods used in both of these studies did not evaluate interactions with other vehicles, traffic lights or reaction to hazards. This arguably may have led to under-reporting of performance difficulties and unsafe driving indicators as the most physically demanding driving tasks were not assessed. Regardless, these papers add to a growing body of evidence with resultant recommendations that clearance to drive is not given to individuals immobilised in a wrist cast that also includes the elbow or thumb. Caution and case-by-case advice is recommended for individuals with an isolated wrist immobilisation. There is an ongoing need to confirm if these findings can be generalised to drivers with actual wrist or forearm fracture pathology, particularly in relation to the behaviours resulting from pain.

At the time of publication of the literature review in Chapter Two, there were no clinical studies found reporting on any aspect of driving performance using participants with wrist or forearm fracture pathology. Since that publication, there has only been one known recent study discovered reporting on this topic.[4] Jones et al. provided the first known clinical study using on-road driving procedures to assess the driving performance of 23 individuals recovering from distal radius fracture (DRF).[4] Almost 70% of the participants in this study passed the driving test within 4 weeks of surgery. The fact that 1 in 3 participants failed the driving test at the early assessment timepoints to a sub-group of individuals with impaired driving capacity following wrist fracture. The finding relating to a sub-group of individuals with increased risk of car crash early in their recovery following wrist fracture is consistent with the results presented in Chapter Six.

Due to the paucity of research, there is no clear understanding if any clinical, demographic or injury related variables are associated with impaired driving performance following wrist or forearm fracture. The preliminary information provided by Jones et al,[4] still provides no clear insight as to which individuals are among the 30% who are not likely to pass the driving test at an early assessment timepoint. As this is the only clinical study reporting on the driving performance of individuals with wrist fracture pathology,[4] the evidence remains

insufficient to provide generalisable recommendations regarding return to driving following wrist and forearm fractures. There is ongoing need for future research to investigate the driving performance of participants with pathology to determine those with the greatest impairment in driving performance following wrist fracture. In addition, no previous studies have reported on car crash rates following wrist fracture.

7.2.2 Contemporary Australian epidemiological findings

It is apparent from the contemporary epidemiology figures that wrist and forearm fractures affect adults of all ages, and consequently drivers of all ages. The increasing incidence of wrist and forearm fracture in middle aged and older females in Australia, as well as increasing surgical management rates of open reduction and internal fixation was highlighted in *Chapter Three*. The increasing incidence infers that the burden of wrist and forearm fractures on the Australian health care system is rising, especially as surgical trends are favouring more expensive procedures such as acute DRF fixation using volar plates rather than k-wire fixation. The increasing incidence of wrist and forearm fractures also implies that decision-making regarding return to driving following wrist fracture is navigated by a growing number of adults and clinicians. Appropriate practices regarding return to driving following injury (including wrist and forearm fractures) that may impair driving capacity is important for individual and community road safety. Conversely, given the high and increasing incidence of wrist and forearm fractures in Australia, optimising timeframes in which individuals return to driving will reduce unnecessary time off work and associated lost productivity and burden to the economy.

The unexpected finding of increasing incidence occurring specifically in middle-aged and older adults warrants further attention. Optimal screening and management of osteoporosis may prevent a portion of wrist fractures and reduce the associated burden of this injury. In some cases, wrist fractures present the first opportunity to diagnose and manage osteoporosis,[5] as osteoporotic fractures are more likely to be diagnosed 15 years earlier at the wrist than at other sites such as the hip.[6] Therefore, appropriate osteoporosis screening and necessary treatment for all individuals with wrist fractures sustained through low velocity mechanisms may help to prevent future osteoporotic fractures in other areas.[7]

Arguably, if fewer adults sustain wrist fractures, then the burden of the return to drive problem is also reduced.

7.2.3 Recovery following wrist fracture is longer than commonly perceived and complications often occur

To provide a comprehensive understanding of the expected recovery trajectory relating to individuals with DRF managed with volar plate fixation, the longitudinal change in outcome measures was examined from the fracture date to the final outcome, as reported in Chapter Four. This meta-analysis confirmed that disability and impairments are highest in the first 6 weeks, with rapid recovery throughout the first 3 months. There are ongoing significant but incremental improvements in outcomes which continue for 6- to- 12 months post fracture (but not thereafter). This enhanced understanding of the expected recovery pathways informed planning the studies in the remainder of this thesis.

As it is expected that outcomes improve for 6- to- 12 months, it is recommended that final functional assessment is not conducted until at least 1 year after the wrist fracture. Other recent publications have noted that follow-up times vary greatly, from 3 months to 10 years.[8] This is likely due to a lack of guidelines relating to follow-up requirements after wrist fractures, meaning authors have made recommendations regarding timing of follow-up assessment based on their expert opinion.[8, 9] It has been proposed elsewhere that final functional outcomes should not be assessed earlier than 6 months for extra-articular fractures, and 2 years post intra-articular or scaphoid fracture, unless there is particular interest in ascertaining rates of post-traumatic arthritis.[9] Statistically significant improvements in grip strength and DASH scores are recorded between 1 and 2 years post fracture, as described Chapter Four. However, these changes are not likely to be clinically significant. Taken together, the above findings suggest that 1 year post fracture is usually an appropriate timepoint to assess 'final' functional outcomes following DRF.

Chosen outcome measures should be appropriate to assess changes in the physical or functional status following wrist and forearm fracture. This longitudinal analysis showed that grip strength and scores in the DASH questionnaire improved rapidly during the early recovery period and continued to improve until at least until 1 year following DRF. Given the

ongoing sensitivity of these outcomes in detecting change over the entire recovery process, it is recommended that grip strength and the DASH questionnaire are included in assessment of outcomes, especially at timepoints greater than 3 months after the fracture.

Individual progress following wrist fracture can be monitored using the expected outcome curves provided in Chapter Four. If progress deviates from the 95% CI in the expected outcome curves (especially early in the recovery), early therapy may successfully manage or prevent ongoing symptoms of pain, stiffness, weakness and/or other complications such as complex regional pain syndrome. Individuals with persistently poorer outcomes than those within the 95% CI of the expected outcome curves should be assessed and counselled regarding secondary surgical procedure management options.

The results from Chapter Three showed that almost 13% of adults with a wrist and forearm fracture have a complicated recovery, including those requiring (re)-admission to hospital in the 30 days following the fracture date and/or those who undergo secondary surgical procedures. This rate did not change between 2008 and 2017. A small proportion (3.6%) of these complications occur in the first month following the fracture, with the remainder not reported until secondary surgery is undertaken around 7 to 8 months after fracture. If clinical outcome assessment findings at 3 months post fracture fall outside the 95% CI in the expected recovery curves provided in Chapter Four, it is recommended that longer term follow-up is arranged at 6 months following the fracture**.** Based on the results of this study, it is expected that at least 1 in 10 individuals with wrist fracture require this longer-term follow-up. The profile of those most likely to require secondary procedures and subsequently justify longer term follow-up were found to be males under 69 years with surgically managed wrist fracture, especially those with concurrent soft tissue wrist injuries or multi-trauma injury patterns and/or those using compensation funding. In addition, those at higher risk of early complication should have particularly close monitoring in the first 30 days of their fracture, namely those under 59 or over 80 years of age, with severe wrist fracture patterns or concurrent wrist injuries/multi-trauma, those with more than two co-morbidities and those using compensable funding.

It is expected that any impairment in driving capacity will be most pronounced during the first 3 months following wrist fracture, when physical deficits are most apparent. Although most individuals will regain the majority of their range of motion, grip strength and upper limb function in the first 3 months, a proportion of individuals with wrist fracture will have complications, more severe fracture and injury patterns with consequent greater impairment and/or disability and slower recovery timeframes. Those whose recovery is outside of the expected recovery trajectories, with lower physical upper limb functional capacity, are arguably those most likely to be involved in a car crash. To explore this hypothesis, driving performance and potential car crash risk were studied for periods longer than 3 months to ensure any changing association between physical function and driving capacity was captured over the time when physical change was expected.

7.2.4 Assessing driving performance following wrist and forearm fractures

Driving performance is challenging to assess following wrist and forearm fractures as there are no standard procedures. In addition to the lack of research, all previous studies use different methods to assess driving performance. Driving assessment procedures vary from formal on-road driving assessment, off-road courses, qualitative assessment of driving tasks during on-road courses and driving simulation, with assessment of routine driving and/or reaction to potentially hazardous scenarios.[10,11] In addition, driving assessment procedures involve many different outcomes including driving test pass/fail results, number of cones knocked down in off-road courses, number of crashes, car swerving/standard deviation of lateral position. The variety in assessment methods precluded performing data extraction and a meta-analysis in Chapter Two. The most physically demanding upper limb tasks faced by drivers are most likely to involve turning corners and quick swerving motions of the steering wheel required in unexpected events to avoid potential crashes.[11] It is assumed that including such tasks is important to ensure the methodology is sensitive enough to detect changes in driving performance between injured and uninjured participants.

This thesis includes the first clinical study to use a driving simulator to measure differences in driving performance between individuals recovering from wrist fracture and uninjured controls. This study showed that driving simulation offers an effective and feasible assessment method with enhanced safety, as reported in Chapter Five. To ensure physically

demanding upper limb driving tasks were included, hazard reaction as well as routine driving was assessed. Despite the pilot design of this study, the small number of patients in the fracture group needs to be considered as a limitation when interpreting these results. The only other known study reporting on driving performance of participants with wrist fracture used on-road assessment methods on a closed course, using a pass/fail test score.[4] As the test was in a closed course, interaction with other vehicles and hazard reaction were not able to be examined. This may have resulted in poor sensitivity in detecting impairment in driving performance and/or car crash risk. Direct comparisons between these two studies are difficult due to the different driving assessment methods and varying outcome measures.

To aid the sensitivity of methodology used in future driving simulation studies on individuals recovering from wrist and forearm fractures, it is necessary to take into account the timing of assessments. The results from the study in Chapter Five showed that steering wheel control is reduced at 4.9 weeks after wrist fracture among those recovering from surgically managed DRF, when compared to uninjured controls. There was no ongoing difference in driving performance between the two groups by the time of the follow-up assessment, 6.9 weeks post-fracture. These results indicate it would be prudent for future studies to complete a baseline assessment no later than 4-5 weeks following the fracture, to ensure any potential impairment in driving performance is detected. Ideally, follow-up assessments performed regularly throughout the initial 12 weeks will capture changes in driving performance during the period when most physical recovery occurs. The results from the one other recent clinical study assessing driving performance following DRF can also be considered in the planning of future studies. Jones et al.[4] found that 70% (n=16/23) of participants passed a driving test at 2.5 weeks following wrist fracture with an additional four participants passing at 4.5 weeks post-fracture. The timing from the driving assessments results in that paper also infers that an early baseline assessment is necessary to ensure sensitivity of methodology in future studies.

7.2.5 The link between physical impairments and driving performance

No studies have directly linked clinical outcomes and driving performance. However, extrapolating findings from clinical assessment findings reported in Chapter Five and other

recent literature may be relevant. At the time of the baseline driving assessment at 4.9 weeks post fracture, the median grip strength was 48%; DASH score was 32 and PRWE score was 60. It should be noted that the clinical assessments for this small cohort compared favourably to the expected recovery indicated in the outcome tables in Chapter Four, yet at this timepoint those recovering from wrist fracture still had impaired steering wheel control when compared to the uninjured group. At the follow-up assessment 2 weeks later, the median grip strength was 72% of the uninjured arm, DASH score 12.93 and PRWE score 20.50. At the follow-up assessment there were no longer any differences in driving performance between the two groups. With obvious caution exercised due to the small sample size, extrapolating the results from this study lead to a hypothesis that driving performance is reduced if grip strength is lower than 48% of the contralateral arm, DASH scores are higher than 32 and PRWE scores higher than 60. These minimum functional requirements form the first evidence-based benchmark of upper limb outcomes required prior to return to driving following wrist and forearm fractures. However, due to limitations there is justification for future studies to confirm if these outcome measures correlate with driving performance in larger populations and more specific groups of wrist and forearm fracture.

Other authors have drawn attention to physical upper limb outcome measures thought to have particular biomechanical relevance for uninjured adults when driving, including supination and pronation range of motion and grip strength.[12,13] The one other clinical study that assessed the driving performance of individuals with wrist fracture pathology also pointed to pain as an important consideration when deciding when to return to driving following wrist fracture.[4] Interestingly, relationships between pain and outcomes following wrist fractures have been discussed by other authors, with high pain in the early recovery period reported to be a predictor of chronic pain[14] and the complication of complex regional pain syndrome.[15] As half of the PRWE questionnaire relates to pain, the results found within this thesis suggest a PRWE score of at least 60 may be a particularly relevant benchmark or minimum functional requirement prior to recommending that patients return to driving following wrist fracture. It is also recommended that future studies investigate the relationship between pain and driving capacity and/or driving performance.

7.2.6 The link between driving behaviour and wrist and forearm fractures

Those recovering from wrist fracture exhibited more cautious driving behaviours such as being less likely to speed than uninjured participants, as reported in *Chapter Five*. These results align with the growing body of evidence documenting more cautious driving behaviours following wrist and forearm fractures.[3,16] For a complete picture of driving performance, it is recommended that assessments measure the physical as well as the behavioural aspects of driving. Percent of time spent speeding and percent of time spent out of the driving lane were the most sensitive outcomes reported in Chapter Five that detected changes between those recovering from wrist fractures when compared to healthy controls. These should be considered when planning future studies and clinical testing as they encompass a measure of driving behaviour as well as physical capacity to control the vehicle.

7.2.7 How long should adults with wrist and forearm fracture take to return to driving?

The optimal timeframe that adults with wrist or forearm fracture should safely return to driving is still unclear, but in the absence of other research, findings from Chapter Five inform clinical decision making. The driving capacity of individuals recovering from wrist fractures managed with acute surgical fixation was impaired compared to uninjured controls at the baseline assessment timepoint performed 4.9 weeks post-surgery, in the first week after cessation of full-time immobilisation when disability and impairments were high. A follow-up assessment at 6.9 weeks did not detect any evidence of a difference in driving performance between the wrist fracture and uninjured groups. The impairment in driving performance recorded at the baseline assessment would insinuate that individuals with an uncomplicated recovery should generally be advised to wait at least 5 weeks before returning to driving after acute wrist fracture fixation surgery, especially as the wrist fracture cohort in the pilot study performed favourably to the expected recovery for the time when the assessments were undertaken. Abstaining from driving for 6-7 weeks following surgically managed DRFs is recommended. Assuming recovery is not complicated or slower than expected, giving medical clearance to return to driving at this timeframe helps to avoid unnecessary incumbrances related to being unfit to drive. It is not known if

these recommendations are relevant to those individuals with conservatively managed wrist or forearm fractures, those with complications, or to those with poor functional recovery.

The frequency of car crashes in the first 3 months following the wrist fracture date have bimodal peaks around week three and week 10 following the wrist fracture, illustrated in a histogram in Chapter Six. These peaks most likely reflect the timeframes in which individuals return to driving following their wrist fracture at week three when it is assumed the acute pain and worst of the symptoms settle, and then around week 10 when immobilisation casts or orthoses are removed, and individuals are using the recovering limb for other light to medium load daily activities. These timeframes are consistent with recent studies that many patients return to driving within 3 weeks of their wrist fracture, and that nearly all return within 3 months.[4,17] A closer investigation of true crash rates at the 3-to-5-week timeframe (accounting for driving exposure) is of particular interest and is important to consider in the planning of future studies.

A surprising reduction in car crash occurrence for the entire 2 years following wrist fracture, when compared to the number of car crashes in the preceding 2 years to the fracture date was described in Chapter Six. However, the data used in this study had no record of driving exposure (or the number of hours spent driving compared to usual practices), therefore true car crash rates were out of scope. Even if individuals return to driving at an early timepoint following their wrist fracture, it is likely that there is a reduction in driving exposure due to the days or weeks that individuals abstain from driving and time taken off work while in the early recovery stages. As driving exposure is assumed to be reduced in the early period following wrist fracture it is likely that the crash rate (when accounting for exposure) was under-represented in this study. Given that, to our knowledge, no other publications have reported on car crash occurrence following any other upper limb injury, these data are the only data available to inform policy and health care decisions.

7.2.8 The wrist and forearm fracture sub-group with increased risk of car crash

Those with more severe wrist fracture injury patterns were almost 80% more likely to be in a car crash in the first 3 months following their fracture date when compared to those with isolated wrist fracture injury patterns, as described in Chapter Six. This was the first study to

show that an injury-related variable was associated with increased risk of being in a car crash following a wrist or forearm fracture. There is a growing body of evidence to point to situations when driving is not recommended following upper limb injury or surgery. Other authors have advocated that driving is not recommended immediately following general anaesthetic, when taking opioid analgesia or when using an immobilisation cast if it also includes the thumb or elbow as well as the wrist.[1,2,16,18-22] The results from this thesis indicate a specific upper limb injury group where driving is not recommended, namely those with severe wrist fracture injury patterns. These individuals should be actively educated on their increased car crash risk in the first 3 months post-fracture. Given the complex nature of the return to driving decision, further justification for delaying return to driving in those with severe wrist fractures could be based on poor physical status, especially if outcomes deviate from the expected recovery trajectories and/or the previously proposed minimum functional requirements are not met.

Recommendations regarding return to driving for those with simple, conservatively managed wrist fractures are more challenging. Patient behaviour suggests that most individuals return to driving early in their recovery and in many cases this is within the first month of the fracture when physical impairments and functional limitations are present.[4,17] However, it remains difficult to give evidence-based advice regarding the impact of wrist fracture within this timeframe. Although there is a small peak in car crash frequency at 3 weeks post wrist fracture, overall car crash occurrence does not significantly increase at any point in the period following wrist fracture when compared to the pre-fracture period. However, it is likely that driving exposure in this early period is reduced, especially if individuals have not returned to work. Consequently, true car crash incidence (accounting for driving exposure) following wrist and forearm fractures is unknown. Future studies are needed within this specific group. If future literature reveals no impairment of driving capacity and/or no increased risk of crash and individuals can return to driving in a more optimal timeframe, then the burden of injury for the individual might not need to be as restrictive, resulting in less time off work and financial strain, less reliance on family members for transportation and/or less social isolation.

7.3 SUMMARY OF RECOMMENDATIONS FOR FUTURE RESEARCH

This thesis contributes to the sparse literature regarding driving following upper limb trauma, including recommendations relating to driving assessment methodology, preliminary evidence-based timeframes and clinical assessment variables relevant to return to driving following wrist and forearm fracture. However, many areas of this complex topic that lack evidence-based knowledge have been discussed in the above sections. A summary of recommendations for future research are provided below.

Future directions of functional capacity assessment prior to return to driving

Clinical studies confirming the association between clinical variables and driving performance following wrist fracture are warranted. These will inform clinicians and assist their decision-making regarding return to driving drive following wrist and forearm fracture.

Standardised and validated assessment of driving performance following wrist fracture

The reliability and validity of using driving simulation to assess driving performance in those recovering from wrist fracture needs to be assessed. Future, larger scale studies are recommended using driving simulation procedures, with the percent of time out of the driving lane and percent of assessment time spent over the speed limit as sensitive outcome measures to identify poorer driving performance in the wrist and forearm fracture population. Standardising the assessment will allow for pooling data into meta-analyses.

Timeframes regarding return to driving following wrist or forearm fracture

Clinical studies are needed to investigate the longitudinal change in driving performance throughout the first 3 months following wrist fracture, ensuring the baseline assessment is performed in the first 2- to 4- weeks following the wrist fracture date.

The car crash risk for those with simple/uncomplicated wrist and forearm fracture Clinical studies are warranted to assess driving performance and/or crash risk (accounting for driving exposure) in individuals recovering from simple/uncomplicated wrist fractures, such as naturalistic studies which provide a means to assess driving exposure as well as near miss incidents. In particular, knowledge is lacking regarding the impact of wrist fracture on

driving for the non-operative patient group, which is the largest proportion of the wrist fracture cohort. Future research is especially indicated for this particular patient group.

Car crash incidence following wrist and forearm fracture

There are no other reports of car crash incidence following wrist and forearm fracture (e.g. car crash rate per unit of driving exposure). Driving assessment methods such as naturalistic studies would provide a means to assess driving exposure as well as near miss incidents.

7.4 SUMMARY OF CONCLUDING REMARKS

This thesis makes valuable and clinically meaningful contributions to the body of literature regarding return to driving following wrist fractures. Prior understanding regarding return to driving following wrist fracture was limited to assessment of the influence of immobilisation casts on uninjured individuals, with the recommendation that individuals abstain from driving while they require wrist immobilisation in a cast that includes either the elbow or thumb. A large meta-analysis has shown that the majority of individuals with wrist fracture recover well with most of the recovery occurring within the first 3 months following their fracture date. The recovery pathway coincides with routine behaviour with most patients returning to driving within the first 3 months following wrist fracture. However, a portion of individuals do not follow expected recovery pathways; around 13% of individuals with wrist fracture suffer complication(s) with some of them undergoing secondary surgical procedures approximately 7 to 8 months following the fracture date. Those with worse physical outcomes and/or a complicated recovery are expected to be at a greater risk of car crash but the understanding regarding the association between physical or functional outcomes with driving performance and/or car crash risk is limited. Emergent understanding of the return to drive challenges has revealed the portion of individuals with more severe wrist fracture injury patterns is almost 80% more likely to be a driver in a car crash in the first 3 months following their fracture date. Those with more severe wrist fracture injury patterns (those with concurrent soft tissue injury to the wrist) diagnosed at the same time as the wrist fracture, especially those of working age, should be actively informed of their increased likelihood of car crash and recommended against return to driving in the first 3 months following their fracture. In addition, preliminary findings suggest if individuals have not achieved a minimum functional requirement of grip strength higher than 48% of the uninjured arm, DASH score lower than 32 and PRWE score lower than 60 they should be cautioned against returning to drive until these clinical milestones are reached. Many areas of this complex topic warrant further investigation. In particular, future studies should focus on the association between physical outcome measures and driving performance and examine the impact of uncomplicated wrist fractures on return to driving.

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APPENDICES

APPENDIX 1: PUBLISHED SUPPLEMENTARY MATERIAL FOR THE PAPER IN CHAPTER THREE

Supplementary Table 1:

Inclusion/Exclusion criteria: fracture group diagnosis ICD-10AM Codes

Supplementary Table 2:

Inclusion/Exclusion criteria: fracture group diagnosis ICD-10AM Codes

Supplementary Table 3:

Acute surgery groups for fracture fixation according to ACHI codes

Supplementary Table 4:

Concurrent wrist injury diagnosis ICD-10AM codes

Supplementary Table 5:

Complication diagnosis ICD-10AM codes

Supplementary Table 6:

Secondary surgical procedure types according to ACHI codes

Supplementary Table 7:

Results: Injuries occurring at the same time as the initial wrist fracture admission

Supplementary Table 8:

Results: Types of acute wrist/forearm surgery performed within 14 days of wrist fracture

Supplementary Table 9:

Results: Secondary surgery procedure types

Supplementary Table 1: Inclusion/exclusion criteria: fracture group diagnosis ICD-10AM Codes

Fracture group	ICD-10AM Code(s)	Description of code
Midshaft	S52.20	Fracture of shaft of ulna
	S52.30	Fracture of shaft of radius
	S52.4	Fracture of shafts of both ulna and radius
Distal radius +/- ulna	S52.50 – S52.59	Fracture of lower end of radius
	S52.6	Fracture of lower end of both ulna and radius
Carpal	S62.0	Fracture of navicular (scaphoid) bone of hand
	S62.1	Fracture of other carpal bone(s)
Multiple		More than one code from more than one of the above groups

Notes:
*1) the following ICD-10AM wrist fracture codes were not included in this cohort, as they could not be grouped accurately: multiple fractures of the forearm (*S52.7*), fracture of other parts of forearm (*S52.8*), fracture of forearm, part unspecified (*S52.9)
2) there is no ICD-10AM code for bilateral wrist fractures so there was no exclusion based on bilateral injury

Supplementary Table 2: Variables extracted from the EDDC and HMDC

Variable	**Definition and inclusion**
Comorbidities	The Charlson Co-morbidity Index (CCI) and Elixhauser Scores (EI) were calculated from the diagnosis codes relating to hospital presentations in the two-years before and after the fracture date (with resultant data from 01/01/2006-31/12/2019). The CCI score uses 19 co-morbidities which are weighted according to their influence on mortality to give a score between 1-6. The EI uses 30 co-morbidities with a final score of -7 to +12. Lower scores in both indexes reflect better health.
Fracture date	A wrist or forearm fracture was recorded as a new event if any fracture related hospital/ED admission occurred more than 18 months following any previous wrist/forearm fracture related admission.
Concurrent injuries	T o the wrist and elsewhere in the body that were diagnosed at the same hospital presentation as the wrist or forearm fracture were grouped as per Appendix 2. The *concurrent wrist injuries* included skin, soft tissue, joint, nerve, vascular injuries to the wrist, hand or forearm. The *concurrent other* injuries included fractures, skin, soft tissue, joint, nerve, vascular and/or organ injuries elsewhere in the body.
Acute fracture management	Conservative or surgical management was specified. Surgery for acute fracture fixation performed in the first 14 days following fracture was recorded, with procedures grouped according to the Australian Classification of Health Interventions, 8th Edition (ACHI) codes in Appendix 3. As the ACHI codes do not specify the type of fixation such as Kirshner-wires, screw or plate, the acute surgery groups included: 1) Closed reduction with internal fixation (CRIF) 2) Open reduction with internal fixation (ORIF) 3) Other (e.g., open reduction with no fixation, external fixation)
Acute surgery (not related to fracture fixation)	Operations performed on skin, soft tissue, nerves, vessels, bones or joints of the hand/wrist/forearm, within 14 days of the fracture diagnosis.

Supplementary Table 3: Acute surgery groups for fracture fixation grouped according to ACHI codes

1) Closed reduction with internal fixation	
ACHI Code	Procedure Description
47381-02	Closed reduction of fracture of shaft of radius with internal fixation
47385-02	Closed reduction of fracture of shaft of radius with dislocation and internal fixation
47363-02	Closed reduction of fracture of distal radius with internal fixation
47381-03	Closed reduction of fracture of shaft of ulna with internal fixation
47385-03	Closed reduction of fracture of shaft of ulna with dislocation and internal fixation
47363-03	Closed reduction of fracture of distal ulna with internal fixation
47390-01	Closed reduction of fracture of shaft of radius and ulna with internal fixation
47348-01	Closed reduction of fracture of carpus with internal fixation
47354-01	Closed reduction of fracture of carpal scaphoid with internal fixation
2) Open reduction with internal fixation	
ACHI Code	Procedure Description
47384-02	Open reduction of fracture of shaft radius with internal fixation
47366-02	Open reduction of fracture of distal radius with internal fixation
47384-03	Open reduction of fracture of shaft ulna with internal fixation
47366-03	Open reduction of fracture of distal ulna with internal fixation
47393-01	Open reduction of fracture of shaft of radius and ulna and internal fixation
47386-01	Open reduction of fracture of shaft of radius with dislocation and internal fixation
47386-03	Open reduction of fracture of shaft of ulna with dislocation and internal fixation
47351-01	Open reduction of fracture of carpus with internal fixation
47357-01	Open reduction of fracture of carpal scaphoid with internal fixation
3) Other (Open reduction with no fixation code and external fixation)	
ACHI Code	Procedure Description
47384-00	Open reduction of shaft of radius
47366-00	Open reduction of fracture of distal radius
47384-01	Open reduction of shaft of ulna
47366-01	Open reduction of fracture of distal ulna
47393-00	Open reduction of fracture of shaft of radius and ulna
47386-00	Open reduction of fracture of shaft of radius with dislocation
47386-02	Open reduction of fracture of shaft of ulna with dislocation
47351-00	Open reduction of fracture of carpus
47357-00	Open reduction of fracture of carpal scaphoid
50130-00	Application of external fixation devices, not elsewhere classified (may be listed in combination with an open or closed reduction code)

Supplementary Table 4: Concurrent wrist injury diagnosis ICD-10AM codes

	Injury Type	Description	ICD-10AM CODE(S)
1	Skin laceration	Superficial injury of wrist and hand	S60.0, S60.1, S60.2, S60.7
		Other superficial injuries of wrist and hand	S60.81, S60.82, S60.84, S60.88, S60.89
		Open wound of wrist and hand	S61.0, S61.1, S61.7
		Open wound of other parts of wrist and hand	S61.81, S61.82, S61.88, S61.9
		Superficial injury of forearm	S50.0, S50.1, S50.7, S50.81, S50.82, S50.83, S50.84, S50.88, S50.9
		Open wound of forearm	S51.0, S51.7, S51.81, S51.82, S51.88, S51.9
		Superficial injuries involving multiple body regions	T00.2, T00.6
		Open wounds involving multiple body regions	T01.2, T01.6
2	Dislocation	Dislocation of wrist	S63.0, S63.00, S63.01, S63.02, S63.03, S63.04, S63.08
3	Ligament	Traumatic rupture of ligament of wrist and carpus	S63.3
		Sprain and strain of wrist	S63.50, S63.51, S63.52, S63.53, S63.58
4	Peripheral nerve	Injury of nerves at wrist and hand level	S64.0, S64.1, S64.2, S64.3, S64.4, S64.7, S64.8, S64.9
		Injury of nerves at forearm level	S54.0, S54.1, S54.2, S54.3, S54.7, S54.8, S54.9
5	Blood vessel	Injury of blood vessels at wrist and hand level	S65.0, S65.1, S65.2, S65.3, S65.4, S65.5, S65.7, S65.8, S65.9
		Injury of blood vessels at forearm level	S55.0, S55.1, S55.2, S55.7, S55.8, S55.9
6	Muscle/Tendon	Injury of muscle and tendon at wrist and hand level	S66.0, S66.1, S66.2, S66.3, S66.4, S66.5, S66.6, S66.7, S66.8, S66.9)
		Injury of muscle and tendon at forearm level	S56.0, S56.1, S56.2, S56.3, S56.4, S56.5, S56.6, S56.7, S56.8
7	Crush	Crushing injury of wrist and hand	S67.0, S67.8
		Crushing injury of forearm	S57.0, S57.8, S57.9
8	Other	Other and unspecified injuries of forearm	S69.7, S59.8, S59.9
		Other and unspecified injuries of wrist and hand	S69.7, S69.8, S69.9

Supplementary Table 5: Complication diagnosis ICD-10AM codes

ICD-10AM CODE(S)	COMPLICATION DESCRIPTION
1 Bleeding complications	
T79.2	Traumatic secondary and recurrent haemorrhage
T81.0	Haemorrhage and haematoma complication a procedure, NEC
T84.81	Haemorrhage and haematoma following insertion of internal orthopaedic prosthetic devices, implants and grafts
2 Infection and wound complications	
T79.3	Post traumatic wound infection, NEC
T80.2	Infection following infusion, transfusion and therapeutic injection
T81.3	Disruption of operation wound, NEC
T81.4	Wound infection following procedure, NEC
T84.5	Infection and inflammatory reaction due to internal joint prosthesis
T84.6	Infection and inflammatory reaction due to internal fixation device (any site)
T84.7	Infection and inflammatory reaction due to internal orthopaedic prosthetic devices, implants and grafts
T89.0	Complication of open wound
T89.00	Complication of open wound, unspecified
T89.01	Open wound with foreign body (with or without infection)
T89.02	Complication of open wound with infection
T89.03	Other complications of open wounds (e.g., delayed healing, delayed treatment)
3 Ischemia of muscle	
T79.6	Traumatic ischemia of muscle (e.g., compartment syndrome)
4 Pain	
T81.81	Pain following a procedure, NEC
T84.83	Pain following insertion of internal orthopaedic prosthetic devices, implants and grafts
5 Failure and rejection and other complications of transplanted organs and tissues, NEC	
T86.84	Bone graft failure and rejection
T86.86	Skin graft and flap failure and rejection
6 Mechanical complications relating to surgery	
T84.0	Mechanical complication of internal joint prosthesis
T84.1	Mechanical complication of internal fixation device of bones of limb
T84.2	Mechanical complication of internal fixation device of other bones
T84.4	Mechanical complication of other internal orthopaedic devices, implants and grafts
T85.65	Mechanical complication of surgical material and sutures

7 Other complications of internal orthopaedic prosthetic devices, implants and grafts	
T84.82	Embolism and thrombosis following insertion of internal orthopaedic prosthetic devices, implants and grafts
T84.84	Sternosis following insertion of internal orthopaedic prosthetic devices, implants and grafts
T84.85	Metallosis following insertion of internal orthopaedic prosthetic devices, implants and grafts
T84.89	Other complication following insertion of internal orthopeadic prosthetic devices, implants and grafts
T84.9	Unspecified complication following insertion of internal orthopaedic prosthetic devices, implants and grafts
8 Sequelae of injuries, poisoning and other consequences of external causes	
T92.0	Sequalae of open wound of upper limb
T92.1	Sequelae of fracture of forearm and upper limb
T92.2	Sequalae of fracture at wrist and hand level
T92.3	Sequelae of dislocation, sprain or strain of upper limb
T92.4	Sequelae of injury of nerve of upper limb
T92.5	Sequalae of injury of muscle and tendon of upper limb
T92.6	Sequelae of crushing injury and traumatic amputation of upper limb
T92.7	Sequalae of unspecified injury of upper limb
T92.8	Sequalae of other specified injury of upper limb
T92.9	Sequalae of unspecified injury of upper limb
T98.1	Sequalae of other and unspecified events of external causes
T98.2	Sequalae of certain early complications of trauma
T98.3	Sequalae of complications of surgical and medical care, NEC

Supplementary Table 6: Secondary procedure types according to ACHI codes

1 Skin	
30026-00	Repair of wound of skin and subcutaneous tissue of other site, superficial
30029-00	Repair of wound of skin and subcutaneous tissue of other site, involving soft tissue
2 Muscle	
30235-00	Repair of ruptured muscle
47966-01	Transfer of muscle, NEC
90585-00	Reattachment of muscle, NEC
90586-00	Other plastic procedures of muscle, NEC
90583-01	Muscle graft, NEC
90582-02	Suture of muscle or fascia, NEC
90577-00	Procurement of muscle or fascia for graft
30238-00	Repair of fascia, NEC
90582-02	Suture of muscle or fascia, NEC
90547-00	Repair of muscle or fascia of hand, not elsewhere classified
3 Tendon	
90583-00	Tendon graft, NEC
46417-00	Transfer of tendon of hand
46426-00	Primary repair of flexor tendon of hand, proximal to A1 pulley
46429-00	Secondary repair of flexor tendon of hand, proximal to A1 pulley
46432-00	Primary repair of flexor tendon of hand, distal to A1 pulley
46435-00	Secondary repair of flexor tendon of hand, distal to A1 pulley
46420-00	Primary repair of extensor tendon of hand
46423-00	Secondary repair of extensor tendon of hand
47969-00	Tenosynovectomy, NEC
47966-00	Transfer of tendon or ligament, NEC
90575-00	Transposition of tendon, NEC
47963-01	Tenoplasty, NEC
90584-01	Reattachment of tendon, NEC
47954-00	Repair of tendon, NEC
47972-00	Open procedure of tendon sheath, NEC
47957-00	Lengthening of tendon, NEC
90578-00	Procurement of tendon for graft
90582-01	Suture of tendon, NEC
47963-02	Repair of tendon of hand, not elsewhere classified
90590-00	Tendon pulley reconstruction, NEC
46414-00	Insertion of artificial tendon prosthesis of hand (prior to tendon graft)
46408-00	Reconstruction of tendon of hand by tendon graft
4 Ligament or joint	
90589-01	Repair of ligament, NEC
50106-00	Joint stabilisation, NEC
49227-00	Arthroscopic pinning of osteochondral fragment of wrist (stabilisation of ligamentus disruption of wrist)
90582-00	Suture of ligament, NEC
49224-03	Arthroscopic chondroplasty of wrist

90542-00	Other repair of wrist
49215-00	Reconstruction of wrist
46445-00	Reconstruction of DRUJ
5 Peripheral nerve	
39300-00	Primary repair of nerve
39318-00	Nerve graft
39321-00	Transposition of nerve
39303-00	Secondary repair of nerve
90016-01	Other procedures on nerves
39324-00	Neurectomy of superficial peripheral nerve
39327-00	Neurectomy of deep peripheral nerve
39312-00	Open neurolysis of interfasicular peripheral nerve trunk
39330-00	Open neurolysis of peripheral nerve, not elsewhere classified
6 Osteotomy or osectomy	
48406-02	Osteotomy of radius
48409-02	Osteotomy of radius with internal fixation
48406-04	Osteotomy of ulna
48409-04	Osteotomy of ulna with internal fixation
48400-00	Osteotomy of accessory bone
90569-00	Osteotomy, NEC
50303-00	Correction of bony deformity
90605-00	Compression with distraction osteosynthesis
90605-01	Osteosynthesis, NEC
48406-03	Osectomy of radius
48409-03	Osectomy of radius with internal fixation
48406-05	Osectomy of ulna
48406-14	Ostectomy of carpal bone
48409-14	Ostectomy of carpal bone with internal fixation
48409-05	Osectomy of ulna with internal fixation
49224-02	Arthroscopic osteoplasty of wrist (includes excision of distal ulna)
48406-13	Osteotomy of carpal bone
48409-13	Osteotomy of carpal bone with internal fixation
7 Joint procedures (debridement, arthroscope, removal of loose bodies	
50102-00	Arthroscopic procedure on joint
49221-00	Arthroscopic drilling of defect of wrist
49221-01	Arthroscopic removal of loose body of wrist (arthroscopic removal of foreign body of wrist)
49212-00	Arthrotomy of wrist (removal of loose or foreign body)
90613-00	Arthroscopic procedure on joint, proceeding to open procedure
50100-00	Arthroscopy of joint, NEC
49218-00	Arthroscope of wrist
90608-01	Arthroscopic procurement of cartilage
90608-00	Procurement of cartilage
50104-00	Synovectomy of joint, NEC
50300-00	Transarticular fixation, NEC
90574-01	Excision of joint, NEC

8 Fusion	
49200-00	Arthrodesis of radiocarpal joint (includes bone graft, internal fixation or procurement of graft through same incision)
47726-00	Arthrodesis of radiocarpal joint (includes bone graft, internal fixation or procurement of graft through separate incision)
50109-00	Arthrodesis of joint, NEC
49203-00	Arthrodesis of intercarpal joint (includes bone graft)
49200-00	Arthrodesis of radiocarpal joint
47726-00	Arthrodesis of intercarpal joint (includes bone graft) with separate incision for bone graft material
9 Bone Graft	
48224-00	Bone graft to radius or ulna
48227-00	Bone graft to radius or ulna with internal fixation
48218-00	Bone graft to radius and ulna
48221-00	Bone graft to radius and ulna with internal fixation
48239-00	Bone graft, NEC
48242-00	Bone graft with internal fixation, NEC
48242-00	Bone graft with internal fixation, NEC
48230-00	Bone graft to scaphoid
48233-00	Bone graft to scaphoid with internal fixation
48236-00	Bone graft to scaphoid with internal fixation and osteotomy
48236-00	Bone graft to scaphoid with internal fixation and osteotomy
10 Fasciotomy	
47981-00	Decompression fasciotomy of forearm
47975-00	Decompression fasciotomy of forearm for acute compartment syndrome
47978-00	Decompression fasciotomy of forearm for chronic compartment syndrome
90567-00	Fasciotomy of upper limb ischemia
30226-00	Fasciotomy, NEC
90579-00	Fasciectomy, NEC
47981-02	Decompression fasciotomy of hand
11 Carpal tunnel release	
39331-00	Endoscopic release of carpal tunnel
39331-01	Release of carpal tunnel
12 Arthroplasty	
50127-00	Arthroplasty of joint, NEC
90597-00	Silastic replacement of distal ulna
46324-00	Arthroplasty of carpal bone (includes synovectomy and tendon transfer/realignment)
49206-00	Excision arthroplasty of wrist (includes proximal carpectomy or styloidectomy)
49209-00	Total arthroplasty of wrist
49200-00	Arthrodesis of radiocarpal joint (includes bone graft, internal fixation or procurement of graft through same incision)
47726-00	Arthrodesis of radiocarpal joint (includes bone graft, internal fixation or procurement of graft through separate incision)
46324-00	Arthroplasty of carpal bone (includes synovectomy and tendon transfer/realignment)
49206-00	Excision arthroplasty of wrist (includes proximal carpectomy or styloidectomy)
49209-00	Total arthroplasty of wrist

13 Synovectomy	
46342-00	Synovectomy of DRUJ
49224-01	Arthroscopic synovectomy of wrist
46348-00	Synovectomy of flexor tendon
46351-00	Synovectomy of flexor tendon, 2 digits
46354-00	Synovectomy of flexor tendon, 3 digits
46357-00	Synovectomy of flexor tendon, 4 digits
46460-00	Synovectomy of flexor tendon > 5 digits
46339-00	Synovectomy of flexor or extensor tendon of hand
14 Tenolysis and release of adhesions	
90540-00	Tenolysis of flexor or extensor tendon of forearm or wrist
49221-02	Arthroscopic release of adhesions of wrist
47960-00	Subcutaneous tenotomy, NEC
47963-00	Open tenotomy, NEC
90571-00	Division of adhesions of soft tissue, NEC
46363-00	Release of flexor sheath of hand
90544-00	Division of adhesions of hand (freeing of adhesions to the fascia, muscle or tendon NOS)
90544-00	Division of adhesions of hand (freeing of adhesions to the fascia, muscle or tendon NOS)
46453-00	Tenolysis of flexor tendon of hand
46453-00	Tenolysis of flexor tendon of hand
46450-00	Tenolysis of extensor tendon of hand
15 Debridement, aspiration or washout	
90573-00	Sequestrectomy of other and unspecified musculoskeletal site (eg antibiotic packing and drilling of bone)
90603-09	Sequestrectomy of radius (includes antibiotic packing and drilling of bone)
90603-10	Sequestrectomy of ulna (includes antibiotic packing and drilling of bone)
90603-11	Sequestrectomy of carpus (includes antibiotic packing or drilling of bone)
90603-09	Sequestrectomy of carpus (includes antibiotic packing or drilling of bone) with bone graft
90603-10	Sequestrectomy of carpus (includes antibiotic packing or drilling of bone) with bone graft - there are 2 codes for this, I'm not sure why)
49224-00	Arthroscopic debridement of wrist
47900-00	Aspiration of bone cyst
50124-00	Aspiration of joint or synovial cavity
90563-00	Aspiration of soft tissue
50103-00	Arthrotomy of joint, NEC
30225-00	Reinsertion of drainage tube into abscess
46519-00	Incision and drainage of middle palmar, thenar or hypothenar spaces of hand
30224-00	Percutaneous drainage of abscess of soft tissue
30223-03	Incision and drainage of abscess of soft tissue
30068-00	Incision and drainage of foreign body in soft tissue
30103-00	Excision of sinus involving soft tissue
30023-00	Excisional debridement of soft tissue
30023-01	Excisional debridement of soft tissue involving bone or cartilage
90580-00	Debridement of open fracture site
46525-00	Incision and drainage of paronychia of hand

46522-00	Incision and drainage of flexor sheath of hand
90545-00	Incision of soft tissue of hand
90545-00	Incision of soft tissue of hand
30216-00	Aspiration of haematoma of skin and subcutaneous tissue
30216-01	Aspiration of abscess of skin and subcutaneous tissue
30216-02	Other aspiration of skin and subcutaneous tissue
30223-00	Incision and drainage of hematoma of skin and subcutaneous tissue
30223-01	Incision and drainage of abscess of skin and subcutaneous tissue
30223-02	Other incision and drainage of skin and subcutaneous tissue
90661-00	Other incision of skin and subcutaneous tissue
90686-01	Non-excisional debridement of skin and subcutaneous tissue
90665-00	Excisional debridement of skin and subcutaneous tissue
16 Reduction of dislocation	
47024-02	Closed reduction of DRUJ
47024-03	Closed reduction of DRUJ with internal fixation
47027-02	Open reduction of DRUJ
47027-03	Open reduction of DRUJ with internal fixation
90541-00	Closed reduction of separated epiphysis of radius or ulna
90541-01	Open reduction of separated epiphysis of radius or ulna
17 Amputation	
44328-02	Disarticulation through wrist
44325-00	Midcarpal amputation
44325-01	Transmetacarpal amputation
18 Revision	
49210-00	Revision arthroplasty of wrist
49211-00	Revision arthroplasty of wrist with bone graft
19 Removal of hardware	
47921-00	Insertion of internal fix device, NEC, reinsertion or revision of internal fixation
50309-00	Adjustment of ring fixator
47927-00	Removal of pin, screw or wire, NEC
47930-00	Removal of plate, rod or nail, NEC
47948-00	Removal of ex fix device
20 Release of contracture	
50112-00	Division of joint contracture, NEC
90570-00	Division of joint capsule, ligament or cartilage, NEC
45515-01	Release of contracture of skin and subcutaneous tissue
45054-00	Escharotomy
21 Incision	
90568-00	Incision of muscle, NEC
90568-01	Incision of bursa, NEC
90568-02	Incision of soft tissue, NEC
22 Excision	
30229-00	Excision of muscle, NEC
90575-00	Excision of soft tissue, NEC
90582-02	Suture of muscle or fascia, NEC
23 Vascular repair	
45500-00	Microsurgical repair of artery of distal extremity or digit
45500-01	Microsurgical repair of vein of distal extremity or digit

45500-02	Microsurgical repair of artery and vein of distal extremity or digit
45502-00	Microsurgical anastomosis of artery
45502-01	Microsurgical anastomosis of vein
45502-02	Microsurgical anastomosis of artery and vein
45503-00	Microsurgical graft of artery and vein
45503-01	Microsurgical graft of vein
45503-02	Microsurgical graft of artery and vein
24 Flaps and grafts	
90670-00	Allograft
90671-00	Xenograft
90672-00	Synthetic skin graft
45400-00	Splint skin graft to small granulating area
45403-00	Split skin graft to extensive granulating area
45488-00	Split skin graft to other sites
45406-00	Split skin graft to other sites
45409-00	Split skin graft to other sites
45412-00	Split skin graft to other sites
45415-00	Split skin graft to other sites
45418-00	Split skin graft to other sites
45460-00	Split skin graft to other sites
45464-00	Split skin graft to other sites
45468-00	Split skin graft to other sites
45471-00	Split skin graft to other sites
45474-00	Split skin graft to other sites
45477-00	Split skin graft to other sites
45480-00	Split skin graft to other sites
48483-00	Split skin graft to other sites
45458-05	Small split skin graft of sites
45448-06	Small split skin graft of thumb
45448-07	Small split skin graft of finger
45439-00	Small split skin graft of other site
45442-00	Extensive split skin graft of any site
45445-00	Split skin graft as an inlay graft
45451-05	Full thickness skin graft of hand
45451-06	Full thickness skin graft of thumb
45451-07	Full thickness skin graft of finger
45451-09	Full thickness skin graft of other site
45018-00	Dermis graft
45206-05	Local skin flap of hand
45206-06	Local skin flap of thumb
45206-07	Local skin flap of finger
45200-00	Local skin flap of other site
45230-00	Delay of direct distant skin flap
45221-01	Direct distant skin flap, first stage
45224-01	Direct distant skin flap, second stage
45230-01	Delay of indirect distant skin flap
45227-00	indirect distant skin flap, formation of tubed pedicle
45236-00	indirect distant skin flap, spreading of tubed pedicle

45233-00	Indirect distant skin flap, prep, transfer and attachment to intermediate site
45233-01	Indirect distant skin flap, prep, transfer and attachment to final site
45018-01	Dermofat graft
45018-02	Fat graft
45018-03	Fascia graft
45015-01	Delay of myocutaneous flap
45003-01	Myocutaneous flap
45015-00	Delay of muscle flap
45009-01	Muscle flap
45563-00	Island flap with vascular pedicle
45563-01	Island flap with neuromusclar pedicle
45562-00	Non-innvervated free flap
45562-01	Innervated free flap
25 Revision or removal of plastic procedures	
45239-00	Revision of local skin flap
45239-01	Revision of direct distant skin flap
45239-02	Revision of indirect distant skin flap
45496-00	Open revision of free tissue flap
45497-00	Complete revision of free tissue flap by liposuction
45498-00	Revision of free tissue flap by liposuction, first stage
45499-00	Revision of free tissue flap by liposuction, second stage
90659-00	Excision of flap monitoring tissue

Supplementary Table 7: Injuries occurring at the same time as the initial wrist fracture admission

Concurrent wrist injury type	**n**
Laceration to skin	1606
Dislocation	559
Neural	156
Ligament	151
Musculotendinous	141
Vascular	32
Crush	<5
Other*	86
Total	**2734**
Concurrent (non-wrist) injury	**n**
Laceration to skin	2350
Organs	2220
Fracture (non-wrist)	1765
Other	545
Musculotendinous	66
Vascular	18
Neural	16
Burns	6
Crush	<5
Total	**6987**

**Other concurrent wrist injury category refers to ICD-10AM codes relating to "other injury to the wrist and forearm"*

Supplementary Table 8: Types of acute wrist/forearm surgery performed within 14 days of wrist fracture

Type of surgical procedure	**n**
Ligament repair	447
Joint procedure (e.g., arthroscope, removal of foreign body)	408
Carpal tunnel release	406
Debridement	335
Skin repair	275
Revision of procedure	220
Osteotomy, ostectomy, correction of bony deformity	190
Nerve repair or release (not carpal tunnel release)	180
Tendon repair	172
Synovectomy	156
Arthroplasty	147
Other*	1096
Total	**4032**

**Other category refers to the total of those from other surgery types to those above, according to ICD-10AM codes detailed in Appendix 4 (including fasciotomy, incision and excision of soft tissue, reduction of dislocation)*

Supplementary Table 9: Secondary surgery procedure types* required by 3628 individuals

Type of surgical procedure	**n**
Osteotomy, ostectomy, correction of bony deformity	560
Tendon repair	450
Carpal tunnel release	428
Bone Graft (with or without fracture fixation)	399
Nerve procedure (repair, transposition, other)	359
Tenolysis and release of adhesions	316
Arthroplasty	284
Fusion	269
Joint procedures (e.g., debridement, arthroscope)	263
Ligament repair	182
Synovectomy	112
Release of contracture	51
Revision of fracture fixation	12
Total number of procedures	**3735**

**each individual may have more than one procedure performed in each operation*

APPENDIX 2: UNPUBLISHED SUPPLEMENTARY MATERIAL FOR THE DATA LINKAGE STUDIES IN CHAPTER THREE AND SIX

Forms relating to the application for the data

Data variable lists: Emergency Department Data Collection

Data variable lists: Hospital Morbidity Data Collection

Data variable lists: Main Roads Data Collection

Data extraction form

Inclusion codes for data extraction

Feasibility letter

Ethics approval letter

Governance approval letter

Government of **Western Australia**
Department of **Health**

For Office Use Only	
DL#	201911.04_001
HREC#	
Version	HREC V1
Date	1/04/2020

Emergency Data

Please select group from the drop down Cohort

Every request for patient data will be evaluated separately on its merit by the Data Custodian. To prevent potential delays it is strongly recommended applicants spend time discussing their needs with the Data Custodian before submitting an application for data: EDDC@health.wa.gov.au

The field names provided here are the variables from the Emergency Department Data Collection (EDDC) that are available to be released for research purposes. EDDC variables that are not listed below are not available for release due to data quality or sensitivity issues.

DOHWA staff may access the EDDC Data Dictionary at:
http://www.health.wa.gov.au/healthdata/docs/EDDC_dictionary.pdf
Non-DOHWA applicants should contact the EDDC Custodian for a copy of the dictionary.

Request variables below by checking boxes

Request	Variable	Description
Patient Information		
☑	Standard Emergency Record Information	This includes the following fields: • Triage code • Disposal code (episode end status) • Departure Destination • Type of visit to ED • Arrival type (transport mode) • Referral Source • Principal Diagnosis • Symptom (presenting problem) • Major Diagnostic Category • Presentation Date (Subset MMYYYY)
☑	Suburb/town/locality name	
☐	Subset Date of birth	MMYYYY
☑	Year of birth	YYYY
☑	Age at presentation	
☑	Sex	
☐	Indigenous Status	Aboriginal or Torres Strait Islander descent
☑	Country of birth	
☐	Marital status	
☑	Employment status	
☐	Presenting complaint	Free text field. Only available for Peel Health Campus.
☑	Australian state/territory identifier	Indicates the state/territory of residence

Geocoding

Geocoding		
Census year(s) requested: ☐1996 ☐2001 ☐2006 ☐2011 ☐16		
☐	Postcode	
☐	RA	Remoteness Area
☐	LGA (ABS)	1996, 2001, 2006, 2011, 2016 census
☐	SLA (ABS)	1996, 2001, 2006 census
☐	SA2 (ABS)	2011, 2016 census
☐	SEIFA	Socioeconomic status consisting of four indices by CD, LGA, SLA and SA2: • Index of Relative Socio-Economic Disadvantage (IRSD) • Index of Relative Socio-Economic Advantage and Disadvantage (IRSAD) • Index of Education and Occupation (IEO) • Index of Economic Resources (IER).

Geocoding Information:

The Data Linkage Branch routinely processes address data from the EDDC to match each record's address to a longitude and latitude. DLB also provides a "Match Quality", a coded field describing the method and specificity of the match. Information on interpreting the match score will be provided with your data. The geocoding process is dependent upon the quality of the address data, and in some cases an address may be difficult or impossible to geocode accurately, or at all.

While the latitude and longitude are not normally provided to researchers for reasons of confidentiality, corresponding geocodes are available, including Statistical Area (SA1 and SA2), Collection District (CD), Statistical Local Area (SLA) and Local Government Area (LGA). Some of these are realigned from one census to the next. The geocodes available are CD, SLA and LGA for the 1996, 2001 and 2006 censes, while SA1, SA2 and LGA are available for 2011 and 2016. Additionally, for each geocode/census combination, the Data Linkage Branch can assign Socio-Economic Indices for Area (SEIFA) and/or Remoteness Areas (RA). Please note that records with poor Match Quality will be assigned a region (e.g. an SA1) based on the centroid of a potentially large match area. This area may not overlap entirely with the assigned region. Therefore, some regions may be assigned in error. This limitation should be noted for any spatial analysis.

The boundaries, SEIFAs and RAs are developed by the Australian Bureau of Statistics (ABS), and the Data Linkage Branch uses mapping files available through the ABS website to attach them to the data. Queries about their interpretation and use should be directed to the ABS. For further information, please visit the ABS website at www.abs.gov.au.

Please note that, due to their small coverage, CD and SA1 are not usually included. Should you require these on your extract please provide written justification in the Sensitive Variables section of this document.

Other Variables

All of the variables below have been determined as sensitive and/or require written justification. Please provide this in the space in the table below.

Request	Variable	Description
☐	Full date of birth	DDMMYYYY
Enter justification here		
☐	Human intent of injury	Human Intent of Injury is not an ICD-10 coded field. Be cautious about the reliability of this variable as it is not a mandatory field. Please refer to list of variables and values for further information.
Enter justification here		
☑	External cause	External cause is not ICD-10 coded field. Be cautious about the reliability of this variable as it is not a mandatory field. Please refer to list of variables and values for further information.
One of our study aims is to define the current epidemiology regarding wrist fracture epidemiology, management and pathways. The external cause is a useful variable relating to the mechanism of injury and the cause of injury (ie high impact vs low impact) may correlate with management type.		
☐	CD (ABS)	Refer to geocoding information above (1996, 2001 and 2006 census)
Enter justification here		
☐	SA1 (ABS)	Refer to geocoding information above (2011 and 2016 census)
Enter justification here		
☐	Funding source	Indicates the source of payment for the account. Please note all data within the EDDC is sourced from publically funded Emergency Departments in Western Australia.
Enter justification here		
☐	URG	
	URG classification type	Urgency Related Group/Urgency Disposition Group (available from 2012 onwards)
	URG Version	The URG/UDG version given
Enter justification here		

☑	Presentation Date	DDMMYYYY
It is important we know the accurate date of wrist fracture or burn injury - this is likely to correlate with the date of emergency data presentation. One of our research aims is to quantify the risk of being a driver in a motor vehicle accident following an upper limb injury (burn or wrist fracture). If we know the exact injury date, the timeframe of this potential MVA risk can be more clearly defined. For example, the MVA risk following a wrist fracture is highest for XX weeks following the injury.		
☐	Presentation Date/Time	DDMMYYYY HH:MM
Enter justification here		
☐	**Patient Identifier (UMRN)**	**Requires DOH HREC and AHS CE approval**
Enter justification here		
☐	**Establishment Code**	**Requires DOH HREC and AHS CE approval**
Enter justification here		

Additional Variables

Request for variables not on this list

	Variable	Description
1		
Enter justification here		
2		
Enter justification here		
3		
Enter justification here		

Comments:

Enter any extra comments here

Government of **Western Australia**
Department of **Health**

For Office Use Only	
DL#	201911.04_001
HREC#	
Version	HREC V1
Date	1/04/2020

Hospital Morbidity Data

Please select group from the drop down Cohort

Every request for inpatient data will be evaluated separately on its merit by the HMDC Data Custodian. To prevent potential delays it is strongly recommended applicants spend time discussing their needs with the HMDC Data Custodian before submitting an application for data. See the contacts at:
http://ww2.health.wa.gov.au/Health-for/Health-professionals/Data-and-statistics

It is imperative applicants have referred to the online summary of HMDC data fields of the HMDC reference manual before requesting data. These documents record the changes in HMDC data collection practices/protocols over time and detail the HMDC variables. See these documents online at:
http://www.datalinkage-wa.org.au/downloads/dataset-information

For all requests, unless requested otherwise, typical exclusions include healthy newborns, boarders, organ procurements, aged care residents, funding (duplicate) hospital cases and residential aged care facilities.

Please note: Certain combinations of variables are potentially identifying and release of these combinations will be at the discretion of the HMDC Data Custodian.

Request variables below by checking boxes

Request	Variable	Description
Standard Information (provided on all HMDC data extracts)		
☑	Standard Morbidity Record Information	Admission age in years
		Sex
		Admission Status. Elective or emergency admission. Variable is unreliable from 1986-1989 and 1996-1998.
		Care Type e.g./ Acute/ Rehabilitation/ Palliative etc.
		Subset admission date - MM/YYYY
		Subset separation date - MM/YYYY
		Mode of separation - e.g. Transferred to another hospital/ deceased/ discharged etc
Patient Information		
☐	Subset date of birth	MM/YYYY
☑	Subset date of birth	YYYY
☐	Indigenous status	
☐	Marital status	Variable may be unreliable.
☑	Employment status	Variable may be unreliable; is not an indication occupation.
☑	Country/State of birth	
☑	State/Territory of residence	
☑ **OR**	Health Region of Hospital **OR (request only one)**	The WA health regions e.g./North & South Metro/ Goldfields/ South-West/ Great Southern/ Wheatbelt/ Midwest/ Pilbara/ Kimberley.

☐	Hospital Type	E.g./ Tertiary/ public metro/ private metro and rural
☐	Interpreter service	Variable may be unreliable.
☐	Language	Variable may be unreliable.
☑	Length of stay	Excludes days on leave ≠ Separation date – admission date.
☑	Source of referral-location	Available on data after July 2000
☑	Source of referral-professional	Available on data after July 2000
☐	Source of referral-transport	Available on data after July 2000
☐	Source of referral	Available on data prior to July 2000
☐	Infant weight	Available where age is less than 1 year.
☑	Funding source	E.g./ AHCA/ private insurance/ self-funded/ worker's compensation etc.
☐	Insurance status	Variable indicates if the patient has hospital (not ancillary) insurance is not an indication of a patient's method of payment
☐	Total leave days	
☐	Number of leave periods	
☐	Days of psychiatric care	
☐	Days of qualified newborn care	
☐	Days of Hospital in the Home care	
☐	Days in Intensive Care Unit - ICU	Available on data prior to July 2013
☐	Hours in ICU	Available on data after July 2013
☐	Hours of Continuous Ventilatory Support	
Diagnosis Codes		
☑	Principal diagnosis	International Classification of Diseases (ICD) codes: Jan 1970 - Dec 1978 ICD-8 Jan 1979 - Dec 1987 ICD-9 Jan 1988 - Jun 1999 ICD-9-CM (Clinical Modification; Aust.) Jul 1999 - ICD-10-AM (Australian Modification) *Be cautious when referring to ICD codes available online which may not be the same as the Australian versions.*
☑	Co-diagnosis	
☑	Additional diagnoses - up to 20	
E-Codes		
☑	External cause of injury	
☑	Activity code	
☑	Place of occurrence	
Procedure Codes		
☑	Principal procedure	Jan 1970 - Dec 1978 Code of Surgical Operations (1968) Jan 1979 - Dec 1987 International Classification of Procedures in Medicine (1978) Jan 1988 - Jun 1999 ICD-9-CM (Clinical Modification Aust.) Jul 1999 - Australian Classification of Health Interventions (ACHI) *Be cautious when referring to procedure codes available online which may not be the same as the Australian versions.*
☑	Additional procedures - up to 10	

Geocoding

Geocoding		
Census year(s) requested: ☐1996 ☐2001 ☐2006 ☐2011 ☐016		
☐	Postcode	
☐	RA	Remoteness Area
☐	LGA (ABS)	1996, 2001, 2006, 2011, 2016 census
☐	SLA (ABS)	1996, 2001, 2006 census
☐	SA2 (ABS)	2011, 2016 census
☐	SEIFA	Socioeconomic status consisting of four indices by CD/ LGA/ SLA and SA2: • Index of Relative Socio-Economic Disadvantage (IRSD) • Index of Relative Socio-Economic Advantage and Disadvantage (IRSAD) • Index of Education and Occupation (IEO) • Index of Economic Resources (IER).

Geocoding Information:

The Data Linkage Branch routinely processes address data from the HMDC to match each record's address to a longitude and latitude. DLB also provides a "Match Quality", a coded field describing the method and specificity of the match. Information on interpreting the match score will be provided with your data. The geocoding process is dependent upon the quality of the address data, and in some cases an address may be difficult or impossible to geocode accurately, or at all.

While the latitude and longitude are not normally provided to researchers for reasons of confidentiality, corresponding geocodes are available, including Statistical Area (SA1 and SA2), Collection District (CD), Statistical Local Area (SLA) and Local Government Area (LGA). Some of these are realigned from one census to the next. The geocodes available are CD, SLA and LGA for the 1996, 2001 and 2006 censes, while SA1, SA2 and LGA are available for 2011 and 2016. Additionally, for each geocode/census combination, the Data Linkage Branch can assign Socio-Economic Indices for Area (SEIFA) and/or Remoteness Areas (RA). Please note that records with poor Match Quality will be assigned a region (e.g. an SA1) based on the centroid of a potentially large match area. This area may not overlap entirely with the assigned region. Therefore, some regions may be assigned in error. This limitation should be noted for any spatial analysis.

The boundaries, SEIFAs and RAs are developed by the Australian Bureau of Statistics (ABS), and the Data Linkage Branch uses mapping files available through the ABS website to attach them to the data. Queries about their interpretation and use should be directed to the ABS. For further information, please visit the ABS website at www.abs.gov.au.

Please note that, due to their small coverage, CD and SA1 are not usually included. Should you require these on your extract please provide written justification in the Sensitive Variables section of this document.

Other Variables

All of the variables below have been determined as sensitive and/or require written justification. Please provide this in the space in the table below.

Hospital Establishment codes are considered identifying information. Provision of these codes requires DOHWA HREC approval and/or hospital ethics approval. Approval from the Chief Executive of the Health Service Provider may also be required.

Request	Variable	Description
☐	Full date of birth	DDMMYYYY
Enter justification here		
☐	Age in days at admission	Available where age in years is less than 1 year
Enter justification here		
☐	CD (ABS)	Refer to geocoding information above (1996/ 2001 & 2006 census)
Enter justification here		
☐	SA1 (ABS)	Refer to geocoding information above (2011 and 2016 census)
Enter justification here		
☑	Admission date	DDMMYYYY
It is important we know the accurate date of wrist fracture or burn injury - this is likely to correlate with the date of hospital admission. One of our research aims is to quantify the risk of being a driver in a motor vehicle accident following an upper limb injury (burn or wrist fracture). If we know the exact injury date, the timeframe of this potential MVA risk can be more clearly defined. For example, the MVA risk following a wrist fracture is highest for XX weeks following the injury.		
☐	Separation date	DDMMYYYY
Enter justification here		
☑	Principal procedure date	DDMMYYYY
The date of the principal procedure is likey to impose subquent function restrictions (for example, the requirement to use a cast or splint for a certain number of weeks following surgery). One of our research aims is to quantify the risk of being a driver in a motor vehicle accident following an upper limb injury (burn or wrist fracture). If we know the exact date of the surgery, the timeframe of this potential MVA risk can be more clearly defined. For example, the MVA risk following a wrist fracture is highest for XX weeks following the surgery		
☑	Additional procedure dates	DDMMYYYY Can be incomplete
The date of the principal procedure is likey to impose subquent function restrictions (for example, the requirement to use a cast or splint for a certain number of weeks following surgery). One of our research aims is to quantify the risk of being a driver in a motor vehicle accident following an upper limb injury (burn or wrist fracture). If we know the exact date of the surgery, the timeframe of this potential MVA risk can be more clearly defined. For example, the MVA risk following a wrist fracture is highest for XX weeks following the surgery		

☐	Mental health legal status	Please also select Days of Psychiatric Care
Enter justification here		
☐	*DRG*	
	Diagnostic Related Group (DRG)	Available July 1993 onwards
	Grouper version	
Enter justification here		
☐	*MDC*	
	Major Diagnostic Category (MDC)	Available July 1993 onwards
	Grouper version	
Enter justification here		
☐	Patient Identifier (UMRN)	May require Health Service/Hospital Chief Executive approval
Enter justification here		
☐	Hospital Identifier	May require Health Service/Hospital Chief Executive approval
Enter justification here		

Additional Variables

Request for variables not on this list

	Variable	Description
1		
Enter justification here		
2		
Enter justification here		
3		
Enter justification here		

Comments:

Enter any extra comments here

Attributes for Standard Crash Release

Attribute Name	Description	Note	Required (Y)
Acc_ID	Accident ID		y
Intx	Intersection Number		
Dist_Err	Distance Error		y
ICWA_Source	ICWA Source OCRF or ICWA	either OCRF or ICWA : ICWA = the Personal Injury database whereas OCRF refers to the Property Damage Only Database.	y
ICWA_Crash_ID	ICWA Crash ID	Reference to ICWA Crash database Additional field added in March 2015.	
Day_No	Day of Week		y
Time	Time		y
Severity	Accident Severity		y
Police	Police Attended		y
Traf_Ctrl	Traffic Control		y
TC_Func	Traffic Control Functioning		y
Feature	Road Feature		y
Align	Road Alignment		y
Grade	Road Grade		y
Atmos	Atmospheric Condition		y
Cond	Road Condition		y
Surface	Road Surface		y
WorkSite	Road Works Site		y
Light	Lighting		y
Damage	Extent Of Damage		y
Spd_Fact	Speed Factor		y
Spd_Lmt	Speed Limit		y
Scope	Accident Scope		y
Acc_Type	Accident Type		y
Inattention	Inattention		y
Fatigue	Fatigue		y
Crash_Suburb	Suburb of Crash Location	Additional Field added in July 2014	y
Police_District	Police District	Additional Field added in July 2014	
LG_No	Local Government Authority Number		
LG_Name	Local Government Authority Name		
Reg_No	Region Number	Combined Midwest-Gascoyne (14) and Wheatbelt South and Wheatblet North (8)	
Reg_Name	Region Name		
Intx_Desc	Intersection Description		y
Source	Source of information		y
Vehicle_Count	Number of vehicle involved in crash	Additional Field added in July 2014	y
Date	Accident Date		y
Road_No	Road Number		
Road_Name	Road Name		
Common_Road_Name	Common Usage Road Name	Additional Field added in May 2014	
SLK	Straight Line Kilometre		y
Cway	Carriageway		y

True_Dist	True Distance	Additional Field added in May 2014	y
Lat	Lattitude of crash locaton	Additional Field added in July 2014	
Long	Longitude of crash location	Additional Field added in July 2014	
Xrd1	First Cross Road Number		
Xrd1_Name	First Cross Road Name		
Xrd1_Common_Name	First Cross Common Road Name	Additional Field added in May 2014	
Xrd2	Second Cross Road Number		
Xrd2_Name	Second Cross Road Name		
Xrd2_Common_Name	Second Cross Common Road Name	Additional Field added in May 2014	
Evt_ID	Event ID		
Rum	Road User Movement		y
Nature	Mr Nature Code		y
MR_Type	Mr Type Code		y
Non_Coll	Non Collision Code		y
Evt_Loc	Event Location Code		y
CV_Unit	Colliding Unit Number		y
CV_Mvmt	Colliding Unit Movement		y
CV_Orig_Dir	Colliding Unit Origin Direction		y
CV_Orig_Leg	Colliding Unit Origin Leg Orient		y
CV_Dest_Dir	Colliding Unit Destination Direction		y
CV_Dest_Leg	Colliding Unit Destination Leg Orient		y
TV_Unit	Target Unit Number		y
TV_Mvmt	Target Unit Movement		y
TV_Ped_Mvmt	Target Unit Pedestrian Movement		y
TV_Impact	Target Unit Impact Point		y
TV_Orig_Dir	Target Unit Origin Direction		y
TV_Orig_Leg	Target Unit Origin Leg Orient		y
TV_Dest_Dir	Target Unit Destination Direction		y
TV_Dest_Leg	Taregt Unit Destination Leg Orient		y
Single_Multi	Single or Multi vehicle crash	Additional Field added in July 2014	y
Unt_ID	Unit ID		
ICWA_Crash_Veh_ID	ICWA Vehicle ID	Reference to ICWA Vehicle database Additional field added in March 2015.	
Unit_No	Unit Number		
U_Type	Unit Type		
Rego_State	Registration State		y
Veh_Register	Vehicle Registered		y
Tow_Req	Tow Required Indicator		y
Veh_Pers	Persons in Vehicle		y
Object_1	First Object Hit		y
Object_2	Second Object Hit		y
Object_3	Third Object Hit		y
Make	Make		
Model	Model		
Agg_Weight	Aggregate Weight	Upload from Vehicle Registration Data from DoT	
Num_Axles	Number of Axles	Upload from Vehicle Registration Data from DoT	
Body_Type	Body Type	Upload from Vehicle Registration Data from DoT	

Num_Cylinder	Number of Cylinders	Upload from Vehicle Registration Data from DoT	
Gross_Mass	Manufacture Gross Comb Mass	Upload from Vehicle Registration Data from DoT	
Power	Power	Upload from Vehicle Registration Data from DoT	
Tare	Tare Weight	Upload from Vehicle Registration Data from DoT	
Yr_Manu	Year of Manufacture	Upload from Vehicle Registration Data from DoT	
Fuel_1	Fuel Type 1	Upload from Vehicle Registration Data from DoT	
Fuel_2	Fuel Type 2	Upload from Vehicle Registration Data from DoT	
Colour_1	Colour 1	Upload from Vehicle Registration Data from DoT	
Colour_2	Colour 2	Upload from Vehicle Registration Data from DoT	
Bull_Bar	Roo or Bull Bar	Upload from Vehicle Registration Data from DoT	
Loaded	Was it Loaded		y
Type_Load	Type of Load		y
HV_Configuration	Heavy Vehicle Configuration		y
Purpose_Travel	Purpose of Travel		y
Date_Reg_First	Date of First Registration	Upload from Vehicle Registration Data from DoT	y
Date_Reg_Exp	Date of Registration Expired	Upload from Vehicle Registration Data from DoT	
Per_ID	Person ID		
ICWA_Crash_Party_ID	ICWA Party ID	Reference to ICWA Person database Additional field added in March 2015.	
Person_No	Person Number		
Rd_User	Road User Type		y
Sex	Sex		y
Age	Age		y
Add_State	State of Address		y
Add_Country	Country of Address		y
Lic_Type	Driver Licence Type		y
Injury	Injury		y
Protection	Protection Worn		
Alcohol	Final Alcohol Reading		y
Airbag	Airbag Activated		y
Seating_Position	Seating position		y

Government of **Western Australia**
Department of **Health**

For Office Use Only	
DL#	201911.04
HREC#	
Version	HREC V.1
Date	1/4/2020

Extraction: Cohort/Case Group

How to complete this form:

Please specify the data to be extracted, listing all data sets and specific detail around selection of a cohort or case group. Any date limits should also be given. If you require matched controls or comparison groups, please use the Extraction: Matched Comparison Group form.
If you require assistance with completing this form, please email DataServices@health.wa.gov.au.

- Please provide one form per unique cohort/case group
- To avoid misinterpretation of cohort/case group definitions and restrictions on data extraction parameters, we suggest using the following format for your definitions and extraction parameters (rather than and/or statements)

  'Individuals who meet all/any of the following criteria…'

  'Linked records which meet all/any of the following criteria…'
- If you are providing International Classification of Diseases (ICD) codes or Australian Classification of Health Interventions (ACHI) codes, please ensure it is clear:
  - If the codes are to be used for your cohort/control selection or to restrict your data extraction;
  - If you are using a combination of ICD codes and ACHI codes please use the above format to clarify if records should meet requirements for all/any codes; and
  - Which data collections the codes should be applied to. For more information on clinical coding see:

    https://ww2.health.wa.gov.au/Articles/A_E/Clinical-Coding-Authority

1. GROUP NAME

1.1 Please create a name for this Cohort/Case Group:

e.g. Epilepsy Cohort

Upper limb burn and wrist fracture cohort

2. COHORT SELECTION

2.1 Cohort/case group selection (tick all that apply):	☒ Selected from pre-linked data collections ☐ Provided for new linkage

2.2 Please provide a description of your cohort/case group and how your study population is defined.

e.g. Individuals who meet all of the following criteria:

– *diagnosed with lung cancer between 1995 and 2005, defined through the WA Cancer Registry aged 18 and over at time of diagnosis*

Individuals with an EDDC or HMDC record that meets the following criteria:

HMDC Criteria

- Admission date between 01/01/2008 and 31/12/2017
- Individual aged 18 and over at the time of admission
- Principal diagnosis of 'burn injury to upper limb' or 'wrist fracture' (ICD-10-AM codes provided)

EDDC criteria:

- Presentation date between 01/01/2008 and 31/12/2017
- Individual aged 18 and over at the time of presentation
- Principal diagnosis of 'burn injury to upper limb' or 'wrist fracture' (ICD-10-AM codes provided)

Please also provide a flag against cohort members of who was included for upper limb burn vs wrist fracture.

Please provide the details of the ICD-10-AM codes including the diagnosis category, sub-categories and codes.

2.3 For quoting purposes please provide an estimate of how many people there will be in your cohort:	40000

2.4 Is your cohort selected from specific disease or procedure groupings?

☐ NO

☒ YES ⟶ please specify the codes you wish to apply and describe how you wish to apply

these codes below, including:

- the version of ICD codes you require (i.e. ICD-9-CM, ICD-10-AM).
  For the time periods and versions of ICD codes used in WA please see:
  http://www.datalinkage-wa.org.au/sites/default/files/HMDS_ICD_DRG.pdf
- whether they should be applied only to the principal disease/procedure code or to any of the multiple codes within a record.

Please attach an Excel spreadsheet of the specific ICD codes or ACHI codes to apply to your cohort/case group selection. Please note that the DLB cannot provide or check ICD codes.

See attached, as based on the ICD-10-AM codes

Please select cases where the principal diagnosis code is as listed in the attached excel spreadsheet, and where there are no secondary codes as also listed in the attached excel spreadsheet.

2.5 Is your cohort selected from specific geographical areas?

SEIFA and RA codes are available for Emergency, Death, Hospital and Midwives data. If you require SEIFA or RA codes, please select this in the variable lists for each dataset (Module 3).

☒ NO

☐ YES ⟶ **Please attach an Excel spreadsheet of the postcodes, SA1/SA2/CDs you require, or specify below:**

3. SERVICE DATA EXTRACTION

Please describe the service data you require for this cohort/case group.

3.1 Is the time period for the service data extraction to be based on an index event?

☐ NO

☒ YES ⟶ please provide a definition of the index event:

The index event is the date of the injury: being the date of emergency department presentation date OR the hospital admission date; in the case of both events (or more than one episode relating to the same injury), the *earliest* date should be used.

3.2 Are the data extraction criteria identical to another group of interest being requested?

☒ NO

☐ YES ⟶ please specify name of group:

3.3 Please specify the datasets you require, the time period and any restrictions on which records you need. Insert rows in the table as required.

Attach variable lists (Module 3) (download from http://www.datalinkage-wa.org.au/forms)

Where requesting Midwives Notification System, Birth Registrations & WA Register of Developmental Anomalies:

Please specify below whether you need records where the individual is the baby, records where they are the parent, or both.

Dataset	Time period	Extraction Criteria/ Restrictions
Emergency Department Data Collection	01/01/2006 – 31/12/2019	*All linked records 2 years prior to index event and all after.*
Hospital Morbidity Data Collection	01/01/2006 – 31/12/2019	*All linked records 2 years prior to index event and all after*
Main Roads WA	01/01/2006 – 31/12/2019	*All linked records 2 years prior to index event and all after*

**Please provide data in batches - health data to be released as soon as ready with MainRoads data to follow as soon as ready.*

***Please provide a flag to distinguish cases where the participant was included due to an event for burns or wrist fracture*

3.4 Please specify any restrictions on WA Cancer Registry data if applicable:

WA Cancer Registry:

Please specify the record scope from the following options:

☐ Malignant and invasive cancers only

☐ Malignant and invasive, benign, in-situ, and uncertain cancers only (excluding squamous cell and basal cell carcinomas of the skin)

☐ All cancers including invasive malignancies, benign, in-situ, uncertain, and squamous cell/basal cell carcinomas of the skin.

3.5 Are the data extraction variables required identical to another group of interest being requested?

☒ NO ⟶ **Attach variable lists (Module 3)**
(download from http://www.datalinkage-wa.org.au/forms)

☐ YES ⟶ Please specify name of group:

INCLUDED CODES

Group	Group name	Subcode	Subgroup name	Code(s) to include
S52	Fracture of forearm	S52.2	Fracture of shaft of ulna	S52.20
S52	Fracture of forearm	S52.3	Fracture of shaft of radius	(include all codes)
S52	Fracture of forearm	S52.4	Fracture of shafts of both ulna and radius	
S52	Fracture of forearm	S52.5	Fracture of lower end of radius	(include all codes)
S52	Fracture of forearm	S52.6	Fracture of lower end of both ulna and radius	
S52	Fracture of forearm	S52.7	Multiple fractures of forearm	
S52	Fracture of forearm	S52.8	Fracture of other parts of forearm	
S52	Fracture of forearm	S52.9	Fracture of forearm, part unspecified	
S62	Fracture at wrist and hand level	S62.0	Fracture of navicular (scaphoid) bone of hand	
S62	Fracture at wrist and hand level	S62.1	Fracture of other carpal bone(s)	(include all codes)

Government of **Western Australia**
Department of **Health**

Associate Professor Dale Edgar
Senior Physiotherapist Research Manager and Head of the Burn Injury Research Node
Fiona Stanley Hospital
Level 4B, 11 Robin Warren Drive
MURDOCH WA 615

In Principle Support of: 201911.04
Project Title: Is it safe to drive after common upper limb traumas? Identifying factors that increase the risk of motor vehicle accident after wrist fractures and upper limb burns

Dear Professor Edgar,

Thank you for submitting your draft application to the Data Linkage Branch. I am pleased to inform you that your application has passed the draft review and can progress to the next stage of the application process. **Please note that data release is still dependent on:**

- Approval from the Data Custodian of MainRoads WA
- DOHWA Human Research Ethics Committee (HREC) approval
- Formal Data Custodian/Steward approval
- Research Governance approval, coordinated by the DOH Research Governance Office

You will need to include this letter with your formal application to DOHWA HREC. All new research projects must be submitted through the Research Governance Service information technology system (RGS). More information can be found at the DOH HREC website and the RGS website. Your formal application must be submitted within three months of this letter, otherwise you will need to resubmit your application and undergo the draft application process again.

Once you have received confirmation of your final DOH HREC approval, please submit it, along with electronic copies of the final versions of all documents, to DataServices@health.wa.gov.au. We recommend zipping the package of documents to save space. See the Data Linkage website for further instructions.

Please find a cost estimate for the project attached. If you have any questions, please contact me on (08) 9222 2413 or by email at emma.douglas2@health.wa.gov.au.

Yours sincerely

[redacted]

Emma Douglas
A/Senior Project Officer
DATA LINKAGE BRANCH

9 April 2020

Government of **Western Australia**
Department of **Health**

Department of Health WA Human Research Ethics Committee
Level 1 C Block
189 Royal Street
East Perth Western Australia 6004

29 May 2020

Associate Professor Dale Edgar
Fiona Stanley Hospital
4B - Burn Unit, 11 Robin Warren Drive
MURDOCH Western Australia 6150

Dear Associate Professor Edgar

PRN:	RGS0000001352
Project Title:	Wrist fracture epidemiology, management pathways and risk of motor vehicle crash rates following upper limb trauma in Western Australia
Protocol Number:	V1.1

Thank you for submitting the above research project for ethical review. This project was considered by the Department of Health WA Human Research Ethics Committee at its meeting held on 29 May 2020. To find the original letter and any possible attachments, click here when logged into RGS.

I am pleased to advise you that the above research project meets the requirements of the *National Statement on Ethical Conduct in Human Research (2007)* and ethical approval for this research project has been granted by Department of Health WA Human Research Ethics Committee.

The Committee considered your application under the Guidelines under the National Statement on Ethical Conduct in Human Research 2.3.10 and was satisfied that it met the criteria to grant a waiver of consent.

The nominated participating site(s) in this project is/are:

Fiona Stanley Hospital, Rockingham General Hospital, Armadale Health Service, Bentley Health Services, Royal Perth Hospital, Sir Charles Gairdner Hospital, WACHS Central Office, Department of Health

[Note: If additional sites are recruited prior to the commencement of, or during the research project, the Coordinating Principal Investigator is required to notify the Human Research Ethics Committee (HREC). Notification of withdrawn sites should also be provided to the HREC in a timely fashion.]

The approved documents include:

Document	Version	Version Date
Ethics Investigator Response letter 23052020	1.0	23/05/2020
Extraction form	1.0	01/04/2020
Feasibility letter from the WADLS	1.0	09/04/2020
Inclusion and exclusion ICD-10-AM Codes for WAHAEF form	1.0	01/04/2020
PRF Letter	1.0	25/11/2019
References for WAHAEF	1.0	22/03/2020
Research Protocol	2.0	01/04/2020
Variable list EDDC	1.0	11/04/2020
Variable list HMDC	1.0	01/04/2020
Variable list MainRoads WA	1.0	01/04/2020
WA Health Student Research and Confidentiality Declaration form	1.0	23/04/2020

Ethical approval of this project from Department of Health WA Human Research Ethics Committee is valid from 29 May 2020 to 29 May 2020 subject to compliance with the 'Conditions of Ethics Approval for a Research Project' (Appendix A).

A copy of this ethical approval letter must be submitted by all site Principal Investigators to the Research Governance Office or equivalent body or individual at each participating institution in a timely manner to enable the institution to authorise the commencement of the project at its site/s.

This letter constitutes ethical approval only. This project cannot proceed at any site until separate site authorisation has been obtained from the Chief Executive or Delegate of the site under whose auspices the research will be conducted at that site.

Government of **Western Australia**
Department of **Health**

Should you have any queries about the Department of Health WA Human Research Ethics Committee's consideration of your project, please contact the Ethics Office at hrec@health.wa.gov.au or on 08 9222 4278. The HREC's Terms of Reference, Standard Operating Procedures and membership are available from the Ethics Office or from http://www.health.wa.gov.au/healthdata/HREC/.

The HREC wishes you every success in your research.

Yours sincerely

Dr Peter Bentley
Chair, **Department of Health WA Human Research Ethics Committee**
Clinical Senior Lecturer
UWA Medical School
Division of Internal Medicine

Government of **Western Australia**
Department of **Health**

Appendix A

CONDITIONS OF ETHICS APPROVAL FOR A RESEARCH PROJECT

The following general conditions apply to the research project approved by the Human Research Ethics Committee (HREC) and acceptance of ethical approval will be deemed to be an acceptance of these conditions by all project investigators:

1. The responsibility for the conduct of this project lies with the Coordinating Principal Investigator (CPI).
2. The investigators recognise the reviewing HREC is registered with the National Health and Medical Research Council and that it complies with the current version of the National Statement on Ethical Conduct in Human Research.
3. A list of HREC member attendance at a specific meeting is available on request, but no voting records will be provided.
4. The CPI will immediately report anything that might warrant review of ethical approval of the project.
5. The CPI will notify the HREC of any event that requires a modification to the protocol or other project documents and submit any required amendments to approved documents, or any new documents, for ethics approval. Amendments cannot be implemented at any participating site until ethics approval is given.
6. The CPI will submit any necessary reports related to the safety of research participants in accordance with the WA Health Research Governance Standard Operating Procedures.
7. Where a project requires a Data Safety Monitoring Board (DSMB), the CPI's will ensure this is in place before the commencement of the project and notify the HREC. All relevant reports from the DSMB should be submitted to HREC.
8. For investigator-initiated and collaborative research group projects the CPI may take on the role of the sponsor. In this case, the CPI is responsible for reporting to the Therapeutic Goods Administration (TGA) any unexpected serious drug or device adverse reactions, and significant safety issues in accordance with the TGA guidelines.
9. If the project involves the use of an implantable device, the CPI will ensure a properly monitored and up to date system for tracking participants is maintained for the life of the device.
10. The CPI will submit a progress report to the HREC annually from the ethics approval date and notify the HREC when the project is completed at all sites. The HREC can request additional reporting requirements as a special condition of a research project. Ethics approvals are subject to the receipt of these reports and approval may be suspended if the report is not received.
11. The CPI will notify the HREC of his or her inability to continue as CPI and will provide the name and contact information of their replacement. Failure to notify the HREC can result approval for the project being suspended or withdrawn.
12. The CPI will notify the HREC of any changes in investigators and/or new sites that will utilise the ethics approval.
13. The HREC has the authority to audit the conduct of any project without notice if some irregularity has occurred, a complaint is received from a third party or the HREC decides to undertake an audit for quality improvement purposes.
14. The HREC may conduct random monitoring of any project. The CPI will be notified if their project has been selected. The CPI will be given a copy of the monitor's report along with the HREC and Research Governance (RG) Office at the site/s.

15. Complaints relating to the conduct of a project should be directed to the HREC Chair and will be promptly investigated according to the WA Health's complaints procedures.
16. The CPI should ensure participant information and consent forms are stored within the participant's medical record in accordance with the WA Health's RecordKeeping Plan.
17. The CPI will notify the HREC of any plan to extend the duration of the project past the expiry date listed above and will submit any associated required documentation. A request for an extension should be submitted prior to the expiry date. One extension of 5 years may be granted but approval beyond this time period may necessitate further review by the HREC.
18. Once the approval period has expired or the project is closed, the CPI will submit a final report. If the report is not received within 30 days the project will be closed and archived.
19. Projects that do not commence within 12 months of the approval date may have their approval withdrawn and the project closed. The CPI must outline why the project approval should remain.
20. The CPI will notify the HREC if the project is temporarily halted or prematurely terminated at a participating site before the expected completion date, with reasons provided. Such notification should include information as to what procedures are in place to safeguard participants.
21. If a project fails to meet these conditions the HREC will contact the CPI to address the identified issues. If, after being contacted by the HREC, the issues are not addressed, the ethics approval will be withdrawn. The HREC will notify the RG Office at each site within WA Health that the project procedures must discontinue, except for those directly related to participant's safety.

Government of **Western Australia**
Department of **Health**

Clinical Excellence

12 November 2020

Mrs Susie Stinton
c/o Dale Edgar
Fiona Stanley Hospital
11 Robin Warren Drive
MURDOCH WA 6150

Dear Mrs Stinton

PRN:	RGS0000001352
Project Title:	Wrist fracture epidemiology, management pathways and risk of motor vehicle crash rates following upper limb trauma in Western Australia
Protocol No:	V1.1

Thank you for submitting the above research project for governance review. I am pleased to advise you that Department of Health has granted authorisation for this research project to be conducted at the following participating site(s):

Department of Health

Site authorisation of this project is valid from 12 November 2020 subject to continued ethical approval from the Department of Health WA Human Research Ethics Committee and compliance with the 'Conditions of Site Authorisation for a Research Project' (Appendix A). To find the original letter and any possible attachments, click here when logged into RGS.

Should you have any queries about Department of Health's consideration of your project, please contact the Research Governance Office at DoH.RGO@health.wa.gov.au or on 08 9222 6413. The Research Governance Office's Standard Operating Procedures are available from the Research Governance Office or from http://ww2.health.wa.gov.au/Articles/N_R/Research-Governance-Office.

I wish you every success in your research.

Yours sincerely

[redacted]

Dr James Williamson
Assistant Director General
Clinical Excellence
Department of Health

189 Royal Street East Perth Western Australia 6004
Telephone (08) 9222 4222 TTY 133 677
PO Box 8172 Perth Business Centre Western Australia 6849
ABN 28 684 750 332
www.health.wa.gov.au

Appendix A

CONDITIONS OF SITE AUTHORISATION FOR A RESEARCH PROJECT

The following general conditions apply to the research project, which has been authorised to be conducted at the above nominated site(s). The acceptance of site authorisation will be deemed to be an acceptance of these conditions by all investigators involved in the research project at the nominated site(s).

1. The responsibility for the conduct of this project at the nominated site(s) lies with the site Principal Investigator (PI).
2. The PI will inform the Research Governance (RG) Office of any event that requires a modification to the protocol or other project documents and submit any required amendments to approved documents, or any new documents, for site authorisation. Amendments cannot be implemented at this site until they have received ethics approval and site authorisation.
3. The PI will submit any necessary reports related to the safety of research participants to the Research Governance Office in accordance with the WA Health Research Governance Standard Operating Procedures.
4. The PI will submit a progress report to the RG Office annually from the ethics approval date and notify the RG Office when the project is completed at the site(s). The RG Office can request additional reporting requirements as a special condition of a research project. Site authorisation is subject to the receipt of these reports and authorisation may be suspended if the report is not received.
5. The PI will notify the RG Office of his or her inability to continue as PI at the site(s) and will provide the name and contact information of their replacement.
6. The PI will notify the RG Office of any changes in investigators at the site(s).
7. The site has the authority to audit the conduct of any project without notice if some irregularity has occurred, a complaint is received from a third party or the site decides to undertake an audit for quality improvement purposes.
8. The site may conduct random monitoring of any project. The PI will be notified if their project has been selected. The PI will be given a copy of the monitor’s report along with the HREC and RG Office.
9. Complaints relating to the conduct of a project should be directed to the RG Office and will be promptly investigated according to the WA Health’s complaints procedures.
10. The PI should ensure participant information and consent forms are stored within the participant’s medical record in accordance with the WA Health’s Recordkeeping Plan.
11. Once the project has been closed at site, the PI will submit a final report. If the report is not received within 30 days the project will be closed and archived.
12. The PI will notify the RG Office if the project is temporarily halted or prematurely terminated at the site(s) before the expected completion date, with reasons provided. Such notification should include information as to what procedures are in place to safeguard participants.
13. If a project fails to meet these conditions the RG Office will contact the PI to address the identified issues. If, after being contacted, the issues are not addressed the site authorisation will be withdrawn.

APPENDIX 3: UNPUBLISHED SUPPLEMENTARY MATERIAL FOR CHAPTER FOUR

PROSPERO Registry information

Unpublished results: Graphs showing the longitudinal recovery of the following outcomes

Pronation (Recorded in degrees)

Radial deviation (Recorded in degrees)

Ulnar deviation (Recorded in degrees)

Wrist flexion/extension arc (Recorded in degrees)

Wrist deviation arc (Recorded in degrees)

Forearm supination/pronation arc (Recorded in degrees)

Extension (Recorded as percentage of the uninjured limb)

Flexion (Recorded as percentage of the uninjured limb)

Pronation (Recorded as percentage of the uninjured limb)

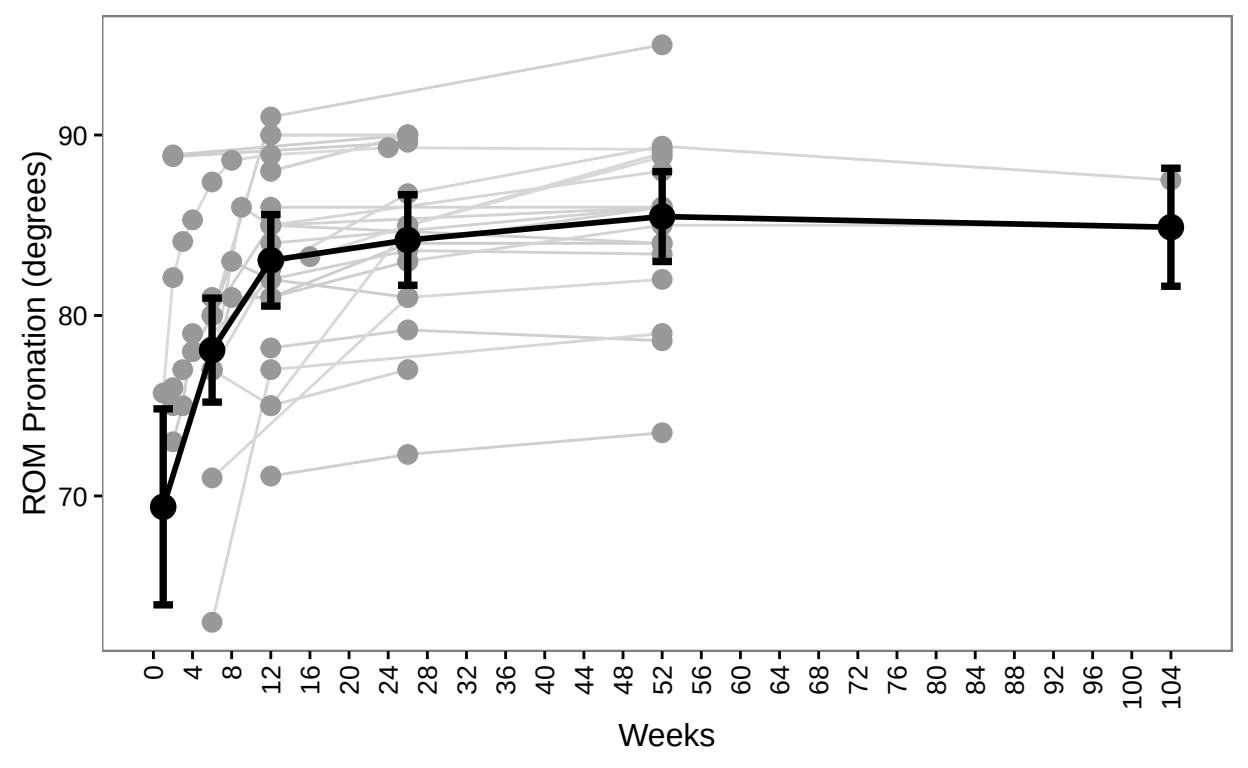
Supination (Recorded as percentage of the uninjured limb)

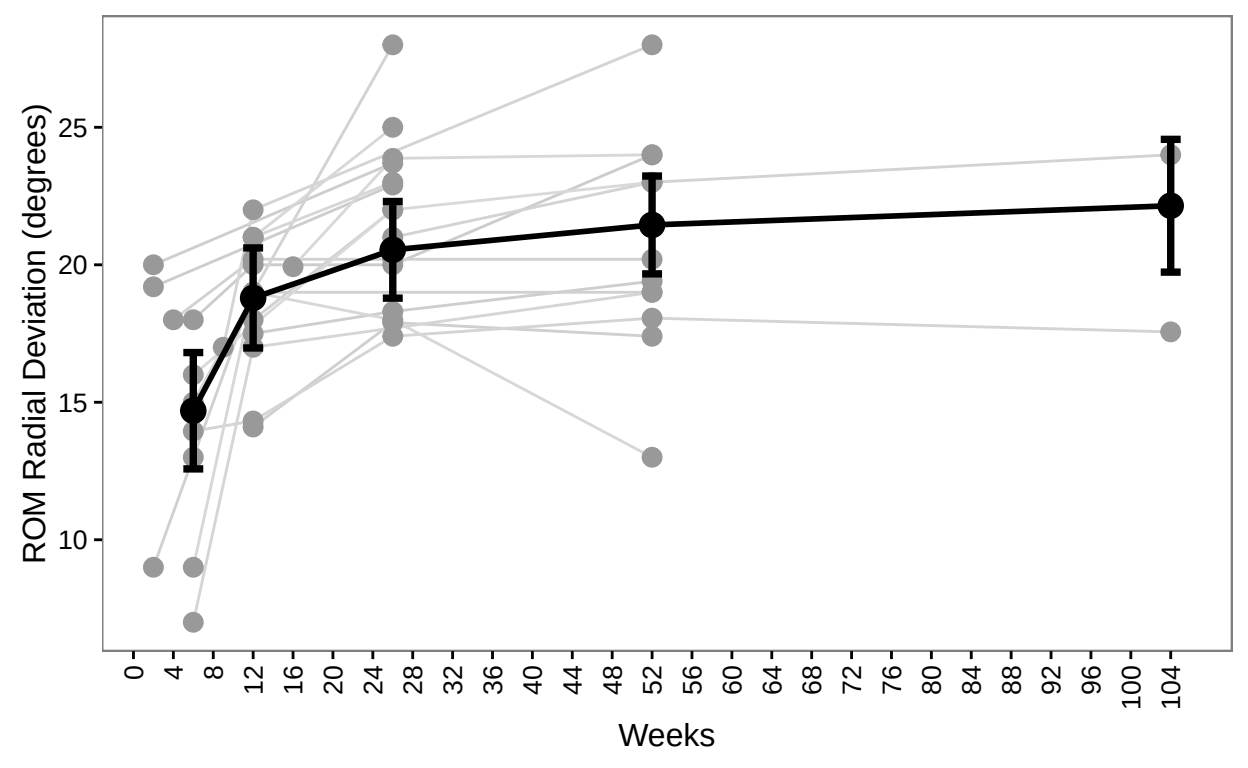
Ulna deviation (Recorded as percentage of the uninjured limb)

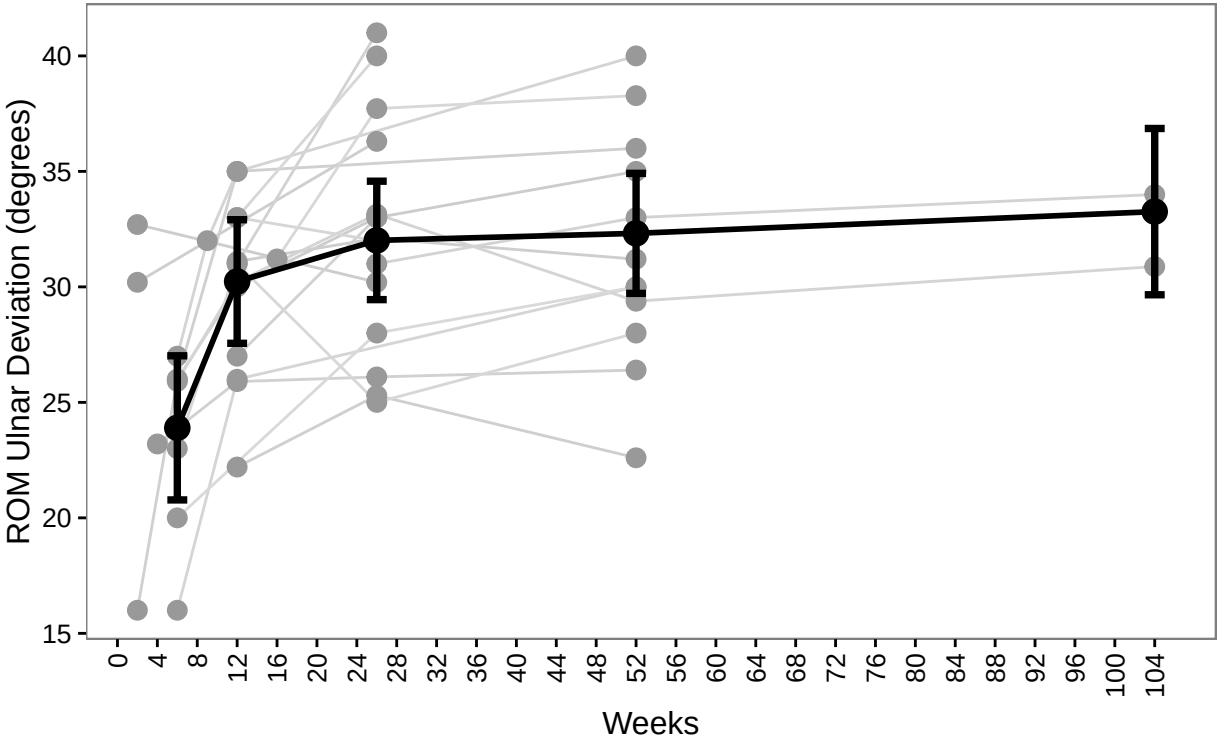
Radial deviation (Recorded as percentage of the uninjured limb)

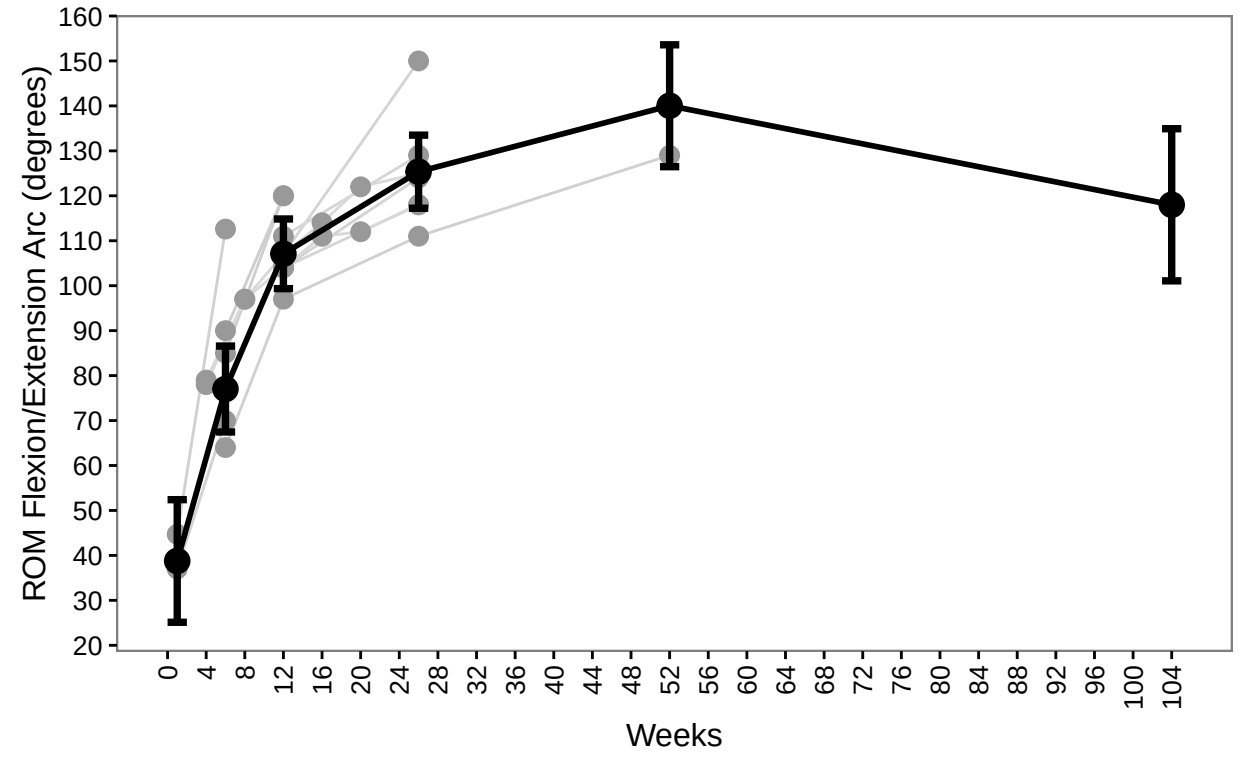
Grip strength (recorded in kg)

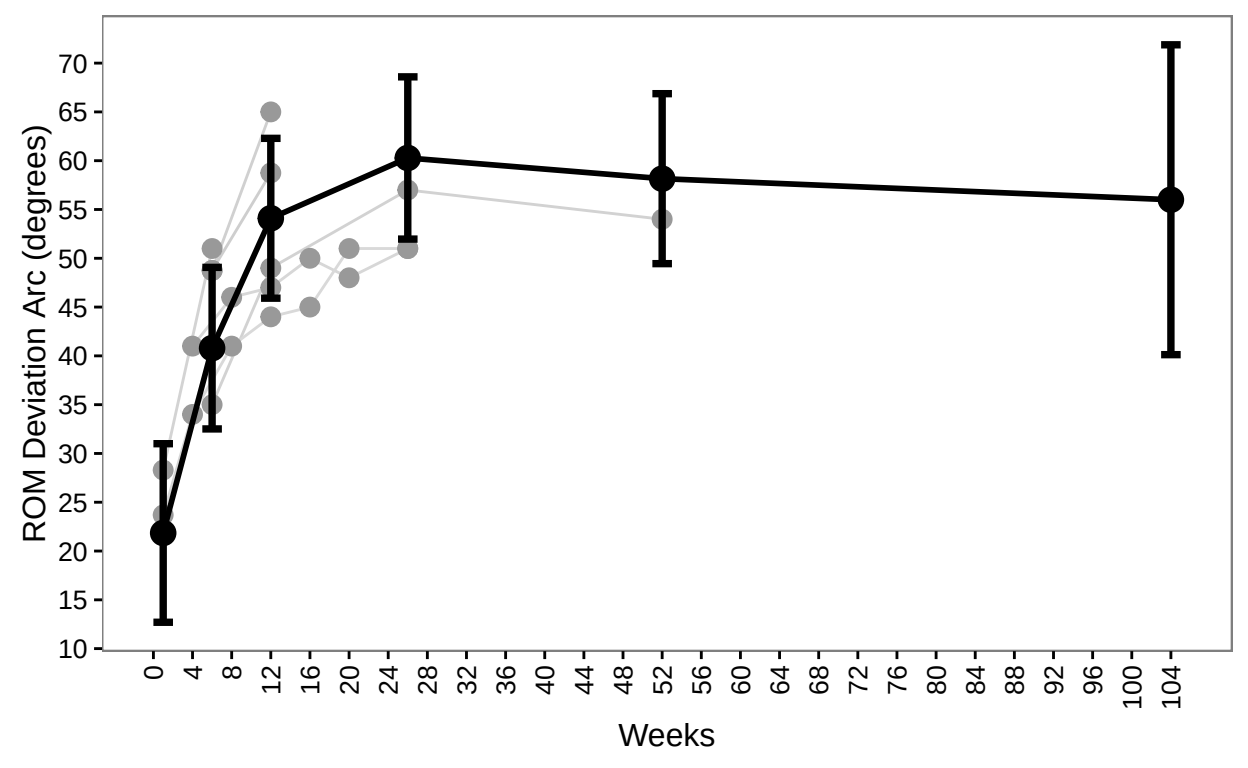
Data category	Information
Registry	PROSPERO International prospective register of systematic reviews
Registration number	CRD42014010133
Date of registration	6/7/2014
Public title	Expected outcomes following distal radius fracture managed with ORIF using a volar plate: a systematic review
Scientific title	Longitudinal recovery following distal radial fractures managed with volar plate fixation
Organisational affiliation of the review	The University of Sydney
Funding sources/sponsors	The University of Sydney
Review team member(s)	Susan Stinton
Review team member(s)	Evangelos Pappas
Review team member(s)	Niamh Moloney
Review team member(s)	Dale Edgar
Review team member(s)	Petra Graham
Contact for public queries	Susan Stinton
Named contact email	sbla5337@uni.sydney.edu.au
Conflicts of interest	Non known
Stage of review	Completed and published

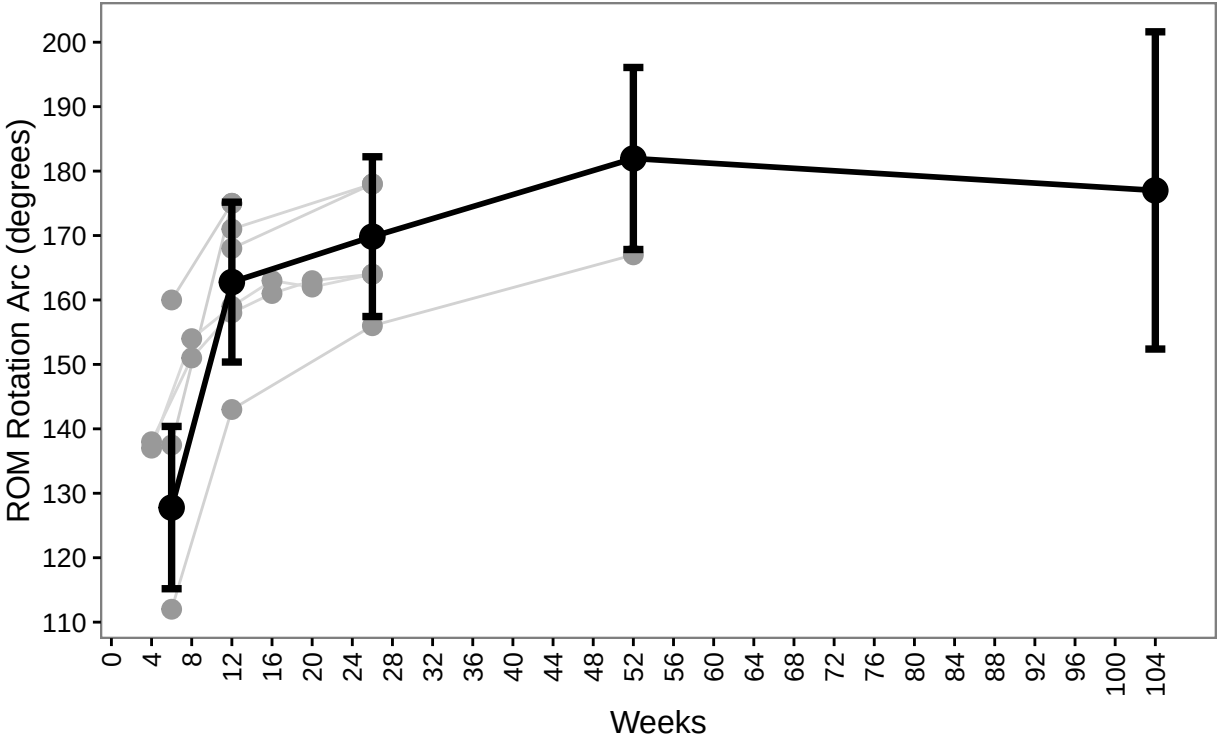

ROM Pronation (degrees)
90
80
70
0
4
8
12
16
20
24
28
32
36
40
44
48
52
56
60
64
68
72
76
80
84
88
92
96
100
104
Weeks

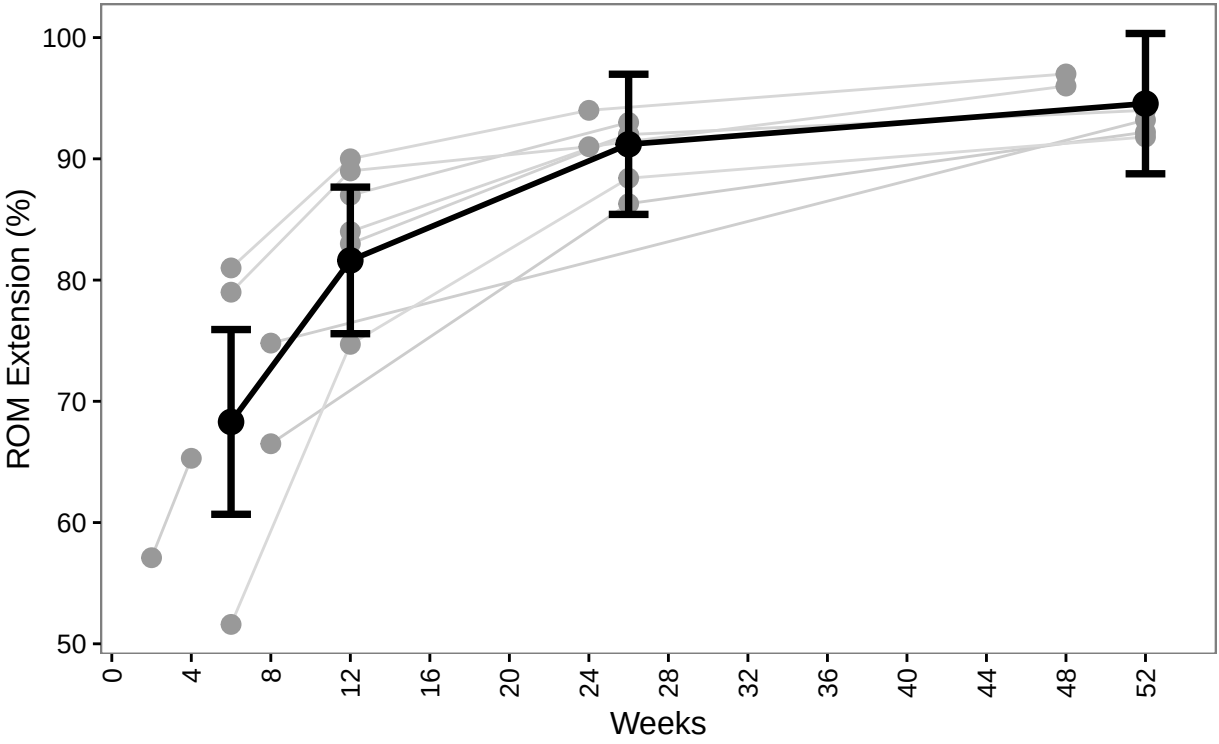

ROM Radial Deviation (degrees)
25
20
15
10
0
4
8
12
16
20
24
28
32
36
40
44
48
52
56
60
64
68
72
76
80
84
88
92
96
100
104
Weeks

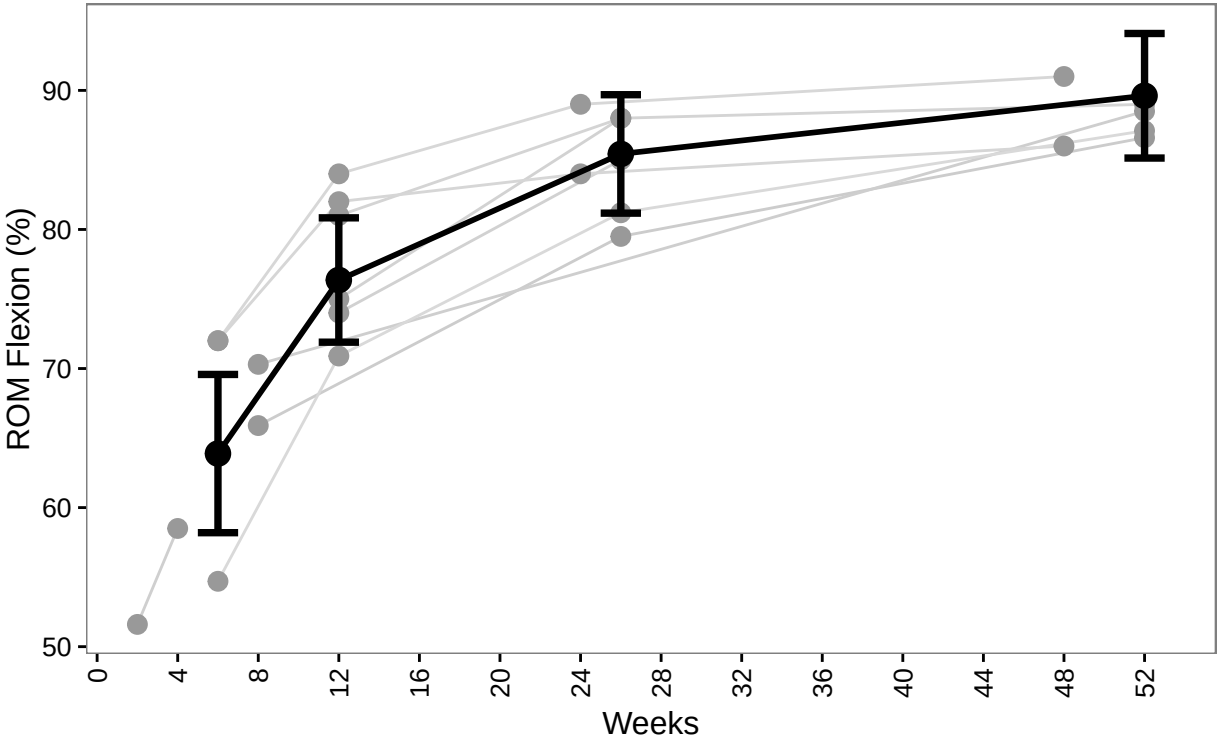

ROM Ulnar Deviation (degrees)
40
35
30
25
20
15
0
4
8
12
16
20
24
28
32
36
40
44
48
52
56
60
64
68
72
76
80
84
88
92
96
100
104
Weeks

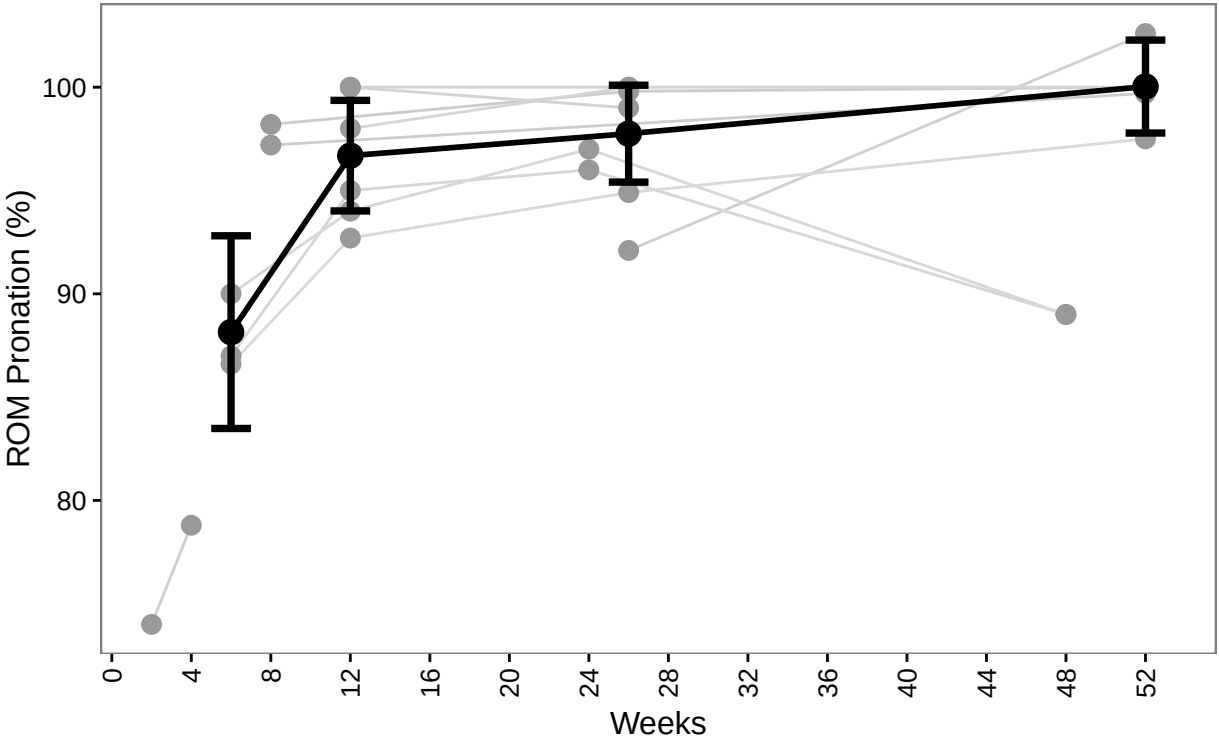

ROM Flexion/Extension Arc (degrees)
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
0
4
8
12
16
20
24
28
32
36
40
44
48
52
56
60
64
68
72
76
80
84
88
92
96
100
104
Weeks

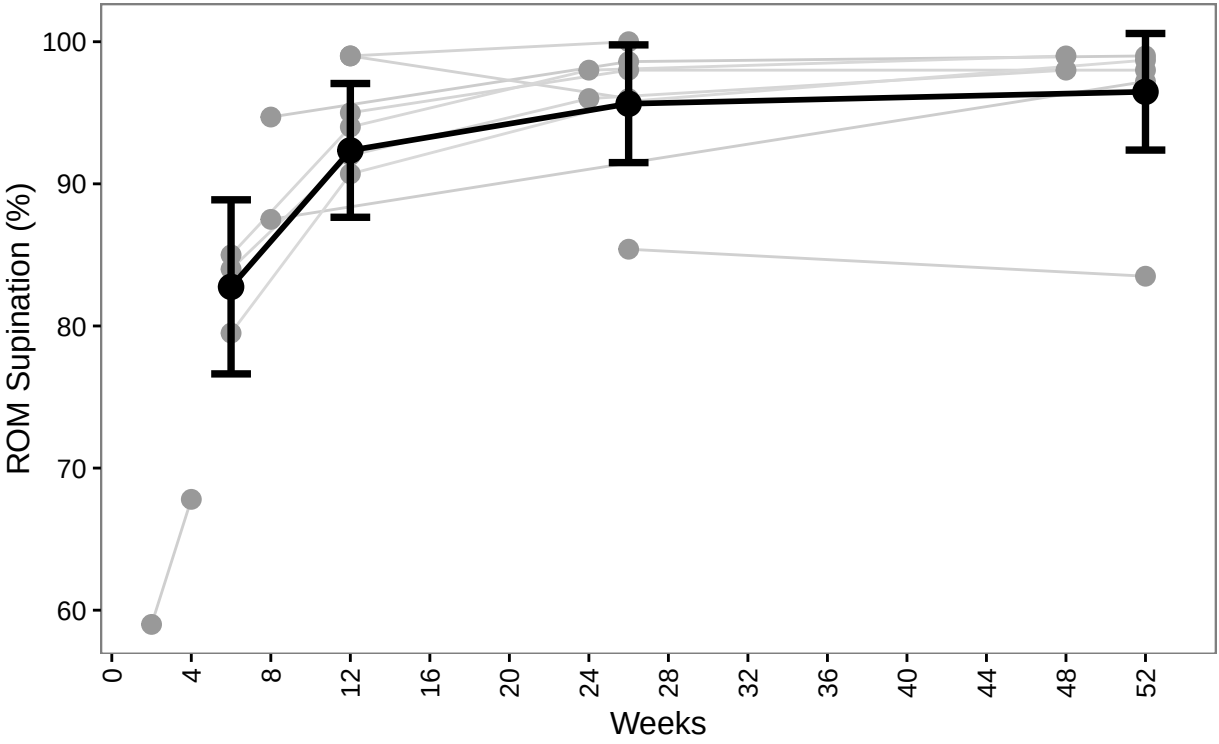

ROM Deviation Arc (degrees)
10
15
20
25
30
35
40
45
50
55
60
65
70
0
4
8
12
16
20
24
28
32
36
40
44
48
52
56
60
64
68
72
76
80
84
88
92
96
100
104
Weeks

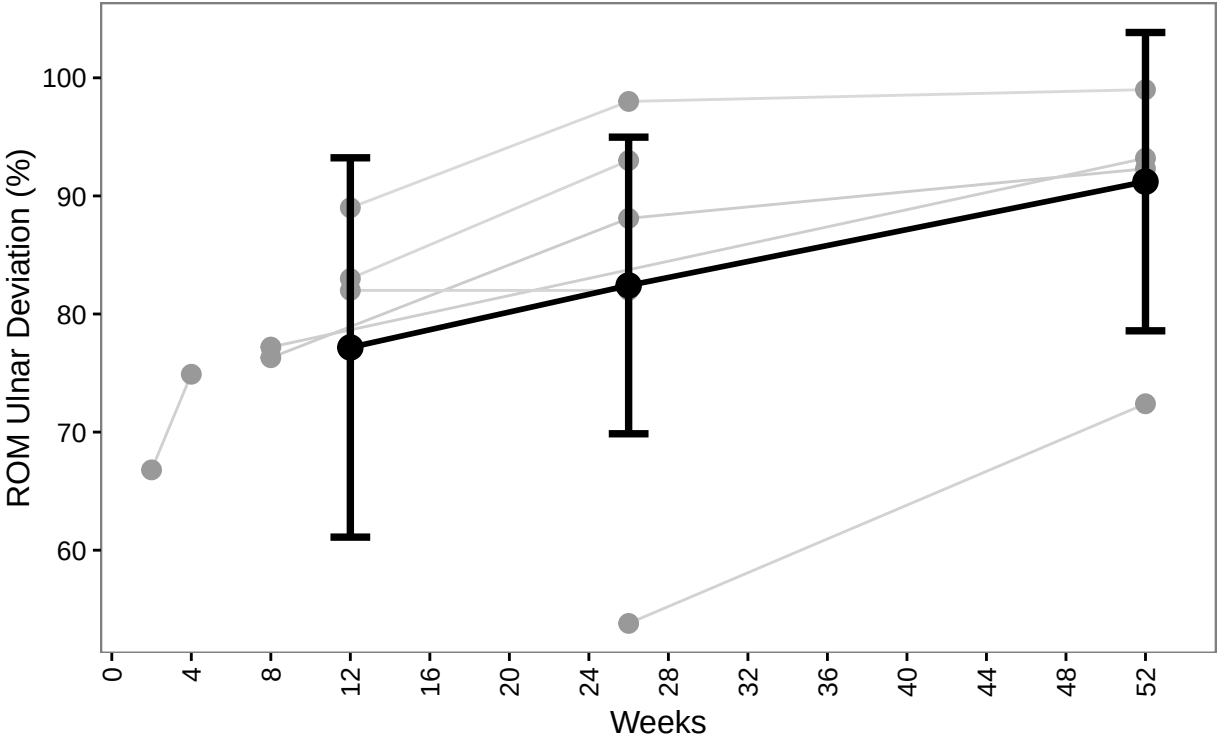

ROM Rotation Arc (degrees)
200
190
180
170
160
150
140
130
120
110
0
4
8
12
16
20
24
28
32
36
40
44
48
52
56
60
64
68
72
76
80
84
88
92
96
100
104
Weeks

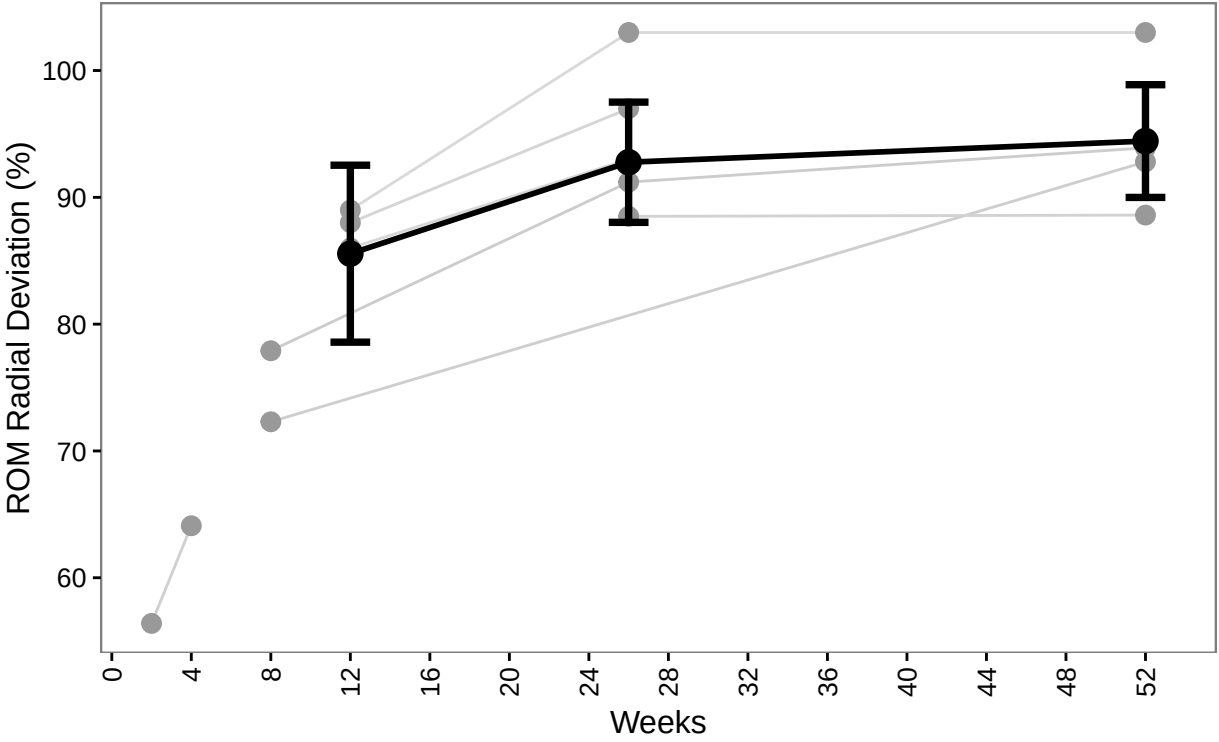

ROM Extension (%)
100
90
80
70
60
50
0
4
8
12
16
20
24
28
32
36
40
44
48
52
Weeks

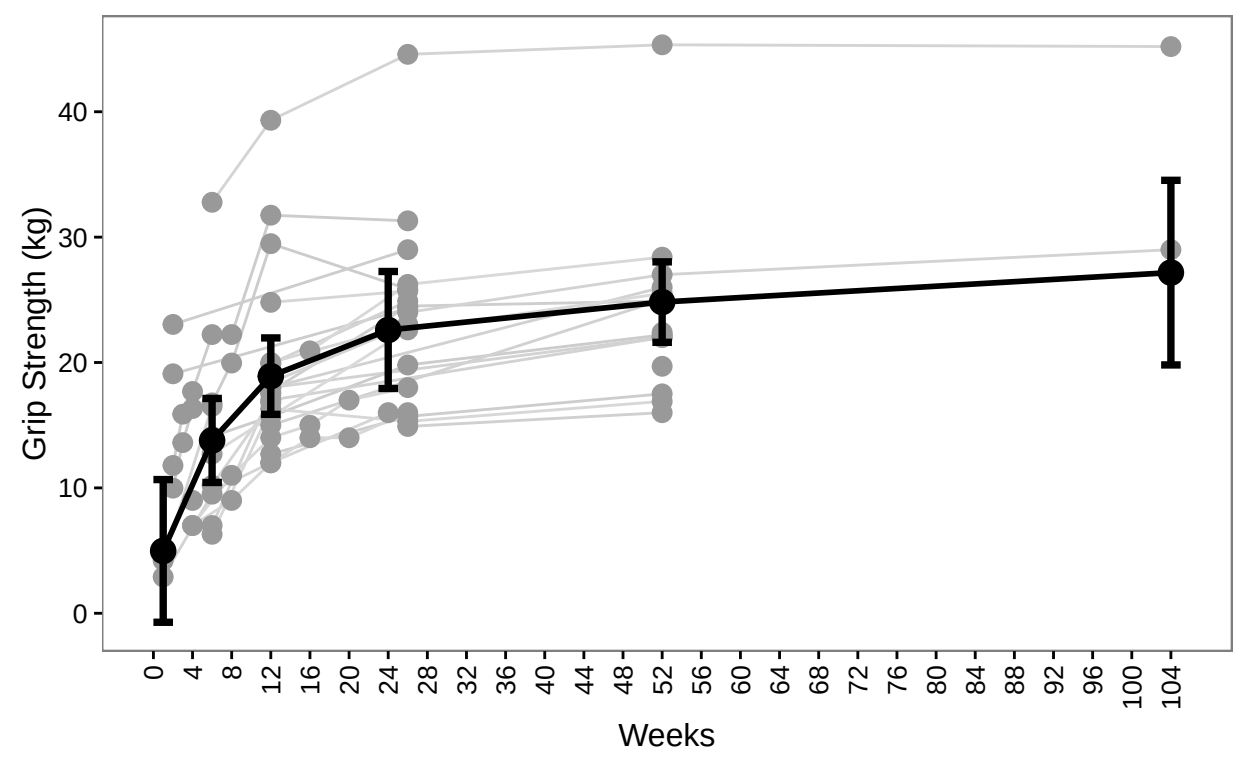

ROM Flexion (%)
90
80
70
60
50
0
4
8
12
16
20
24
28
32
36
40
44
48
52
Weeks


ROM Pronation (%)
100
90
80
0
4
8
12
16
20
24
28
32
36
40
44
48
52
Weeks


ROM Supination (%)
100
90
80
70
60
0
4
8
12
16
20
24
28
32
36
40
44
48
52
Weeks


ROM Ulnar Deviation (%)
100
90
80
70
60
0
4
8
12
16
20
24
28
32
36
40
44
48
52
Weeks


ROM Radial Deviation (%)
100
90
80
70
60
0
4
8
12
16
20
24
28
32
36
40
44
48
52
Weeks


Grip Strength (kg)
0
10
20
30
40
0
4
8
12
16
20
24
28
32
36
40
44
48
52
56
60
64
68
72
76
80
84
88
92
96
100
104
Weeks

APPENDIX 4: UNPUBLISHED SUPPLEMENTARY MATERIAL FOR CHAPTER FIVE

Ethics approval letter

Site approval letters

University of Sydney

Mungovan Breckenridge Physiotherapy & Associates

Patient information form

Consent forms

Patient consent form

Surgeon consent form

Advertisements

Pamphlet

Poster

Questionnaires

Disability of the arm, shoulder and hand (DASH)

Patient rated wrist evaluation (PRWE)

HREC Ref: **(4220) AU RED HREC/15/WMEAD/52**

6 May 2015

Mr John Breckenridge
Mungovan Breckenridge Physiotherapy & Associates
Westmead Private Physiotherapy
Cnr Darcy and Mons Rds
Westmead NSW 2145

Dear Mr Breckenridge

Project title: 'When Can I Drive? Factors influencing driving performance following a wrist fracture: A prospective, cohort study'

Thank you for Susan Stinton's emails dated 2 and 6 May 2015 addressing the matters raised in the HREC's letter dated 9 April 2015 following single ethical review of the above project at its meeting held on 31 March 2015.

This HREC has been accredited by the NSW Department of Health as a lead HREC to provide the single ethical and scientific review of proposals to conduct research within the NSW public health system. This lead HREC is constituted and operates in accordance with the National Health and Medical Research Council's *National Statement on Ethical Conduct in Human Research* and the *CPMP/ICH Note for Guidance on Good Clinical Practice.*

This proposal meets the requirements of the National Statement and I am pleased to advise that the HREC has now granted ethical approval of this **multicentre** research project to be conducted at:

- Westmead Private Physiotherapy, Chief Investigator Mr John Breckenridge
- Norwest Orthopaedic and Sport Physiotherapy Principal Investigator Mrs Susan Stinton
- Central West Orthopaedic and Sports Physiotherapy Principal Investigator Mrs Susan Stinton
- Sports Physiotherapy and Work Rhabilitattion Centre Principal Investigator Mrs Susan Stinton
- University of Sydney Principal Investigator Mrs Susan Stinton

The following documentation has been reviewed and approved by the HREC:

- NEAF submission code AU/1/4EAC116

- Revised Protocol Version 2 dated 26 April 2015
- Revised Participant Information and Consent Form Version 2 dated 1 May 2015 2015
- DASH Questionnaire, version 1, dated 17 December 2014
- Advertisement, version 1, dated 17 December 2014
- Orthopaedic Surgeon Consent Form, version 1, undated

Please note the following conditions of approval:

- The Chief Investigator will immediately report anything which might warrant review of ethical approval of the project in the specified format, including unforeseen events that might affect continued ethical acceptability of the project.
- **For clinical trials of implantable medical devices only** – The Chief Investigator will confirm to the HREC that a process has been established for tracking the participant, with consent, for the lifetime of the device and will immediately report any device incidents to the Therapeutic Goods Administration (TGA).
- The Chief Investigator will immediately report any protocol deviation / violation, together with details of the procedure put in place to ensure the deviation / violation does not recur.
- The Chief Investigator will provide to the HREC in the specific format, proposed amendments to the research protocol or conduct of the research which may affect the ethical acceptability of the project, must be provided to the HREC to review in the specific format. Copies of all amendments when approved by the HREC must also be provided to the Research Governance Officer.
- The Chief Investigator must notify the HREC, giving reasons, if the project is discontinued at a site before the expected date of completion.
- The Chief Investigator must provide an annual report to the HREC and a final report at completion of the study, in the specified format. HREC approval is valid for 12 months from the date of final approval and continuation of the HREC approval beyond the initial 12 month approval period is contingent upon submission of an annual report each year. A copy of the Annual / Final Research Report Form can be obtained electronically from the Research Office on request.
- The HREC has the discretion to adopt other appropriate mechanisms for monitoring depending on the complexity, design and risk perceived including
    1. Discussion of relevant aspects of the project with investigators, at any time,
    2. Random inspection of research sites, data or consent documentation,
    3. Interview with research participants or other forms of feedback from them, and
    4. Request and review reports from independent agencies such as a Data Safety Monitoring Board.
- If your research project is an interventional trial, please ensure it is registered on one of the clinical trial registries, eg http://www.actr.org.au.
- It should be noted that compliance with the ethical guidelines is entirely the responsibility of the Chief Investigator.

You are reminded that this letter constitutes *ethical approval only*. You must not commence this research project at a site until separate authorisation from the Chief Executive or delegate of that site has been obtained. Copies of this letter, together with any approved documents as enumerated above, must be forwarded to all site investigators for submission to the relevant Research Governance Officer.

Should you have any queries about the HREC's Terms of Reference, Standard Operating Procedures or membership, please contact the Acting Research Ethics Manager through the Research Office on 9845 8183 or emailing kellie.hansen@health.nsw.gov.au.

In all future correspondence concerning this study, please quote approval number **(4220) AU RED HREC/15/WMEAD/52**

The HREC wishes you every success in your research.

Yours sincerely

[redacted]

Mrs Kellie Hansen
Research Ethics Manager
WSLHD Research & Education Network

Principal Investigator	Mr John Breckenridge
Study Title	When Can I Drive? Factors influencing driving performance following a wrist fracture: A prospective, cohort study

[redacted]

Professor Michael Kassiou

Associate Dean Research and Innovation
Faculty of Health Sciences

20th May, 2015

Human Research Ethics Committee
Research Office, Level 2, REN Building
Westmead Hospital, Hawkesbury and Darcy Roads
WESTMEAD NSW 2145

To Whom It May Concern:

RE: HREC Ref: (4220) AU RED HREC/15/WMEAD/52
Project title: "When Can I Drive? Factors influencing driving performance following a wrist fracture: A prospective, cohort study."

As a delegate from the Faculty of Health Sciences at the University of Sydney , being the Associate Dean Research and Innovation , I authorise the above research project to be conducted at the University of Sydney

Sincerley,

[redacted]

PROFESSOR MICHAEL KASSIOU
Associate Dean Research and Innovation
Faculty of Health Sciences, University of Sydney
75 East Street, Lidcombe NSW 2121
T: +61 2 9351 0849
E: michael.kassiou@sydney.edu.au

Physio
Central West Orthopaedic & Sports Physiotherapy Blacktown

Suite 203, 30 Campbell Street,
Blacktown NSW 2148

Ph 02 9672 3511
Fax 02 9672 4911
www.centralwestphysio.com.au

Western Sydney Local Health District Human Research Ethics Committee

4th February 2015

To Whom It May Concern:

RE: Proposed research study
'When Can I Drive? Factors influencing driving performance following a wrist fracture: A prospective, cohort study'.

Principle Researcher:
Susan Stinton
Associate researchers (student supervisors):
Dr Evangelos Pappas
Dr Niamh Moloney
Dr Dale Edgar

This letter is to confirm that as Principle Physiotherapist, Mungovan Breckenridge Physiotherapy & Associates, I have read the Scientific Protocol and I grant permission for the above research study to be conducted at Central West Orthopaedic and Sports Physiotherapy, Norwest Orthopaedic and Sports Physiotherapy and Westmead Private Physiotherapy services, pending approval by WSLHD Human Research Ethics Committee.

I understand that the study will be conducted by the above investigators, and will involve selected research subjects according to the stated inclusion criteria, and following provision of written informed consent.

I understand that the Principle Researcher, Susan Stinton, is completing this research as part of her post graduate research degree at the University of Sydney. The associate researchers are Susan's university supervisors.

[redacted]

Sean F. Mungovan
B.App.Sc.(Phty) MPhil
Principal Physiotherapist
Hon. Fellow University of Melbourne

John Breckenridge
B.Sc., Grad. Dip. Phty,
M.Hlth.Sc. (Sports Phty)
Principal Physiotherapist
APA Sports Physiotherapist
Hand Therapist CHT MAHTA

Kieran Lorraine
B. Health Sciences
B.App.Sc. (Phty)
Hand Therapy
Physiotherapist

Chris Wynne
B.App.Sc., M.Phty
Pilates Instructor
Physiotherapist

Julie Nguyen
B. Physiotherapy, CMP
Aquatic Therapy
Certified Mulligan Practitioner
Physiotherapist

Lillian Adjetey
B.Kine, B.Sc
M. Phty
Women's Health
Physiotherapist

Lee Corey
B.Med.Rad.(NM)
M.Phty
Pilates Instructor
Physiotherapist

Mathew Ah Chow
MN/B.App.Sc. (Ex. & Sport Sc.)
DPT
Physiotherapist

QIP ACCREDITED PHYSIOTHERAPY

Consent Form – Participant

Non-Interventional Study – *Adult providing own consent*

Title	When Can I Drive? Factors influencing driving performance following a wrist fracture: A prospective, cohort study.
Protocol Number	N/A
Coordinating Principal Investigator/ Principal Investigator	Susan Stinton
Location	Mungovan Breckenridge Physiotherapy & Associates and The University of Sydney

Part 1 What does my participation involve?

1 Introduction

You are invited to take part in this research project, *When Can I Drive? Factors influencing driving performance following a wrist fracture.* The research project aims to find out more about what indicates when it is safe to return to driving following a wrist fracture.

This Participant Information Sheet/Consent Form tells you about the research project. It explains the tests and research involved. Knowing what is involved will help you decide if you want to take part in the research.

Please read this information carefully. Ask questions about anything that you don't understand or want to know more about. Before deciding whether or not to take part, you might want to talk about it with a relative, friend or local doctor.

Participation in this research is voluntary. If you don't wish to take part, you don't have to. You will receive the best possible care whether or not you take part.

If you decide you want to take part in the research project, you will be asked to sign the consent section. By signing it you are telling us that you:
• Understand what you have read
• Consent to take part in the research project
• Consent to the tests and research that are described
• Consent to the use of your personal and health information as described.

You will be given a copy of this Participant Information and Consent Form to keep.

2 What is the purpose of this research?

Health professionals are commonly asked by patients at what point "it is safe" to return to drive a motor vehicle following their wrist fracture. This is a difficult question to answer because research and medical assessment guidelines in this area are lacking. The main aim of this study is to assist in the development of better guidelines on return to driving following a wrist fracture.

The results of this research will be used by the study physiotherapist, Susan Stinton, to obtain a Masters in Physiotherapy degree (by research). The study physiotherapist, Susan Stinton, has initiated this research. This research is being conducted through The University of Sydney and the Clinical Research Institute

Consent Form – Participant

Non-Interventional Study – *Adult providing own consent*

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3 What does participation in this research involve?

If you agree to participate in the study, you will be asked to sign the attached Written Informed Consent form. You will then be asked to attend on one or two occasions. Each occasion will take approximately one hour of your time. The study will be held at the Driving Lab at the University of Sydney, Camperdown campus.

On each visit to the driving lab there will be two parts of the test. The first section will involve filling out details about your age, fracture details, driving history and other information about your employment and hobbies, as well as two questionnaires that ask questions about your current level of function and about any pain you have in your wrist. A physiotherapist will measure the movement in your arm and your gripping strength. You will then be asked to take a quick test called "Recognise" which asks you to decide if images on a screen are of a left or a right hand.

The second part of the assessment will be done on a driving simulator which is a real *Smart Car*, linked to video screens and assessment devices. First you will need to show the physiotherapist that you can hold the steering wheel, use the indicators, the horn and the hand brake. If you are unable to do these tasks then you will not need to complete the next stage. If you are able to do these tasks, you will be given approximately 5 minutes to practise driving on the driving simulator. It is a bit like a car game in a video arcade. You will then be asked to drive through two driving circuits which take about 10 minutes each.

This research project has been designed to make sure the researchers interpret the results in a fair and appropriate way.

There are no costs associated with participating in this research project, nor will you be paid. You will be reimbursed for reasonable travel expenses to attend the Driving Lab at the University of Sydney.

Consent Form – Participant

Non-Interventional Study – *Adult providing own consent*

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4 What do I have to do?

You will be required to attend the driving laboratory at the University of Sydney Camperdown campus on one or two occasions. Each occasion will require approximately an hour of your time.

5 Other relevant information about the research project

We are aiming to have approximately 70 participants in this study. Half of the participants will have a wrist fracture, the other half are healthy participants. The participants who have a fractured wrist may receive physiotherapy treatment at a practice of their choice.

This assessment is not a legal test of driving ability, and will not be used to dictate your own driving ability. Your personal medical clearance to drive lies with your treating specialist.

6 Do I have to take part in this research project?

Participation in any research project is voluntary. If you do not wish to take part, you do not have to. If you decide to take part and later change your mind, you are free to withdraw from the project at any stage.

Your decision whether to take part or not to take part, or to take part and then withdraw, will not affect your routine treatment, your relationship with those treating you or your relationship with any of the members of the team at Westmead Private Physiotherapy Services.

7 What are the possible benefits of taking part?

We cannot guarantee or promise that you will receive any additional benefits from this research, however this study aims to improve our knowledge about recommendations on driving ability in people who have had a wrist fracture. It may inform future guidelines; however, there will be no clear additional benefit to you from your participation in this research.

9 What are the possible risks and disadvantages of taking part?

This research does not involve any treatment. You may experience some effects from the testing procedure, and they may be mild, moderate or severe

It is possible that you may feel pain in the driving assessment; similar to if you have done something too hard for your wrist to cope with. If you do feel pain during the driving assessment, you may stop the test at any point. To make sure your wrist will be able to cope with the assessment, you will be required to have consent from your wrist doctor prior to your first assessment.

Title	When Can I Drive? Factors influencing driving performance following a wrist fracture: A prospective, cohort study.
Protocol Number	N/A
Coordinating Principal Investigator/ Principal Investigator	Susan Stinton
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There may be side effects that the researchers do not expect or do not know about and that may be serious. Tell your study researcher immediately about any new or unusual symptoms.

If you have any side effects, talk with your study researcher. Your study researcher will also be monitoring you for possible side effects during the testing procedures to ensure your safety and comfort.

10 What if new information arises during this research project?

Sometimes during the course of a research project, new information becomes available about the treatment that is being studied. If this happens, your study physiotherapist will tell you about it and discuss with you whether you want to continue in the research project. If you decide to withdraw, your study researcher will make arrangements for your regular health care to continue. If you decide to continue in the research project you will be asked to sign an updated consent form.

Also, on receiving new information, your study doctor might consider it to be in your best interests to withdraw you from the research project. If this happens, he/ she will explain the reasons and arrange for your regular health care to continue.

13 What if I withdraw from this research project?

If you decide to withdraw from this research project, please notify a member of the research team before you withdraw. A member of the research team will inform you if there are any special requirements linked to withdrawing.

If you do withdraw your consent during the research project, the study researcher and relevant study staff will not collect additional personal information from you, although personal information already collected will be retained to ensure that the results of the research project can be measured properly and to comply with law. You should be aware that data collected by the researcher up to the time you withdraw will form part of the research project results. If you do not want them to do this, you must tell them before you join the research project.

14 Could this research project be stopped unexpectedly?

It is not expected that this research will stop before completion.

15 What happens when the research project ends?

If you give us your permission by signing the consent document, we plan to discuss/publish the results in a research article, which may be submitted for publication in a peer-reviewed journal. In any publication, information will be provided in such a way that you cannot be identified. Results of

Title	When Can I Drive? Factors influencing driving performance following a wrist fracture: A prospective, cohort study.
Protocol Number	N/A
Coordinating Principal Investigator/ Principal Investigator	Susan Stinton
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the study will be provided to you, if you wish. The conduct of this study also forms part of the research required for Susan Stinton's thesis for her postgraduate physiotherapy research degree at the University of Sydney.

Part 2 How is the research project being conducted?

16 What will happen to information about me?

By signing the consent form you consent to the study doctor and relevant research staff collecting and using personal information about you for the research project. Any information obtained in connection with this research project that can identify you will remain confidential. All results will be held securely at the University of Sydney for seven years, as required by the university, and data stored following completion of the study will be coded so that it is not be able to be identified.

It is anticipated that the results of this research project will be published and/or presented in a variety of forums. In any publication and/or presentation, information will be provided in such a way that you cannot be identified, except with your permission.

In accordance with relevant Australian and/or NSW privacy and other relevant laws, you have the right to request access to the information collected and stored by the research team about you. You also have the right to request that any information with which you disagree be corrected. Please contact the research team member named at the end of this document if you would like to access your information.

Any information obtained for the purpose of this research project that can identify you will be treated as confidential and securely stored. It will be disclosed only with your permission, or as required by law.

17 Complaints and compensation

Every reasonable precaution will be taken to ensure your safety during the course of this study. If you suffer any injuries or complications as a result of this study, you should contact the study researchers as soon as possible, who will assist you in arranging appropriate medical treatment. Compensation may be available if your injury or complication is sufficiently serious and is caused by unsafe equipment, or by the negligence of one of the parties involved in the study (for example, the researcher). If you receive compensation that includes an amount for medical expenses, you will be required to pay for your medical treatment from those compensation monies. You do not give up any legal rights to compensation by participating in this study.

If you are not eligible for compensation for your injury or complication under the law, but are eligible for Medicare, then you can receive any medical treatment required for your injury or complication free of charge as a public patient in any Australian public hospital.

Consent Form – Participant

Non-Interventional Study – *Adult providing own consent*

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18 Who is organising and funding the research?

This research project is being conducted by Susan Stinton, as part of her research degree through the University of Sydney.

The Australian Hand Therapy Association has provided a research grant to assist in the running costs of this project.

19 Who has reviewed the research project?

All research in Australia involving humans is reviewed by an independent group of people called a Human Research Ethics Committee (HREC). The ethical aspects of this research project have been approved by the HREC of the Western Sydney Local Health District.
This project will be carried out according to the National Statement on Ethical Conduct in Human Research (2007). This statement has been developed to protect the interests of people who agree to participate in human research studies.

Approval has been given by the Clinical Research Institute at Westmead Private Physiotherapy Services for supervising the standard of care where the research will be carried out.

Consent Form – Participant

Non-Interventional Study – *Adult providing own consent*

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20 Further information and who to contact

The person you may need to contact will depend on the nature of your query.
If you want any further information concerning this project or if you have any medical problems which may be related to your involvement in the project (for example, any side effects), you can contact the principal study researcher on 9633 1035 or any of the following people:

Clinical contact person

Name	Susan Stinton
Position	Principal researcher
Telephone	9633 1035 or 0413353572
Email	Sbla5337@uni.sydney.edu.au

For matters relating to research at the site at which you are participating, the details of the local site complaints person are:

Complaints contact person

Name	Sean Mungovan
Position	Westmead Private Physiotherapy Services
Telephone	02 9633 1035
Email	smungovan@pnc.com.au

If you have any complaints about any aspect of the project, the way it is being conducted or any questions about being a research participant in general, then you may contact The Secretary, WSLHD Human Research Ethics Committee, on (02) 9845 8183, or by email: researchoffice@swahs.health.nsw.gov.au

Thank you for taking the time to consider this study.

If you wish to take part in it, please sign the attached consent form.

This information sheet is for you to keep.

Consent Form - Participant

Title	When Can I Drive? Factors influencing driving performance following a wrist fracture: A prospective, cohort study.
Protocol Number	N/A
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Declaration by Participant

I have read the Participant Information Sheet or someone has read it to me in a language that I understand.

I understand the purposes, procedures and risks of the research described in the project.

I have had an opportunity to ask questions and I am satisfied with the answers I have received.

I freely agree to participate in this research project as described and understand that I am free to withdraw at any time during the project without affecting my future health care.

I understand that that this assessment is not a legal test of driving ability, and will not be used to dictate my own driving ability. My personal medical clearance to drive lies with my treating specialist.

I understand that I will be given a signed copy of this document to keep.

Name of Participant (please print) _____

Signature _____ Date _____

Name of Witness* to Participant's Signature (please print) _____

Signature _____ Date _____

* Witness is not to be the investigator, a member of the study team or their delegate. In the event that an interpreter is used, the interpreter may not act as a witness to the consent process. Witness must be 18 years or older.

Declaration by Study Physiotherapist/Senior Researcher†

I have given a verbal explanation of the research project, its procedures and risks and I believe that the participant has understood that explanation.

Name of Study Doctor/ Senior Researcher† (please print) _____

Signature _____ Date _____

† A senior member of the research team must provide the explanation of, and information concerning, the research project.

Note: All parties signing the consent section must date their own signature.

Form for Withdrawal of Participation

Title	When Can I Drive? Factors influencing driving performance following a wrist fracture: A prospective, cohort study.
Protocol Number	N/A
Coordinating Principal Investigator/ Principal Investigator	Susan Stinton
Location	Mungovan Breckenridge Physiotherapy & Associates and The University of Sydney

Declaration by Participant

I wish to withdraw from participation in the above research project and understand that such withdrawal will not affect my routine treatment, my relationship with those treating me or my relationship with Westmead Private Physiotherapy Services.

Name of Participant (please print) _____

Signature _____ Date _____

In the event that the participant's decision to withdraw is communicated verbally, the Study Researcher will need to provide a description of the circumstances below.

Declaration by Study Doctor/Senior Researcher†

I have given a verbal explanation of the implications of withdrawal from the research project and I believe that the participant has understood that explanation.

Name of Study Doctor/
Senior Researcher† (please print) _____

Signature _____ Date _____

Consent Form – Orthopaedic Surgeon

Study Title:	When Can I Drive? Factors influencing driving performance following a wrist fracture: A prospective, cohort study.
Chief Investigator :	Susan Stinton
Department:	Mungovan Breckenridge Physiotherapy & Associates University of Sydney

Declaration by Orthopaedic Surgeon

I have read and understand the processes of this study, as detailed in the Scientific Protocol.

I understand the purposes, procedures and risks of the research described in the project.

I have had an opportunity to ask questions and I am satisfied with the answers I have received.

I have treated the following participant for management of their wrist fracture with open reduction and internal fixation.

I freely give consent for the following participant to participate in this research project as described and understand that I am free to withdraw this consent at any time during the project.

Name of Participant (please print) _____

Name of Doctor/ (please print) _____

Signature _____ Date _____

Note: All parties signing the consent section must date their own signature

Research Study on Driving Following a Wrist Fracture

Study Title: When Can I Drive? Factors Influencing driving performance following a wrist fracture: a prospective, cohort study.
Pamphlet Version 2: Date 27/2/2016.

THE UNIVERSITY OF SYDNEY

Physio

Would you like to be involved in a study on driving following a wrist fracture?

Do you have a current driver's licence?

If you have answered yes to the above questions, you may be eligible to participate in a research study.

If you are interested in volunteering in this study, or if you would like further information please contact
Susie Stinton
Telephone: 9633 1035 or 0413 353 572
Email: sbla5337@uni.sydney.edu.au

The aims of this study are to:

1) Compare the driving performance of people who are recovering from a wrist fracture to people without a wrist injury
2) Find out when it is safe to return to driving following a wrist fracture

Participation in this study requires approximately 45-60 minutes of your time on two occasions. You will be assessed in a driving simulator at the University of Sydney. The driving simulator is a bit like a video game; but it uses video technology to assess driving performance. You will also have an assessment of your wrist and arm movement, strength and function.

Please note the driving assessment is NOT an actual driving test and should not be used by participants to determine their individual driving performance.

Participants may be reimbursed for reasonable travel related expenses to attend the Driving Lab at the University of Sydney. This reimbursement will be in the form of a Coles Myer voucher, up to the value of $30 per assessment attendance.

This research study is being conducted by Susie Stinton who is a physiotherapist at Mungovan Breckenridge Physiotherapy & Associates and a research student at the University of Sydney. This study has been approved by the WSLHD Human Research Ethics Committee.

Research Study on Driving Following a Wrist Fracture

Would you like to be involved in a study on driving following a wrist fracture?
Do you have a current drivers licence?

If you have answered yes to all of the above questions, you may be eligible to participate in a research study.

You may be reimbursed for reasonable travel expenses to attend the Driving Lab at the University of Sydney.

This research study is being conducted by Susie Stinton who is a physiotherapist at Mungovan Breckenridge Physiotherapy & Associates and a research student at the University of Sydney.

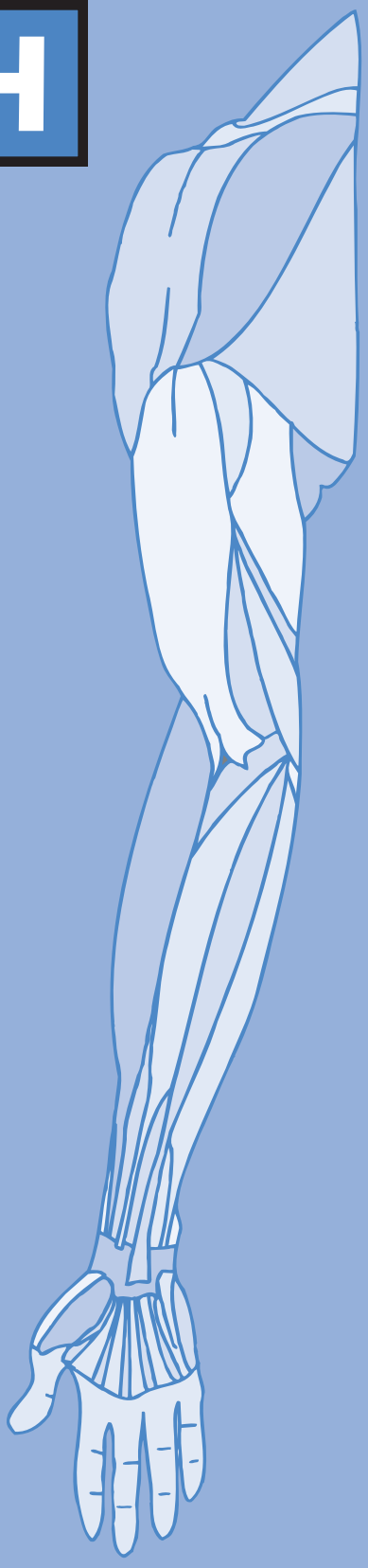
If you are interested in volunteering in this study, or if you would like further information please contact Susie Stinton Telephone: 9633 1035 or email: sbla5337@uni.sydney.edu.au

This study has been approved by the WSLHD Human Research Ethics Committee.

THE UNIVERSITY OF SYDNEY

Physio

THE DASH



INSTRUCTIONS

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

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

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

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

Disabilities of the Arm, Shoulder and Hand

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

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

Disabilities of the Arm, Shoulder and Hand

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

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

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

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

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

	STRONGLY DISAGREE	DISAGREE	NEITHER AGREE NOR DISAGREE	AGREE	STRONGLY AGREE
30. I feel less capable, less confident or less useful because of my arm, shoulder or hand problem. *(circle number)*	1	2	3	4	5

DASH DISABILITY/SYMPTOM SCORE = $\left[\left(\frac{\text{sum of n responses}}{n}\right) - 1\right] \times 25$, where n is equal to the number of completed responses.

A DASH score may <u>not</u> be calculated if there are greater than 3 missing items.

WORK MODULE (OPTIONAL)

The following questions ask about the impact of your arm, shoulder or hand problem on your ability to work (including home-making if that is your main work role).

Please indicate what your job/work is:_____

❒ I do not work. (You may skip this section.)

Please circle the number that best describes your physical ability in the past week. Did you have any difficulty:

	NO DIFFICULTY	MILD DIFFICULTY	MODERATE DIFFICULTY	SEVERE DIFFICULTY	UNABLE
1. using your usual technique for your work?	1	2	3	4	5
2. doing your usual work because of arm, shoulder or hand pain?	1	2	3	4	5
3. doing your work as well as you would like?	1	2	3	4	5
4. spending your usual amount of time doing your work?	1	2	3	4	5

SPORTS/PERFORMING ARTS MODULE (OPTIONAL)

The following questions relate to the impact of your arm, shoulder or hand problem on playing *your musical instrument or sport or both*. If you play more than one sport or instrument (or play both), please answer with respect to that activity which is most important to you.

Please indicate the sport or instrument which is most important to you:_____

❑ I do not play a sport or an instrument. (You may skip this section.)

Please circle the number that best describes your physical ability in the past week. Did you have any difficulty:

	NO DIFFICULTY	MILD DIFFICULTY	MODERATE DIFFICULTY	SEVERE DIFFICULTY	UNABLE
1. using your usual technique for playing your instrument or sport?	1	2	3	4	5
2. playing your musical instrument or sport because of arm, shoulder or hand pain?	1	2	3	4	5
3. playing your musical instrument or sport as well as you would like?	1	2	3	4	5
4. spending your usual amount of time practising or playing your instrument or sport?	1	2	3	4	5

SCORING THE OPTIONAL MODULES: Add up assigned values for each response; divide by 4 (number of items); subtract 1; multiply by 25.
An optional module score may <u>not</u> be calculated if there are any missing items.

Research Excellence
Advancing Employee
Health

[redacted] _____ [redacted] _____

PATIENT RATED WRIST EVALUATION

*The questions below will help us understand how much difficulty you have had with your wrist in the past week. You will be describing your **average** wrist symptoms **over the past week** on a scale of 0-10.* Please provide an answer for **ALL** questions. If you did not perform an activity, please **ESTIMATE** the pain or difficulty you would expect. If you have **never** performed the activity, you may leave it blank.

1. PAIN

Rate the **average** amount of pain in your wrist over the past week by circling the number that best describes your pain on a scale from 0-10. A zero **(0)** means that you **did not** have any pain and a **ten (10)** means that you had the **worst pain you have ever experienced** or that **you could not do the activity because of pain.**

RATE YOUR PAIN: Sample Scale ☞	0 1 2 3 4 5 6 7 8 9 10 No Pain — Worst Ever
At rest	0 1 2 3 4 5 6 7 8 9 10
When doing a task with a repeated wrist movement	0 1 2 3 4 5 6 7 8 9 10
When lifting a heavy object	0 1 2 3 4 5 6 7 8 9 10
When it is at its worst	0 1 2 3 4 5 6 7 8 9 10
How often do you have pain?	0 1 2 3 4 5 6 7 8 9 10 Never — Always

2. FUNCTION

A. SPECIFIC ACTIVITIES

*Rate the **amount of difficulty** you experienced performing each of the items listed below - over the past week, by circling the number that describes your difficulty on a scale of 0-10. A **zero** (0) means you did not experience any difficulty and a **ten** (10) means it was so difficult you were unable to do it at all.*

Sample scale →	0 1 2 3 4 5 6 7 8 9 10 No Difficulty — Unable To Do
Turn a door knob using my affected hand	0 1 2 3 4 5 6 7 8 9 10
Cut meat using a knife in my affected hand	0 1 2 3 4 5 6 7 8 9 10
Fasten buttons on my shirt	0 1 2 3 4 5 6 7 8 9 10
Use my affected hand to push up from a chair	0 1 2 3 4 5 6 7 8 9 10
Carry a 10lb object in my affected hand	0 1 2 3 4 5 6 7 8 9 10
Use bathroom tissue with my affected hand	0 1 2 3 4 5 6 7 8 9 10

B. USUAL ACTIVITIES

*Rate the **amount of difficulty** you experienced performing your **usual** activities in each of the areas listed below, over the past week, by circling the number that best describes your difficulty on a scale of 0-10. By "usual activities", we mean the activities you performed **before** you started having a problem with your wrist. A **zero** (0) means that you did not experience any difficulty and a **ten** (10) means it was so difficult you were unable to do any of your usual activities.*

Personal care activities (dressing, washing)	0 1 2 3 4 5 6 7 8 9 10
Household work (cleaning, maintenance)	0 1 2 3 4 5 6 7 8 9 10
Work (your job or usual everyday work)	0 1 2 3 4 5 6 7 8 9 10
Recreational activities	0 1 2 3 4 5 6 7 8 9 10

APPENDIX 5: PUBLISHED SUPPLEMENTARY MATERIAL FOR CHAPTER SIX

Supplementary Table 1:

Acute surgery groups for fracture fixation grouped according to Australians Classification of Health Intervention (ACHI) codes

Supplementary Table 2:

Concurrent wrist injury diagnosis ICD-10AM codes

Supplementary Table 3:

Complication diagnosis ICD-10AM codes

Supplementary Table 4:

Secondary procedure types according to ACHI codes

Supplementary Table 5:

Number of car crashes in the two years after wrist fracture

Supplementary Section 6:

Additional results

Supplementary Table 1: Acute surgery groups for fracture fixation grouped according to Australians Classification of Health Intervention (ACHI) codes

1) Closed reduction with internal fixation	
ACHI Code	Procedure Description
47381-02	Closed reduction of fracture of shaft of radius with internal fixation
47385-02	Closed reduction of fracture of shaft of radius with dislocation and internal fixation
47363-02	Closed reduction of fracture of distal radius with internal fixation
47381-03	Closed reduction of fracture of shaft of ulna with internal fixation
47385-03	Closed reduction of fracture of shaft of ulna with dislocation and internal fixation
47363-03	Closed reduction of fracture of distal ulna with internal fixation
47390-01	
47348-01	Closed reduction of fracture of carpus with internal fixation
47354-01	Closed reduction of fracture of carpal scaphoid with internal fixation
2) Open reduction with internal fixation	
ACHI Code	Procedure Description
47384-02	Open reduction of fracture of shaft radius with internal fixation
47366-02	Open reduction of fracture of distal radius with internal fixation
47384-03	Open reduction of fracture of shaft ulna with internal fixation
47366-03	Open reduction of fracture of distal ulna with internal fixation
47393-01	Open reduction of fracture of shaft of radius and ulna and internal fixation
47386-01	Open reduction of fracture of shaft of radius with dislocation and internal fixation
47386-03	
47351-01	Open reduction of fracture of carpus with internal fixation
47357-01	Open reduction of fracture of carpal scaphoid with internal fixation
3) Other (Open reduction with no fixation code and external fixation)	
ACHI Code	Procedure Description
47384-00	Open reduction of shaft of radius
47366-00	Open reduction of fracture of distal radius
47384-01	Open reduction of shaft of ulna
47366-01	Open reduction of fracture of distal ulna
47393-00	Open reduction of fracture of shaft of radius and ulna
47386-00	Open reduction of fracture of shaft of radius with dislocation
47386-02	Open reduction of fracture of shaft of ulna with dislocation
47351-00	Open reduction of fracture of carpus
47357-00	Open reduction of fracture of carpal scaphoid
50130-00	Application of external fixation devices, not elsewhere classified (may be listed in combination with an open or closed reduction code)

Supplementary Table 2: Concurrent wrist injury diagnosis ICD-10AM codes

Injury Type	**Description**	**ICD-10AM CODE(S)**
Skin laceration	Superficial injury of wrist and hand	S60.0, S60.1, S60.2, S60.7
	Other superficial injuries of wrist and hand	S60.81, S60.82, S60.84, S60.88, S60.89
	Open wound of wrist and hand	S61.0, S61.1, S61.7
	Open wound of other parts of wrist and hand	S61.81, S61.82, S61.88, S61.9
	Superficial injury of forearm	S50.0, S50.1, S50.7, S50.81, S50.82, S50.83, S50.84, S50.88, S50.9
	Open wound of forearm	S51.0, S51.7, S51.81, S51.82, S51.88, S51.9
	Superficial injuries involving multiple body regions	T00.2, T00.6
	Open wounds involving multiple body regions	T01.2, T01.6
Dislocation	Dislocation of wrist	S63.0, S63.00, S63.01, S63.02, S63.03, S63.04, S63.08
Ligament	Traumatic rupture of ligament of wrist and carpus	S63.3
	Sprain and strain of wrist	S63.50, S63.51, S63.52, S63.53, S63.58
Peripheral nerve	Injury of nerves at wrist and hand level	S64.0, S64.1, S64.2, S64.3, S64.4, S64.7, S64.8, S64.9
	Injury of nerves at forearm level	S54.0, S54.1, S54.2, S54.3, S54.7, S54.8, S54.9
Blood vessel	Injury of blood vessels at wrist and hand level	S65.0, S65.1, S65.2, S65.3, S65.4, S65.5, S65.7, S65.8, S65.9
	Injury of blood vessels at forearm level	S55.0, S55.1, S55.2, S55.7, S55.8, S55.9
Muscle/Tendon	Injury of muscle and tendon at wrist and hand level	S66.0, S66.1, S66.2, S66.3, S66.4, S66.5, S66.6, S66.7, S66.8, S66.9
	Injury of muscle and tendon at forearm level	S56.0, S56.1, S56.2, S56.3, S56.4, S56.5, S56.6, S56.7, S56.8
Crush	Crushing injury of wrist and hand	S67.0, S67.8
	Crushing injury of forearm	S57.0, S57.8, S57.9
Other	Other and unspecified injuries of forearm	S69.7, S59.8, S59.9
	Other and unspecified injuries of wrist and hand	S69.7, S69.8, S69.9

Supplementary Table 3: Complication diagnosis ICD-10AM codes

ICD-10AM CODE(S)	COMPLICATION DESCRIPTION
1 Bleeding complications	
T79.2	Traumatic secondary and recurrent haemorrhage
T81.0	Haemorrhage and haematoma complication a procedure, NEC
T84.81	Haemorrhage and haematoma following insertion of internal orthopaedic prosthetic devices, implants and grafts
2 Infection and wound complications	
T79.3	Post traumatic wound infection, NEC
T80.2	Infection following infusion, transfusion and therapeutic injection
T81.3	Disruption of operation wound, NEC
T81.4	Wound infection following procedure, NEC
T84.5	Infection and inflammatory reaction due to internal joint prosthesis
T84.6	Infection and inflammatory reaction due to internal fixation device (any site)
T84.7	Infection and inflammatory reaction due to internal orthopaedic prosthetic devices, implants and grafts
T89.0	Complication of open wound
T89.00	Complication of open wound, unspecified
T89.01	Open wound with foreign body (with or without infection)
T89.02	Complication of open wound with infection
T89.03	Other complications of open wounds (e.g., delayed healing, delayed treatment)
3 Ischemia of muscle	
T79.6	Traumatic ischemia of muscle (e.g., compartment syndrome)
4 Pain	
T81.81	Pain following a procedure, NEC
T84.83	Pain following insertion of internal orthopaedic prosthetic devices, implants and grafts
5 Failure and rejection and other complications of transplanted organs and tissues, NEC	
T86.84	Bone graft failure and rejection
T86.86	Skin graft and flap failure and rejection
6 Mechanical complications relating to surgery	
T84.0	Mechanical complication of internal joint prosthesis
T84.1	Mechanical complication of internal fixation device of bones of limb
T84.2	Mechanical complication of internal fixation device of other bones
T84.4	Mechanical complication of other internal orthopaedic devices, implants and grafts
T85.65	Mechanical complication of surgical material and sutures

7 Other complications of internal orthopaedic prosthetic devices, implants and grafts	
T84.82	Embolism and thrombosis following insertion of internal orthopaedic prosthetic devices, implants and grafts
T84.84	Sternosis following insertion of internal orthopaedic prosthetic devices, implants and grafts
T84.85	Metallosis following insertion of internal orthopaedic prosthetic devices, implants and grafts
T84.89	Other complication following insertion of internal orthopeadic prosthetic devices, implants and grafts
T84.9	Unspecified complication following insertion of internal orthopaedic prosthetic devices, implants and grafts
8 Sequelae of injuries, poisoning and other consequences of external causes	
T92.0	Sequalae of open wound of upper limb
T92.1	Sequelae of fracture of forearm and upper limb
T92.2	Sequalae of fracture at wrist and hand level
T92.3	Sequelae of dislocation, sprain or strain of upper limb
T92.4	Sequelae of injury of nerve of upper limb
T92.5	Sequalae of injury of muscle and tendon of upper limb
T92.6	Sequelae of crushing injury and traumatic amputation of upper limb
T92.7	Sequalae of unspecified injury of upper limb
T92.8	Sequalae of other specified injury of upper limb
T92.9	Sequalae of unspecified injury of upper limb
T98.1	Sequalae of other and unspecified events of external causes
T98.2	Sequalae of certain early complications of trauma
T98.3	Sequalae of complications of surgical and medical care, NEC

Supplementary Table 4: Secondary procedure types according to ACHI codes

1 Skin	
30026-00	Repair of wound of skin and subcutaneous tissue of other site, superficial
30029-00	Repair of wound of skin and subcutaneous tissue of other site, involving soft tissue
2 Muscle	
30235-00	Repair of ruptured muscle
47966-01	Transfer of muscle, NEC
90585-00	Reattachment of muscle, NEC
90586-00	Other plastic procedures of muscle, NEC
90583-01	Muscle graft, NEC
90582-02	Suture of muscle or fascia, NEC
90577-00	Procurement of muscle or fascia for graft
30238-00	Repair of fascia, NEC
90582-02	Suture of muscle or fascia, NEC
90547-00	Repair of muscle or fascia of hand, not elsewhere classified
3 Tendon	
90583-00	Tendon graft, NEC
46417-00	Transfer of tendon of hand
46426-00	Primary repair of flexor tendon of hand, proximal to A1 pulley
46429-00	Secondary repair of flexor tendon of hand, proximal to A1 pulley
46432-00	Primary repair of flexor tendon of hand, distal to A1 pulley
46435-00	Secondary repair of flexor tendon of hand, distal to A1 pulley
46420-00	Primary repair of extensor tendon of hand
46423-00	Secondary repair of extensor tendon of hand
47969-00	Tenosynovectomy, NEC
47966-00	Transfer of tendon or ligament, NEC
90575-00	Transposition of tendon, NEC
47963-01	Tenoplasty, NEC
90584-01	Reattachment of tendon, NEC
47954-00	Repair of tendon, NEC
47972-00	Open procedure of tendon sheath, NEC
47957-00	Lengthening of tendon, NEC
90578-00	Procurement of tendon for graft
90582-01	Suture of tendon, NEC
47963-02	Repair of tendon of hand, not elsewhere classified
90590-00	Tendon pulley reconstruction, NEC
46414-00	Insertion of artificial tendon prosthesis of hand (prior to tendon graft)
46408-00	Reconstruction of tendon of hand by tendon graft
4 Ligament or joint	
90589-01	Repair of ligament, NEC
50106-00	Joint stabilisation, NEC
49227-00	Arthroscopic pinning of osteochondral fragment of wrist (stabilisation of ligamentus disruption of wrist)
90582-00	Suture of ligament, NEC

49224-03	Arthroscopic chondroplasty of wrist
90542-00	Other repair of wrist
49215-00	Reconstruction of wrist
46445-00	Reconstruction of DRUJ
5 Peripheral nerve	
39300-00	Primary repair of nerve
39318-00	Nerve graft
39321-00	Transposition of nerve
39303-00	Secondary repair of nerve
90016-01	Other procedures on nerves
39324-00	Neurectomy of superficial peripheral nerve
39327-00	Neurectomy of deep peripheral nerve
39312-00	Open neurolysis of interfasicular peripheral nerve trunk
39330-00	Open neurolysis of peripheral nerve, not elsewhere classified
6 Osteotomy or osectomy	
48406-02	Osteotomy of radius
48409-02	Osteotomy of radius with internal fixation
48406-04	Osteotomy of ulna
48409-04	Osteotomy of ulna with internal fixation
48400-00	Osteotomy of accessory bone
90569-00	Osteotomy, NEC
50303-00	Correction of bony deformity
90605-00	Compression with distraction osteosynthesis
90605-01	Osteosynthesis, NEC
48406-03	Osectomy of radius
48409-03	Osectomy of radius with internal fixation
48406-05	Osectomy of ulna
48406-14	Ostectomy of carpal bone
48409-14	Ostectomy of carpal bone with internal fixation
48409-05	Osectomy of ulna with internal fixation
49224-02	Arthroscopic osteoplasty of wrist (includes excision of distal ulna)
48406-13	Osteotomy of carpal bone
48409-13	Osteotomy of carpal bone with internal fixation
7 Joint procedures (debridement, arthroscope, removal of loose bodies	
50102-00	Arthroscopic procedure on joint
49221-00	Arthroscopic drilling of defect of wrist
49221-01	Arthroscopic removal of loose body of wrist (arthroscopic removal of foreign body of wrist)
49212-00	Arthrotomy of wrist (removal of loose or foreign body)
90613-00	Arthroscopic procedure on joint, proceeding to open procedure
50100-00	Arthroscopy of joint, NEC
49218-00	Arthroscope of wrist
90608-01	Arthroscopic procurement of cartilage
90608-00	Procurement of cartilage
50104-00	Synovectomy of joint, NEC
50300-00	Transarticular fixation, NEC

90574-01	Excision of joint, NEC
8 Fusion	
49200-00	Arthrodesis of radiocarpal joint (includes bone graft, internal fixation or procurement of graft through same incision)
47726-00	Arthrodesis of radiocarpal joint (includes bone graft, internal fixation or procurement of graft through separate incision)
50109-00	Arthrodesis of joint, NEC
49203-00	Arthrodesis of intercarpal joint (includes bone graft)
49200-00	Arthrodesis of radiocarpal joint
47726-00	Arthrodesis of intercarpal joint (includes bone graft) with separate incision for bone graft material
9 Bone Graft	
48224-00	Bone graft to radius or ulna
48227-00	Bone graft to radius or ulna with internal fixation
48218-00	Bone graft to radius and ulna
48221-00	Bone graft to radius and ulna with internal fixation
48239-00	Bone graft, NEC
48242-00	Bone graft with internal fixation, NEC
48242-00	Bone graft with internal fixation, NEC
48230-00	Bone graft to scaphoid
48233-00	Bone graft to scaphoid with internal fixation
48236-00	Bone graft to scaphoid with internal fixation and osteotomy
48236-00	Bone graft to scaphoid with internal fixation and osteotomy
10 Fasciotomy	
47981-00	Decompression fasciotomy of forearm
47975-00	Decompression fasciotomy of forearm for acute compartment syndrome
47978-00	Decompression fasciotomy of forearm for chronic compartment syndrome
90567-00	Fasciotomy of upper limb ischemia
30226-00	Fasciotomy, NEC
90579-00	Fasciectomy, NEC
47981-02	Decompression fasciotomy of hand
11 Carpal tunnel release	
39331-00	Endoscopic release of carpal tunnel
39331-01	Release of carpal tunnel
12 Arthroplasty	
50127-00	Arthroplasty of joint, NEC
90597-00	Silastic replacement of distal ulna
46324-00	Arthroplasty of carpal bone (includes synovectomy and tendon transfer/realignment)
49206-00	Excision arthroplasty of wrist (includes proximal carpectomy or styloidectomy)
49209-00	Total arthroplasty of wrist
49200-00	Arthrodesis of radiocarpal joint (includes bone graft, internal fixation or procurement of graft through same incision)
47726-00	Arthrodesis of radiocarpal joint (includes bone graft, internal fixation or procurement of graft through separate incision)
46324-00	Arthroplasty of carpal bone (includes synovectomy and tendon transfer/realignment)
49206-00	Excision arthroplasty of wrist (includes proximal carpectomy or styloidectomy)
49209-00	Total arthroplasty of wrist

13 Synovectomy	
46342-00	Synovectomy of DRUJ
49224-01	Arthroscopic synovectomy of wrist
46348-00	Synovectomy of flexor tendon
46351-00	Synovectomy of flexor tendon, 2 digits
46354-00	Synovectomy of flexor tendon, 3 digits
46357-00	Synovectomy of flexor tendon, 4 digits
46460-00	Synovectomy of flexor tendon > 5 digits
46339-00	Synovectomy of flexor or extensor tendon of hand
14 Tenolysis and release of adhesions	
90540-00	Tenolysis of flexor or extensor tendon of forearm or wrist
49221-02	Arthroscopic release of adhesions of wrist
47960-00	Subcutaneous tenotomy, NEC
47963-00	Open tenotomy, NEC
90571-00	Division of adhesions of soft tissue, NEC
46363-00	Release of flexor sheath of hand
90544-00	Division of adhesions of hand (freeing of adhesions to the fascia, muscle or tendon NOS)
90544-00	Division of adhesions of hand (freeing of adhesions to the fascia, muscle or tendon NOS)
46453-00	Tenolysis of flexor tendon of hand
46453-00	Tenolysis of flexor tendon of hand
46450-00	Tenolysis of extensor tendon of hand
15 Debridement, aspiration or washout	
90573-00	Sequestrectomy of other and unspecified musculoskeletal site (eg antibiotic packing and drilling of bone)
90603-09	Sequestrectomy of radius (includes antibiotic packing and drilling of bone)
90603-10	Sequestrectomy of ulna (includes antibiotic packing and drilling of bone)
90603-11	Sequestrectomy of carpus (includes antibiotic packing or drilling of bone)
90603-09	Sequestrectomy of carpus (includes antibiotic packing or drilling of bone) with bone graft
90603-10	Sequestrectomy of carpus (includes antibiotic packing or drilling of bone) with bone graft - there are 2 codes for this, I'm not sure why)
49224-00	Arthroscopic debridement of wrist
47900-00	Aspiration of bone cyst
50124-00	Aspiration of joint or synovial cavity
90563-00	Aspiration of soft tissue
50103-00	Arthrotomy of joint, NEC
30225-00	Reinsertion of drainage tube into abscess
46519-00	Incision and drainage of middle palmar, thenar or hypothenar spaces of hand
30224-00	Percutaneous drainage of abscess of soft tissue
30223-03	Incision and drainage of abscess of soft tissue
30068-00	Incision and drainage of foreign body in soft tissue
30103-00	Excision of sinus involving soft tissue
30023-00	Excisional debridement of soft tissue
30023-01	Excisional debridement of soft tissue involving bone or cartilage
90580-00	Debridement of open fracture site
46525-00	Incision and drainage of paronychia of hand

46522-00	Incision and drainage of flexor sheath of hand
90545-00	Incision of soft tissue of hand
90545-00	Incision of soft tissue of hand
30216-00	Aspiration of haematoma of skin and subcutaneous tissue
30216-01	Aspiration of abscess of skin and subcutaneous tissue
30216-02	Other aspiration of skin and subcutaneous tissue
30223-00	Incision and drainage of hematoma of skin and subcutaneous tissue
30223-01	Incision and drainage of abscess of skin and subcutaneous tissue
30223-02	Other incision and drainage of skin and subcutaneous tissue
90661-00	Other incision of skin and subcutaneous tissue
90686-01	Non-excisional debridement of skin and subcutaneous tissue
90665-00	Excisional debridement of skin and subcutaneous tissue
16 Reduction of dislocation	
47024-02	Closed reduction of DRUJ
47024-03	Closed reduction of DRUJ with internal fixation
47027-02	Open reduction of DRUJ
47027-03	Open reduction of DRUJ with internal fixation
90541-00	Closed reduction of separated epiphysis of radius or ulna
90541-01	Open reduction of separated epiphysis of radius or ulna
17 Amputation	
44328-02	Disarticulation through wrist
44325-00	Midcarpal amputation
44325-01	Transmetacarpal amputation
18 Revision	
49210-00	Revision arthroplasty of wrist
49211-00	Revision arthroplasty of wrist with bone graft
19 Removal of hardware	
47921-00	Insertion of internal fix device, NEC, reinsertion or revision of internal fixation
50309-00	Adjustment of ring fixator
47927-00	Removal of pin, screw or wire, NEC
47930-00	Removal of plate, rod or nail, NEC
47948-00	Removal of ex fix device
20 Release of contracture	
50112-00	Division of joint contracture, NEC
90570-00	Division of joint capsule, ligament or cartilage, NEC
45515-01	Release of contracture of skin and subcutaneous tissue
45054-00	Escharotomy
21 Incision	
90568-00	Incision of muscle, NEC
90568-01	Incision of bursa, NEC
90568-02	Incision of soft tissue, NEC
22 Excision	
30229-00	Excision of muscle, NEC
90575-00	Excision of soft tissue, NEC
90582-02	Suture of muscle or fascia, NEC
23 Vascular repair	
45500-00	Microsurgical repair of artery of distal extremity or digit

45500-01	Microsurgical repair of vein of distal extremity or digit
45500-02	Microsurgical repair of artery and vein of distal extremity or digit
45502-00	Microsurgical anastomosis of artery
45502-01	Microsurgical anastomosis of vein
45502-02	Microsurgical anastomosis of artery and vein
45503-00	Microsurgical graft of artery and vein
45503-01	Microsurgical graft of vein
45503-02	Microsurgical graft of artery and vein
24 Flaps and grafts	
90670-00	Allograft
90671-00	Xenograft
90672-00	Synthetic skin graft
45400-00	Splint skin graft to small granulating area
45403-00	Split skin graft to extensive granulating area
45488-00	Split skin graft to other sites
45406-00	Split skin graft to other sites
45409-00	Split skin graft to other sites
45412-00	Split skin graft to other sites
45415-00	Split skin graft to other sites
45418-00	Split skin graft to other sites
45460-00	Split skin graft to other sites
45464-00	Split skin graft to other sites
45468-00	Split skin graft to other sites
45471-00	Split skin graft to other sites
45474-00	Split skin graft to other sites
45477-00	Split skin graft to other sites
45480-00	Split skin graft to other sites
48483-00	Split skin graft to other sites
45458-05	Small split skin graft of sites
45448-06	Small split skin graft of thumb
45448-07	Small split skin graft of finger
45439-00	Small split skin graft of other site
45442-00	Extensive split skin graft of any site
45445-00	Split skin graft as an inlay graft
45451-05	Full thickness skin graft of hand
45451-06	Full thickness skin graft of thumb
45451-07	Full thickness skin graft of finger
45451-09	Full thickness skin graft of other site
45018-00	Dermis graft
45206-05	Local skin flap of hand
45206-06	Local skin flap of thumb
45206-07	Local skin flap of finger
45200-00	Local skin flap of other site
45230-00	Delay of direct distant skin flap
45221-01	Direct distant skin flap, first stage
45224-01	Direct distant skin flap, second stage
45230-01	Delay of indirect distant skin flap

45227-00	indirect distant skin flap, formation of tubed pedicle
45236-00	indirect distant skin flap, spreading of tubed pedicle
45233-00	Indirect distant skin flap, prep, transfer and attachment to intermediate site
45233-01	Indirect distant skin flap, prep, transfer and attachment to final site
45018-01	Dermofat graft
45018-02	Fat graft
45018-03	Fascia graft
45015-01	Delay of myocutaneous flap
45003-01	Myocutaneous flap
45015-00	Delay of muscle flap
45009-01	Muscle flap
45563-00	Island flap with vascular pedicle
45563-01	Island flap with neuromusclar pedicle
45562-00	Non-innvervated free flap
45562-01	Innervated free flap
25 Revision or removal of plastic procedures	
45239-00	Revision of local skin flap
45239-01	Revision of direct distant skin flap
45239-02	Revision of indirect distant skin flap
45496-00	Open revision of free tissue flap
45497-00	Complete revision of free tissue flap by liposuction
45498-00	Revision of free tissue flap by liposuction, first stage
45499-00	Revision of free tissue flap by liposuction, second stage
90659-00	Excision of flap monitoring tissue

Supplementary Table 5: Number of car crashes in the two years after wrist fracture

	Number of car crashes (% of group)
0-3 months	138 (12.9%)
3-6 months	130 (12.0%)
6-9 months	142 (13.1%)
9-12 months	148 (13.7%)
12-15 months	128 (11.8%)
15-18 months	149 (13.8%)
18-21 months	128 (11.8%)
21-24 months	118 (10.9%)
Total	1081 (100%)

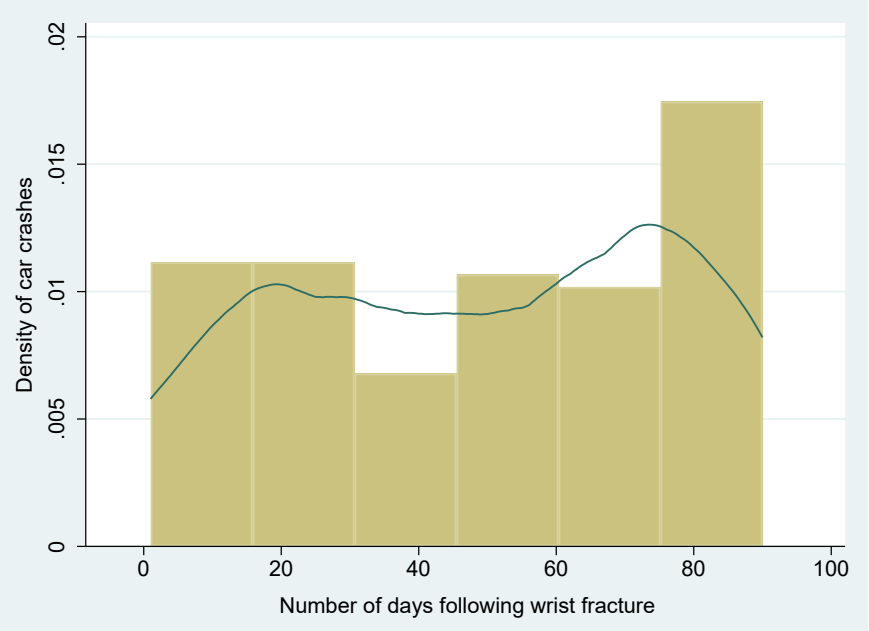
Supplementary Section 6: Additional results

Secondary analysis was conducted of car crash distribution among those with isolated wrist fracture, compared to those with concurrent injury to the wrist or elsewhere in the body (i.e., multi-trauma injury patterns). Cox proportional hazards modelling confirmed that after accounting for age, sex and behavioural factors, those with multi-trauma injury patterns were more likely ($p<0.001$) to crash earlier in their recovery compared to those with isolated wrist fractures. The number of car crashes in the first quarter of the year following the fracture date was almost double the number of crashes occurring in the remaining nine months of the first year for those with more severe wrist fracture injury patterns (Supplementary *Table 4*).

Supplementary Table 6: Number (%) of crashes in the first year following wrist fracture for those with isolated wrist fractures and for those with concurrent multi-trauma injury patterns

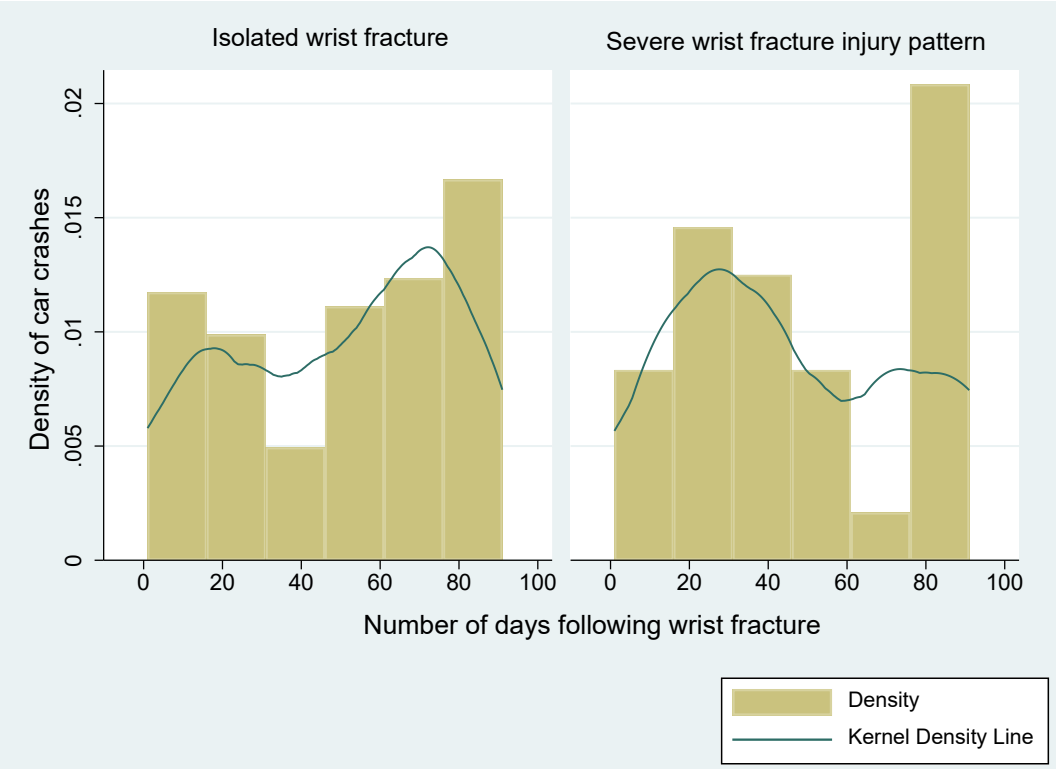
Time post fracture	Crashes among those with multi trauma (n=56)	Crashes among those with isolated wrist fracture (n=341)
0-3 months	19 (39.3%)	86 (22.4%)
3-6 months	10 (20.2%)	90 (22.4%)
6-9 months	10 (20.2%)	107 (28%)
9-12 months	10 (20.2%)	108 (27%)

Supplementary Figure 1a: Car crashes in the first 3 months following wrist fracture date, illustrated on a Kernel Density plot



**Density relates to the proportion of those involved in a car crash on each day after wrist fracture*

Supplementary Figure 1b: Car crashes in the first 3 months following wrist fracture date, comparing those with multi-trauma injuries to those with isolated wrist fracture injuries as illustrated on a with a Kernel Density plot



**Density relates to the proportion of those involved in a car crash on each day after wrist fracture*