Diagnostic accuracy in the clinical examination for identifying a triangular fibrocartilage complex injury

Rebecca Tuhi

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Supervisors

Dr Steven White

Dr Julie Collis

Associate Professor Alain Vandal

Abstract

TFCC injuries are a common cause of ulnar wrist pain, which can impact patients' functional ability and quality of life. In Aotearoa, New Zealand patients with musculoskeletal injuries, such as wrist injuries are often initially assessed and treated by hand therapists and physiotherapists. As part of assessment and diagnosis procedures, clinical diagnostic tests are routinely used to either confirm or exclude suspicions. Despite their widespread use, the supporting literature is not favourable in regards to their usefulness. A systematic review of the literature highlights the high reliability of diagnostic tests for TFCC injuries. However, their ability to either exclude or confirm TFCC injuries is limited, and there is a lack of a conclusive singular diagnostic test that can accurately do both. To date, there has not been any study that has investigated both the reliability and diagnostic accuracy of multiple TFCC diagnostic tests or investigated a combination of clinical factors that could improve predictability of TFCC injuries.

A prospective pilot study was undertaken. Twenty-three participants were recruited from Auckland-based hand orthopaedic specialists and prospectively assessed to determine inter-rater reliability and diagnostic accuracy of individual TFCC diagnostic tests and a range of clinical parameters. The tests were compared against the criterion measure of specialist diagnosis based on MRI scans. This pilot study indicated that the accuracy of TFCC diagnostic tests were limited, with many tests failing to meet acceptable thresholds for diagnostic accuracy statistical metrics, and not being statistically significant. Overall, several tests indicated moderate usefulness for confirming TFCC injuries but limited usefulness for excluding such injuries. The ulnar fovea sign test had 0.50 sensitivity, 0.57 specificity. The piano key test had high specificity and positive predictive (PPV) values of 100%, but low sensitivity value of 0.13. The shear test had high specificity (0.86) and positive likelihood ratio (LR+) of 3.06. The grind test had sensitivity of 0.50, specificity at 0.86, LR+ of 3.50, negative likelihood ratio (LR-) of 0.58, PPV of 89%, negative predictive value (NPV) of 43%. The GRIT test specificity of 0.14, sensitivity of 0.56, LR+ 3.06, LR– 0.66 and NPV of 13%.

A concurrent reliability study of 20 participants showed high levels of inter-rater reliability for the grind, ulnar fovea sign and piano key TFCC diagnostic tests with 0.57,

0.57 and 0.51 kappa scores. The shear test had the lowest levels of inter-rater reliability at 0.01. GRIT had an intra-class correlation of 0.60, and standardised grip strength in neutral was 0.88.

The results of this pilot study have reinforced the inability of a singular diagnostic test to accurately determine TFCC injuries, but a combination of nine variables within the clinical examination has shown to increase the predictability of TFCC injuries. These were: being of male gender, strain mechanism of injury, the presence of constant symptoms, presence of crepitus, pain intensity with pronation-based ADLS, presence of pain with supination-based ADLS, passive radial deviation and pronation range of motion, and grip strength in a neutral position. This model was shown to accurately predict the presence of a TFCC injury, in this participant cohort.

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Attestation of Authorship statement

I hereby declare that this submission is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person (except where explicitly defined in the acknowledgements), nor material which to a substantial extent has been submitted for the award of any other degree or diploma of a university or other institution of higher learning

Signed _____

Date 26th November 2022

Acknowledgements

Ehara taku toa i te toa takitahi, engari kē he toa takitini

My success should not be bestowed onto me alone, it was not individual success but the success of a collective

Undertaking this journey would have not been achievable without my whānau. To my husband, Hayden thank you for your unwavering support and belief that whatever we set our mind to, we can achieve. At times, the journey seems never ending, and has had many challenges, but together we have always found a way through. Whatever the future brings, having you there by my side we can overcome and achieve anything. To our son Cohen, who made his debut halfway through this thesis; I know that this journey took precious time away from you at such a vital time in your life. This was a double edge sword, trying to be the example of always striving towards your dreams, but also giving everything, you need and deserve. But this journey showed me balance is possible with focus, planning and the value of a community. Our extended whānau, in particular our parents, who have graciously taken Cohen, whilst I have had to focus and spend time studying, have been a blessing.

I have been so fortunate to have the guidance and expertise of my supervisors; Dr Steve White, Dr Julie Collis and Professor Alain Vandal. Steve and Julie, you have pushed me academically and professionally. You've asked the hard questions, encouraged me out of my comfort zone, you've made me think bigger yet also reigned me in and made more refined. At times it was hard and it was frustrating, but without your nudging I would not have gotten this to where it is today. Alain, your expertise has been invaluable and your statistical input has elevated this study. Thank you for your guidance and patience.

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Mutu-Grigg, Mr Albert Yoon, a special thanks for your time, expert opinion and recruiting participants. Your reception team have been instrumental in collating all required paperwork. Without the generous financial support from Hand Therapy New Zealand for both participants and my research assistance, as well as At Therapy with their generous loan of equipment, this project would not have been possible. Thank you for supporting our field and the development of research in New Zealand.

Ethics

Ethical approval for this study was granted on the 28th of March 2019 by the Auckland University of Technology Ethics Committee (reference19/74). Copies of ethical approval, participant information sheets, participant brochures, expression of interest forms, screening questionnaires and consent forms are included in Appendices C, D, E, F, G, H.

List of Abbreviations

ACC	Accident compensation corporation
AROM	Active range of motion
CT	Computer tomography
DRUJ	Distal radioulnar joint
ECU	Extensor carpi ulnaris
GRIT	Gripping rotatory impaction test
ICC	intraclass coefficient
IOM	Interosseous membrane
LR-	Negative likelihood ratio
LR+	Positive likelihood ratio
K	Kappa
MRA	Magnetic resonance angiography
MRI	Magnetic resonance imaging
NPRS	numeric pain rating scale
NPV	Negative predictive value
NRT	Negative reference test
PABAK	Prevalence-Adjusted Bias-Adjusted Kappa
PPV	Positive predictive value
PRISMA	Preferred Reporting Items for Systematic reviews and Meta-Analyses
PROM	Passive range of motion
PRT	Positive reference test
PQ	Pronator quadratus
QUADAS	Quality Assessment of Diagnostic Accuracy Studies-Comparative
RUCJ	Radioulnar carpal joint
Sn	Sensitivity
Sp	Specificity
T	Tesla
TFCC	Triangular Fibrocartilage Complex
UCJ	Ulnocarpal joint
95% CI	95% confidence interval

Chapter 1: Introduction

1.1 Structure of the thesis

The thesis is structured as follows. Chapter one introduces the thesis, its aims and structure. Chapter two is a narrative review of the TFCC that provides background information on the relevant anatomy and biomechanics of the TFCC. This chapter also outlines the problems of TFCC injuries, including the mechanisms of injury, demographics, and injury classification. It presents key information about the diagnostic process of TFCC injuries, including diagnostic tests and the commonly used investigation methods. Chapter three identifies and critically reviews existing studies that have explored the reliability and diagnostic accuracy of TFCC diagnostic tests, and the use of MRI to diagnose TFCC injuries in a systematic review. This chapter justifies the pilot study and helps to establish the use of MRI as an appropriate criterion measure. Chapter four describes a pilot study that first examines the validity of individual diagnostic tests for the diagnosis of a traumatic TFCC injury. Second, it investigates if a combination of clinical factors improves the ability to predict a traumatic TFCC injury. Finally, chapter five summarises the thesis and discusses the implications for clinical practice. The thesis concludes with recommendations for future research.

1.2 The problem

Wrist injuries can have a debilitating impact on a patient's quality of life and mental well-being, by causing pain and the loss of function, leading to limitations in their ability to work and participate in recreational activities (Roux et al., 2005). Wrist sprains are a common complaint in Aotearoa, New Zealand, with 59,360 new cases and 72,053 active cases recorded in 2021 (Accident Compensation Corporation, 2021), costing a total of NZD $112,358.396. The majority (33,412) of new cases in 2021 were fall-related accidents, 16,288 were sports-related and 7,598 were work-related. Ulnar-sided wrist pain is frequently caused by damage to the triangular fibrocartilage complex (TFCC) that occurs secondary to a traumatic injury. There is limited published epidemiological data on TFCC injuries in New Zealand; however, a 2017 audit undertaken by this author of a Auckland hand therapy clinic identified 150/1467 patients with suspected TFCC injuries over a four-month period (Tuhi, 2019).

In Aotearoa, New Zealand physiotherapists and hand therapists are often the primary health providers diagnosing and treating wrist sprains, rather than general practitioners (GP) or orthopaedic specialists. Although specialist referral is sometimes needed for further investigation of magnetic resonance imaging (MRI) or arthroscopy, the majority of patients are diagnosed and treated entirely by physiotherapists or hand therapists. The clinical diagnosis of TFCC injuries is based on patients' history, clinical presentations, and diagnostic tests. Current research suggests that TFCC diagnostic tests may have limited usefulness and, as a result, lead to inaccurate diagnoses. Therapists must be confident in their abilities and in the use of assessment tools to correctly diagnose injuries and, accordingly, implement appropriate treatment strategies. The research in this thesis investigates the reliability, diagnostic accuracy of clinical tests, and therapists' ability to predict TFCC injuries based off the clinical assessment.

1.3 Background

Diagnostic tests are routinely used as part of a clinical examination to aid the identification of the source of musculoskeletal pain, dysfunction and disability. The accuracy of these tests determines the utility of the information obtained from them. A test with poor accuracy has limited clinical usefulness in diagnosing or excluding pathologies. The implication of an incorrect diagnosis is the execution of an incorrect management pathway. This may include referral for unwarranted investigations, subsequent intervention with unnecessary or inappropriate treatment methods and potentially suboptimal or prolonged recovery (Friedman & Khan, 2019).

The TFCC is a multicomponent structure located over the ulnar aspect of the wrist. It plays a predominant role in wrist stability by allowing the wrist to have a wide and multi-directional movement range, and for the hand to grasp, load and transfer weight. Injury to the TFCC can occur by falling onto the hand or through loading in an end-range wrist position (Jawed et al., 2020). TFCC injuries are often associated with pain, restricted movement and impaired grip strength, thereby impacting patients' functional ability.

As part of the diagnosis process, therapists routinely use diagnostic tests in patients with ulnar-sided wrist pain to assist in differentiating between structures and

confirming the presence of a TFCC injury (Pang & Yao, 2017). Health professionals must have confidence in these tests. There is limited research concerning the clinical utility of wrist diagnostic tests, despite their extensive clinical use. Two existing systematic reviews (Andersson et al., 2015; Valdes & LaStayo, 2013) investigated the accuracy of diagnostic tests involving the upper limb. Based on their review, Andersson et al., (2015) concluded that diagnostic tests were of limited diagnostic value in determining TFCC-specific injuries. This supported the conclusion of an earlier review by Valdes and LaStayo (2013), who concluded that the majority of diagnostic tests, in particular those that were wrist-related, did not have adequate research evidence to justify their clinical use. These reviews were well-conducted but broad in scope and included multiple pathologies and upper limb regions, including the wrist, hand, thumb, and elbow. As a result, they both failed to report detailed information of use to clinicians, specific to the diagnosis of a TFCC injury. These systematic reviews also failed to evaluate the reliability of the included diagnostic tests. In addition, no individual papers or reviews have considered or evaluated the use of multiple diagnostic tests, or other clinical elements to increase predictability of TFCC injuries.

The current accepted gold standard for the diagnosis of TFCC injuries is direct visualisation through arthroscopic investigation (Andersson et al., 2015; Prosser et al., 2011). However, this does not reflect current clinical practice in Aotearoa, New Zealand, where MRI is routinely used to diagnose TFCC injuries, for those patients referred to an orthopaedic specialist. There is substantial evidence that supports the use of MRI to diagnose TFCC injuries (Deyle, 2011; Skalski et al., 2016; Smith et al., 2012) . Although both arthroscopy and MRI may each be considered ‘the best’ diagnostic tool, both have substantial cost implications, and arthroscopy has additional risks associated with the surgical procedure involved (Smith et al., 2012). Many patients are not referred to specialists and have higher level investigations, and diagnosis of a TFCC injury is made solely by a physiotherapist or hand therapist. The ability to diagnose TFCC injuries using diagnostic tests can reduce the risks and costs associated with higher level investigative methods. The use of clinical diagnostic tests will also likely lead to a more timely diagnosis and, as a result, more appropriate treatment for patients with TFCC injuries.

Although diagnostic tests are widely used by physiotherapists and hand therapists, there is no conclusive evidence that these tests have significant clinical value for detecting TFCC injuries. Given the emphasis that is placed on diagnostic tests in the diagnostic process for therapists, especially for those therapists and patients who do not have direct access to high-level imaging or investigative methods, the clinical utility of these tests is crucial. The current recommendations are limited by the available research on diagnostic TFCC tests. The need for prospective studies investigating the clinical utility of individual tests, and identifying other predictors of TFCC injury, will be directly beneficial to clinicians in terms of aiding in the diagnostic process and patient management.

1.4 Research aims

The purpose of this research is to extend the body of knowledge on the diagnosis of a traumatic TFCC injury. Accordingly, this research investigates the following questions:

1. How reliable are diagnostic tests for detecting TFCC injuries?
2. How accurate are diagnostic tests for detecting TFCC injuries?
3. What combination of information gathered from the clinical assessment increases predictability of TFCC injuries?

1.5 Significance of the research

This research will impact both clinicians who treat ulnar-sided wrist pain and patients that experience this condition. The recommendations presented in this thesis are intended to aid therapists' ability to correctly diagnose traumatic TFCC injuries, thereby providing a solid foundation for correct patient management. This should increase therapists' confidence to pursue conservative management strategies, if appropriate. This aspect will benefit therapists who have had minimal exposure to wrist injuries in their clinical practice and will allow those who do not have access to hand surgeons or MRI facilities to conduct a comprehensive diagnostic exam. Correct diagnosis and implementation of treatment strategies would ensure that patients are treated in the most appropriate way, optimising patient recovery from injury and return to their baseline function.

Chapter 2: The TFCC

2.1 Introduction

This chapter provides key background information for this research. It describes the anatomical and biomechanical influences of the TFCC, injuries to the TFCC, terminology, epidemiological data, mechanisms of injury, classification systems and the process for diagnosing TFCC injuries.

2.2 The TFCC

The TFCC is a multi-component structure that sits across the ulnar aspect of the distal wrist and involves both the distal radioulnar joint (DRUJ) and the ulnocarpal joint (UCJ). It lies between articular surfaces of the radius, ulna and the lunate and triquetral carpal bones. The integrity of the TFCC is vital for ensuring a full range of pain-free movement and wrist stability during loaded or gripping tasks (Sachar, 2008). The wrist is an inherently unstable anatomical structure that gains stability via surrounding ligaments and muscles (Altman, 2016). In addition, there are specific joints that provide muscular attachments and muscles that dynamically support and stabilise the TFCC and ulnar wrist, which will be described in the following section.

2.2.1 Components of the TFCC

The structures that make up the TFCC are the triangular fibrocartilage (TFC) disc, the radioulnar and ulnocarpal ligaments, the meniscus homologue and the subsheath of the extensor carpi ulnaris (ECU) tendon (Palmer & Werner, 1981), as shown in Figure 1 and Figure 2. These structures will be described with relevance to TFCC injury.

Figure 1.

An axial *illustration of the TFCC*

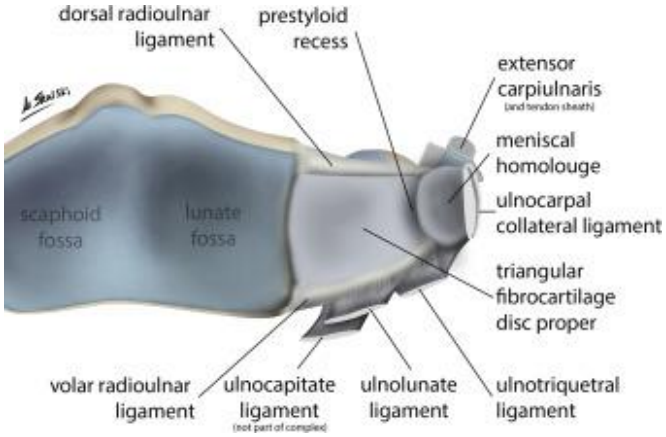

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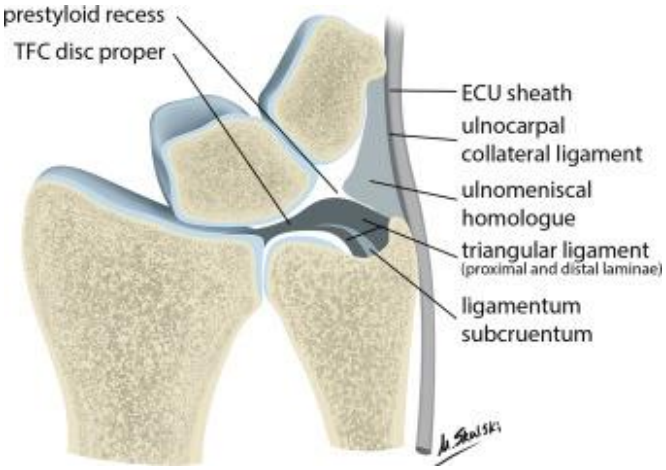
Figure 2.

The mid-coronal section of the TFCC



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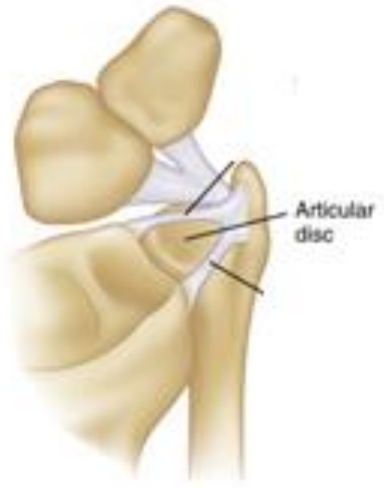
The TFC disc

The TFC disc (shown in Figure 3), is considered the largest portion of the TFCC (Skalski et al., 2016). It sits across the distal articular surface of the ulna, arising from the sigmoid notch of the radius, covers the distal ulna and inserts into the ulnar styloid process and fovea (Nakamura et al., 2001). It is divided into central and peripheral portions, an important division for the healing of TFC injuries (Kirchberger et al., 2015; Shin et al., 2004). Approximately 10-40% of the TFCC is well-vascularised, including the peripheral, volar, medial and dorsal margins, through the volar and dorsal radiocarpal

branches of the ulnar artery, and the dorsal and volar branch of the anterior interosseous artery (Bednar et al., 1991; Mikić, 1992; Thiru et al., 1986). Conversely, the more central structures, particularly the central TFC disc, are avascular, which has a negative impact on its ability to regenerate and heal following an injury (Casadei & Kiel, 2020).

Figure 3.

The TFC disc



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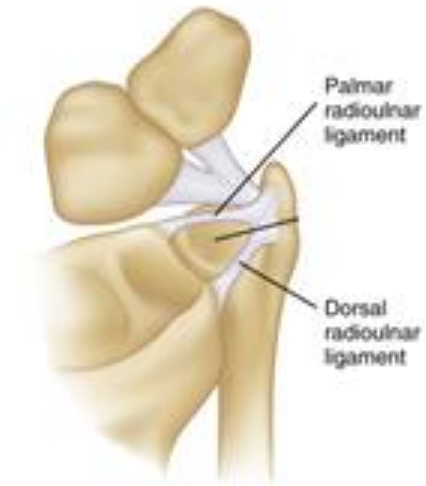
Radioulnar ligaments

The radioulnar ligaments (shown in Figure 4) sit across the dorsal and volar aspects of the DRUJ. They lie within a transverse plane, arising from the radial sigmoid notch and attaching to the base of the ulnar styloid process (Skalski et al., 2016). The radioulnar ligaments are divided into deep and superficial fibres, with two separate insertion points on the ulna (Thomas & Sreekanth, 2012). The deep radioulnar ligament fibres are known as the ligamentum subcruentum, which insert into the ulnar fovea, whereas the superficial fibres insert into the base of the ulnar styloid (Kleinman, 2007; Shin et al., 2004). Reciprocal tightening and slacking of the volar and dorsal DRUJ ligaments which occur during the arc of rotation movement, aids with joint stability (Altman, 2016).

Figure 4.

Radioulnar ligaments



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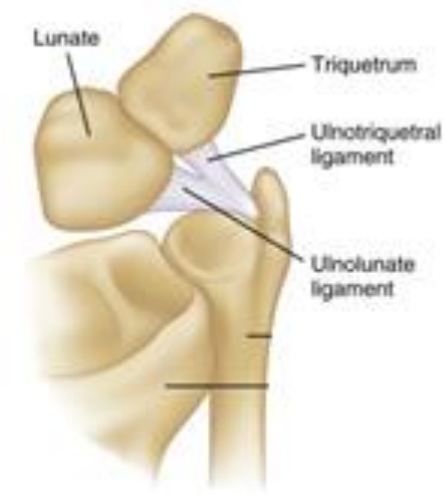
Ulnocarpal ligaments

The extrinsic ulnocarpal ligaments comprise the ulnotriquetral, ulnocapitate and ulnolunate ligaments. As shown in Figure 5, these three ligaments arise as a single unit from the ulnar fovea and the base of the ulnar styloid, then divide into a fan shape and attach onto the base of the triquetrum, capitate, and lunate bones respectively (Moritomo, 2013). The ulnocarpal ligaments are primary stabilisers of the volar aspect of the ulnocarpal joint (Shin et al., 2004), which is realized by limiting dorsal ulnar translation forces (Moritomo, 2013).

Figure 5.

Ulnocarpal ligaments



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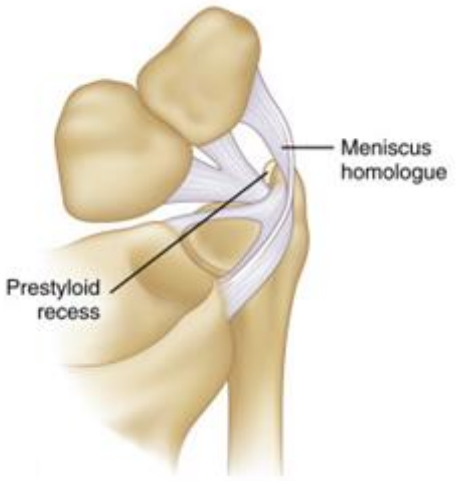
Meniscus Homologue

The meniscus homologue (Figure 6) is thickened fibrous tissue located between the ulnar styloid process and the triquetrum (Buck et al., 2009). The role of the meniscus homologue in the TFCC is not well-understood, and its anatomical properties have been debated. Its anatomical connections to the dorsal radioulnar ligament and ECU sheath suggest that it has a suspensory role and provides additional stability to the TFCC (Nakamura & Yabe, 2000).

Figure 6.

Meniscus Homologue



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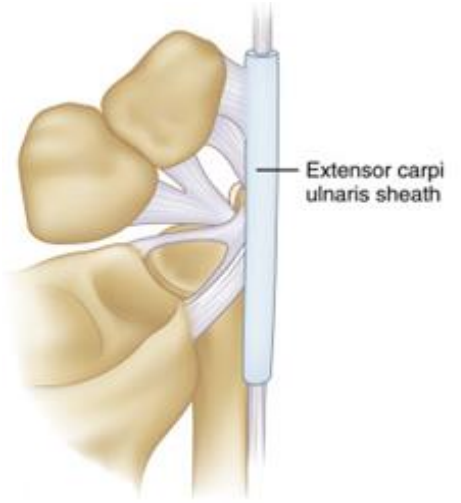
The ECU subsheath

The ECU tendon sheath is a band of connective tissue 1.5–2 cm in length that encases the ECU tendon at the level of the distal ulna (Maffuli et al., 2005). It sits on the dorsal–ulnar border of the TFCC, having ascended through the sixth dorsal extensor compartment (Pang & Yao, 2017). As shown in Figure 7 it is located deep within the extensor retinaculum and is attached to the ulna (Campbell et al., 2013). Its role within the TFCC is to provide stability to the complex's lateral border and reduce friction for ECU (Moore et al., 2006).

Figure 7.

The ECU sheath



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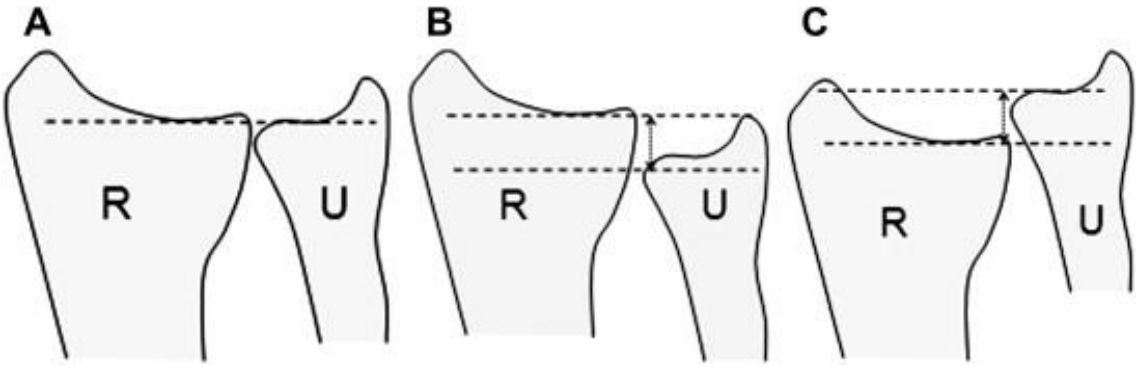
2.2.2 Articulations relevant to the TFCC

The DRUJ serves as an articulation between the distal aspect of the radius and the ulna. In conjunction with the proximal radioulnar joint, it permits movement in the transverse plane, including forearm rotation into supination and pronation positions (Kleinman, 2007). The DRUJ aids in the transmission of the load from the carpal bones to the radius and ulna. Weight is predominately loaded onto the radius at approximately 80%, compared to onto the ulna at 20% (Palmer, 1987). This ratio is significantly impacted by the degree of ulnar variance and the integrity of the TFCC and DRUJ ligaments. Ulnar variance is the position of the ulna in relation to the radius (De Smet, 1994). As shown in Figure 8, typically, the distal ulna is in line with the radius. A positive variance is determined if the level of the ulna is more than 2.5mm beyond the radial margin of the radius at the DRUJ; conversely, a negative variance occurs when the ulna is 2.5mm below the radial margin (Cerezal et al., 2002). Ulnar variance can be idiopathic or acquired through trauma causing osseous shortening, such as with a distal radius fracture (Biswas, 2015).

Figure 8.

Ulnar variance



Note: Reprinted from: Pitfalls of Wrist MR Imaging. Malone, W. James, DO, Magnetic Resonance Imaging Clinics of North America, Volume 18, Issue 4, 643-662. (A–C) Neutral, negative, and positive ulnar variance, respectively. R, radius; U, ulna. Copyright (2010), with permission from Elsevier.

The presence of a positive ulnar variance can make the TFCC vulnerable to both acute and chronic articular disc injuries (Casadei & Kiel, 2020). Positive ulnar variance places an increased load on the TFCC, which can often lead to pain and functional limitations especially in a pronated position (Jawed et al., 2020).

2.2.3 Muscles supporting the TFCC

Dynamic stability of the ulnar wrist and the TFCC is generated through ECU and pronator quadratus (PQ) (Altman, 2016). ECU stabilises the ulnar wrist, through lifting and depressing the ulnar head during rotation (Altman, 2016; Campbell et al., 2013; Ghatan et al., 2016; Spinner & Kaplan, 1970). PQ aids dynamic stability through compressing the ulnar into the radius during rotation (Altman, 2016; Johnson & Shrewsbury, 1976; Sakamoto et al., 2015; Stuart, 1996). The interosseous membrane (IOM), a broad ligamentous structure, prevents the separation of the radius and ulna during load or movement (Matthias & Wright, 2016; McGinley & Kozin, 2001; Rabinowitz et al., 1994; Shepard et al., 2001).

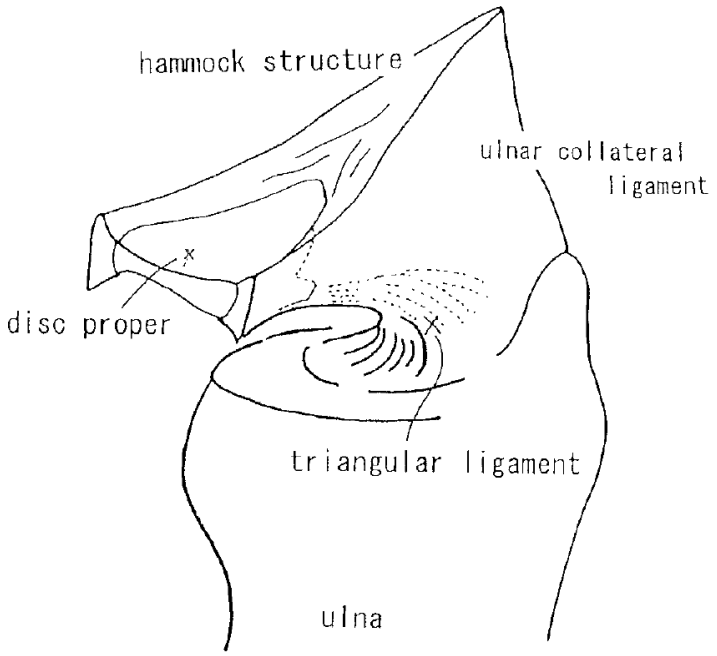
2.2.4 The function of the TFCC

The TFCC is a key structure in the wrist that primarily serves to stabilise the DRUJ and UCJ (Nakamura, Yabe, & Horiuchi, 1996; Shin et al., 2004). A secondary role of the TFCC is shock absorption and force transmission through the ulna and the ulnar aspect of the carpus (Kirchberger et al., 2015; Palmer & Werner, 1981).

The TFCC is a complex structure that to date is not entirely understood. Several analogies have been used to aid in better understanding the anatomy and function of the TFCC. The 'hammock concept' was used by Nakamura et al. (1996), in which the authors separated the TFCC into three distinct components. As shown in Figure 9, the proximal portion refers to the proximal triangular ligament (also referred to as the ligamentum subcruentum), the distal hammock structure of the TFC disc and the ulnar collateral ligament. In the hammock analogy, the three components work together to provide suspension which, with firm insertion points and a looser internal structure, allows for both mobility and stability.

Figure 9.

The TFCC hammock concept



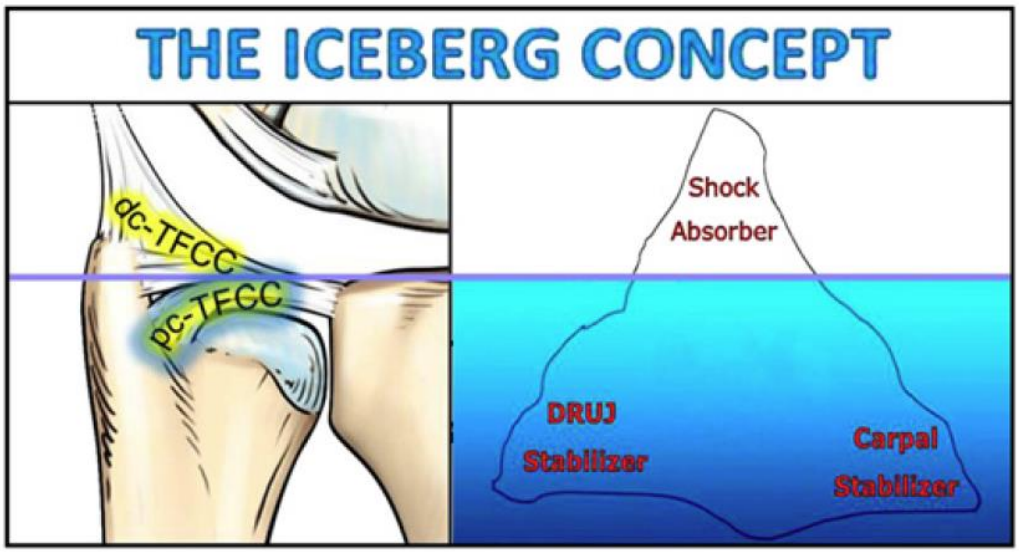
Note: Reprinted from: Functional anatomy of the triangular fibrocartilage complex. Nakamura, T., Yabe, Y., & Horiuchi, Y. The Journal of Hand Surgery: British & European Volume, 21(5), 581-586. Copyright (1996), with permission from Elsevier.

More recently, an 'iceberg concept' was used to describe the TFCC (see Figure 10) (Atzei & Luchetti, 2011). In this analogy, the TFCC is represented by a triangular-shaped iceberg. The apex of the iceberg is the distal portion of the TFCC, which comprises the ulnar collateral ligaments and the TFC disc proper, which is responsible for shock absorption. The larger submerged portion of the iceberg refers to the foveal insertions of the TFCC (also comprising the proximal TFCC structures), including ligamentum subcruentum and DRUJ ligaments. The structures in submerged portion of the iceberg

are responsible for DRUJ and carpal stabilisation, which is considered to have greater functional importance, than the protruding part of the iceberg.

Figure 10.

The iceberg concept applied to the TFCC



Note: Reprinted from: Foveal TFCC tear classification and treatment. Atzei, A., & Luchetti, R. *Hand Clinics, 27*(3), 263-272. Copyright (2011), with permission from Elsevier.

2.3 Injuries to the TFCC

As previously described, the TFCC plays a significant role in wrist stability, shock absorption and force transmission. Injury to the TFCC not only has pain implications but can also have a significant impact on upper limb function, particularly with gripping, loading and weight-bearing activities. This section discusses the terminology associated with TFCC injuries as well as established epidemiological data on this injury population. Additionally, the mechanisms of injury and the classification of TFCC injuries will be presented.

2.3.1 TFCC injury terminology

The term 'TFCC injury' is used in the literature to describe both acute traumatic injuries and degeneration of the TFCC. It can also refer to the injury of any of the multiple structures that comprise the TFCC complex. The focus of this thesis is on traumatic TFCC injuries. In this section, I define the term 'traumatic TFCC injury'.

'Traumatic injury' refers to a sequalae of events causing an immediate onset of symptoms. The New Zealand Accident Compensation Corporation (ACC) defines an

accident or trauma as ”the application of force or resistance external to the human body, or a sudden movement of the body to avoid a force or resistance” (Accident Compensation Act 2001, p.63). It is a specific identifiable event, with a specific point in time, rather than a gradual process or onset of symptoms. The terms ‘acute’, ‘subacute’ and ‘chronic’ denote the time since the onset of an injury or symptoms. The definitions of these timeframes vary in the literature and according to regions of the body and pathology. Acute timeframes range between one to six weeks, while for chronic injury, timeframes range from four weeks to six months (Flint et al., 2013). Within New Zealand, the ACC defines ‘acute’ in the context of lower back pain as pain that has been present for up to three months (Accident Compensation Corporation, 2004), but fails to provide a framework for ‘acute’ vs ‘chronic’ for wrist and hand injuries.

In this thesis the term ‘traumatic TFCC injury’ will be used to specifically describe damage to the TFCC as the result of a sudden, definable incident. TFCC degeneration, is not the focus of the present thesis and will not be further discussed. This thesis is confined to a focus on traumatic injuries. This is because degenerative injuries are less commonly observed in community-based hand therapy clinics, which predominately have an ACC caseload.

2.3.2 Mechanism of TFCC injury

TFCC injuries can be sustained as a result of multiple mechanisms of injury, such as a fall onto an outstretched hand (FOOSH) with the forearm in a pronated position (Doarn & Wysocki, 2016). Activities that involve rotation and compressive loads using the wrist in an ulnar deviated position are also likely to cause TFCC injuries (Palmer, 1990). This position is common in manual tasks such as hammering, digging or using screwdrivers, as well as in sporting activities, such as racquet sports, e.g. tennis, baseball or golf (Cober & Trumble, 2001; Doarn & Wysocki, 2016). The additional impact of the ball or ground can often also cause injury to the TFCC. Everyday tasks, such as the lifting or dropping of heavy items using the wrist in a non-neutral position may overload specific TFCC structures and cause injury.

2.3.3 Prevalence and Incidence of TFCC injuries

The epidemiology of TFCC injuries within New Zealand has to date not been reported. Internationally, there is a paucity of studies defining the demographics or characteristics of people with TFCC injuries. Additionally, there is no data on the relationships between TFCC injuries and patient characteristics, such as ethnicity, occupation, or participation in sporting activities.

Some relevant data are available from ACC, whose statistics report 59,360 new claims for all soft tissue injuries of the wrist for the 2021 calendar year (Accident Compensation Corporation, 2021). Combined with active claims, the ACC reported a total cost for treatment of these injuries as NZD$112,358,366. Active claims for 2021 had 38,830 payments for radiology, including high-tech imaging services. Physiotherapy and hand therapy services payments totalled NZD$39,439 (Accident Compensation Corporation, 2021). These costs encompass all wrist injuries, however, and are not specific for TFCC damage, as these are not reported as an individual category. A four-month audit of clinical caseloads was undertaken by this author (Tuhi, 2019) from September to December 2017 of a large hand therapy practice in central Auckland (Handworks) identified 150/1,467 (10%) new patients who presented with ulnar wrist pain. The male-to-female ratio was evenly spread (72 males, 78 females). The majority (97 patients, 65%) of patients injured their dominant hand and the mean age was 39 years with a range of 13–82 years. Of these 150 patients, 38 (25%) were referred for further investigation and underwent MRI. Of those referred, approximately 75% had a TFCC injury confirmed by MRI.

TFCC injuries combined with osseous injuries have been reported, most commonly with distal radius fractures. Triangular fibrocartilage complex injuries associated with distal radius fractures have been reported to be present in 35–78% of cases (Geissler et al., 1996; Lindau et al., 2000). More recently Yan et al. (2019) reported a 96% incidence rate of TFCC injuries in patients with a known distal radius fracture. However, these authors reported no significant relationship between the degree of TFCC injury or the type of distal radius fracture, or the presence of an ulnar styloid fracture or DRUJ instability.

Age is also reported to have a significant impact on TFCC injury rates, with prevalence rates increasing with older age (Chan et al., 2014; Lordache et al., 2012). Chan et al. (2014) reported that in patients 30 years and younger, there was a 27% prevalence rate of TFCC injury, compared to 49% in those above the age of 70. This correlates well with the known anatomical avascular nature of the TFC disc and its lack of regenerative properties. However, the true rates of traumatic injuries are unknown, with studies failing to discriminate between traumatic and degenerative TFCC injuries. Likely, traumatic injuries are more common in a younger population, while the risk of degenerative injuries increases with age.

2.3.4 Classification of TFCC injury

Various classification systems have been proposed for TFCC injuries. Some are TFCC-injury specific, such as those devised by Palmer (1989) and Atzei and Luchetti (2011), while others are more generalised classifications, such as the Outerbridge (1961) classification, which describes the quality of joint cartilage. The Palmer (1989) and Atzei and Luchetti (2011) classification systems provide consistency in terms of describing TFCC injuries, and they are used in both research and clinical domains. An advantage of these systems is that they are useful for describing MRI findings, as well as those derived via direct visualisation, e.g., arthroscopy, thereby providing consistency through multiple methods of investigation.

The most commonly used system is the Palmar (1989) classification system. This classification divides TFCC injuries into traumatic injuries (type 1) and pathological changes (type 2), as shown in Table 1. Type 1 TFCC injuries are further divided according to injury location. Type 2 originally described the increasing severity of pathological changes that occurred with ulnar impaction, but despite the original intentions of Palmer, type 2 is frequently referred to as ‘degeneration’. Differing terms have been used to refer to type 1 injuries, including ‘tear’, ‘lesion’ or ‘sprain’. Throughout this thesis, the term ‘injury’ will be used. The most common TFFC injury is often reported as being a type 1B, a traumatic tear where the TFCC is torn from its attachment at the base of the ulna styloid as a result of a sudden movement or force (Nozaki et al., 2017). Other studies have reported type 1A as the most common, which occurs when there is an isolated central disc perforation (Schmauss et al., 2016).

Table 1.

The Palmar classification system

Type	Description
Type 1	
1A	Central TFC perforation
1B	Ulna TFC avulsion +/– ulna styloid fracture
1C	Distal TFC avulsion +/– disruption of distal ulnocarpal ligaments
1D	Radial TFC avulsion +/– sigmoid notch fracture
Type 2	
2A	TFC wear
2B	TFC wear + lunate and/or ulna chondromalacia
2C	TFC perforation + lunate and/or ulnar chondromalacia
2D	TFC perforation + lunate and/or ulnar chondromalacia + lunate triquetral ligament perforation
2E	TFC perforation + lunate and/or ulnar chondromalacia + lunate triquetral ligament perforation + ulnocarpal arthritis

Note: TFC – triangular fibrocartilage

Reprinted from: Triangular fibrocartilage complex lesions: A classification. Palmer. A. K. *Journal of Hand Surgery America.* 21(5), 581-586 Copyright (1989), with permission from Elsevier.

The Palmer classification has been validated against MRI. These validation studies showed excellent intra-rater and good inter-rater reliability (Nozaki et al., 2017; Oneson et al., 1996). The review conducted by Smith et al. (2012) showed reasonable rates of sensitivity and specificity with use of the Palmer classification with MRI, but noted that this method performed at greater field strengths had increased accuracy values compared to those performed at lower field strengths. While the Palmar classification is commonly used, there are some limitations to it. In particular, it is limited by its strict division of type 1 and 2 categories. It has been reported that traumatic lesions often cannot be distinguished from degenerative or pre-existing lesions (Atzei & Luchetti, 2011). Additionally, the Palmar classification does not differentiate between the structures that comprise the TFCC. In this thesis, the Palmer (1989) classification system will be used to classify TFCC injuries, given its widespread use and proven clinical utility.

2.4 Diagnosis of TFCC injury

This section discusses the process of diagnosing a TFCC injury. I will firstly discuss factors that influence the initial assessment and the formulation of differential diagnoses. Following on, I will outline the patient interview, the physical assessment, and finally, differential diagnoses.

The goal of a musculoskeletal assessment is to identify the causes of pain, impairment and dysfunction and often serves as the foundation for decision making in clinical practice (Croft et al., 2015; Mustafa et al., 2017). The diagnostic process can generate large volumes of information to determine a specific pathology or condition. Knowledge, clinical experience, and clinician critical thinking can influence the utility of this information. It should highlight the patient's history and experience, as well as symptomatic and mechanical responses to load to reduce uncertainty, establish the nature and severity of an injury and the potential causes of injury or dysfunction.

2.4.1 Patient interview

The patient interview is the foundational basis of the physical assessment (Cadogan et al., 2013) and includes determining the history and mechanism of pain/injury, patient's symptoms, and functional limitations and goals for treatment/recovery. The specific biomechanical force that caused the injury is important to note as it may help to differentiate a TFCC injury from injury to other ulnar wrist structures (Read, 2013).

Patients with a suspected TFCC injury will typically complain of ulnar-sided wrist pain that is aggravated by rotation/deviation movement and activity. They may also complain of weakness when gripping, instability or crepitus (Casadei & Kiel, 2020). These symptoms may be present over the dorsal, medial or volar aspect of the ulnar wrist. The onset of symptoms may be immediate or progressive in nature; this difference in onset may allude to acute injuries compared to repetitive force or degenerative injuries. The frequency, intensity and duration of symptoms are important to note. Questioning whether the patient has any functional impairments will often highlight aggravating biomechanical stressors. In the case of TFCC injuries, gripping and twisting actions, such as opening a door or pouring water from a jug can often aggravate an injury, as can weightbearing tasks, e.g., pushing up from the floor or a chair (Palmer, 1990).

The numerical pain rating scale (NPRS) is a common measure used to quantify pain intensity. Rated 0-10, indicating no pain to the worst pain possible. The NPRS can be utilised to measure pain intensity with different variables, such as pain intensity variation during a 24-hour period, or with specific activities or with elements of the clinical examination such as ROM or diagnostic tests. The NPRS has been shown to have sufficient reliability and validity for self-reported pain intensity (Hawker et al., 2011).

2.4.2 Physical assessment

The clinical examination is a key component in the diagnosis of TFCC injuries. Diagnostic tests are used to determine the likelihood of the presence or absence of an a specific condition (Parikh et al., 2008). Depending on the desired effect, a diagnostic test may refer to the reproduction of familiar pain, instability, fear or apprehension, neural symptoms, or strength limitations. The response to a particular test can be either negative or positive, and the definition of a 'positive' or 'negative' test can vary across assessments. Many diagnostic tests are pain provocations tests (PPT). A positive PPT is defined as one that reproduces or increases familiar pain or symptoms, by two points on the NPRS. A negative PPT is defined as a test that does not reproduce or increase familiar symptoms or pain (Laslett et al., 2005). Familiar pain was defined by Laslett et al. (2005, p.209) as "pain verified by the patient as being the complaint that has led the patient to seek diagnosis and treatment". Multiple diagnostic tests are available that aim to determine TFCC injuries; these are outlined in Appendix A. Diagnostic tests can be used individually or in combination with one another. Reliance on a single test for making a diagnosis is not always recommended because of insufficient clinical accuracy (Alqarni et al., 2011). Therefore, clinicians often use a combination of diagnostic tests, frequently referred to as clusters. In this context, a cluster effect is when multiple tests are used together to increase the likelihood of correctly predicting or excluding an injury (Hegedus et al., 2015). Cluster effects have been well established for shoulder and sacroiliac joints (Biederwolf, 2013; Saueressig et al., 2021) but have yet to be established for the TFCC.

2.4.3 Investigations

Imaging is considered a valuable component of the diagnostic process, despite strong evidence of a poor correlation between a patient's symptoms and structural

abnormalities observed via medical imaging (Wheeler et al., 2018). Multiple forms of imaging techniques are utilised to investigate suspected TFCC injuries, including plain radiography, computer tomography (CT), MRI, magnetic resonance arthrography (MRA) and arthroscopy (Shin et al., 2004; Watanabe et al., 2010). No one imaging modality demonstrates perfect accuracy (Treiser et al., 2018), however arthroscopy which allows for clear visualisation and testing of the TFCC, is considered to be the gold standard for TFCC injury diagnosis (Andersson, Andernord, et al., 2015b; Prosser et al., 2011). Despite this, arthroscopy is not routinely used by hand surgeons in Aotearoa New Zealand as a first-line diagnostic investigation (Heiss-Dunlop, personal communication, 2 October 2018). Many specialists prefer MRI, which is less invasive, less costly, relatively accessible, and has been shown to be an effective imaging modality for diagnosing TFCC injuries (Crues & Bydder, 2007; Skalski et al., 2016; Smith et al., 2012).

The timing of a specific method of investigation is at the discretion of healthcare specialists making the referral for investigation. X-rays are considered as being the backbone of medical imaging and are typically the first line of investigation for musculoskeletal pain or injury, to determine any abnormality from the standardised anatomy. As such, they are commonly performed at the time of injury (Copeland & Byerly, 2021). In comparison, arthroscopy, MRI and MRA, which provide more detailed information on soft tissue structures, tend to be conducted at a later date. This timeframe is broad in scope and to some degree dependent on being referred to a specialist service. However, despite varying timeframes, multiple authors have reported that there is no difference in long-term outcomes related to early imaging for musculoskeletal conditions (Carey, 2009; Chou et al., 2009; Wheeler et al., 2018).

2.5 Summary

Wrist sprains, including TFCC injuries, have a substantial rate of prevalence in Aotearoa New Zealand with high associated costs that include radiological services and post-injury rehabilitation. The epidemiological data specifically for TFCC injuries are lacking; nonetheless, there is a reported increase in TFCC injuries with distal radius fractures and in older adults. Currently, the epidemiology and prevalence of patients presenting with TFCC injuries are unknown.

This chapter summarised current concepts pertaining to the anatomy and biomechanics of the TFCC, the diagnosis of a TFCC injury, including specifics undertaken during patient interview, objective assessment, diagnostic tests and types of investigations utilised. The following chapter presents an evaluation and discussion of the current literature as it concerns the efficacy of provocation tests and MRI for TFCC diagnosis.

Chapter 3: Systematic Reviews

3.1 Introduction

This chapter investigates the literature that has considered the reliability and diagnostic accuracy of TFCC diagnostic tests, as well as the efficacy of MRI in the diagnosis of TFCC injuries. The chapter starts by providing an overview of the statistical metrics that are used to determine the reliability and accuracy of diagnostic tests. It outlines the systematic literature review that was undertaken and discusses its results. The chapter concludes by discussing the recommendations for clinical practice, based on these results.

3.2 Statistical metrics

A diagnostic test can be evaluated according to numerous characteristics. These features, such as reliability and accuracy, can influence the quality of test results and subsequent recommendations. This section provides an overview of common statistical metrics that are used within efficacy studies. The aim of doing so, is to provide the reader with a better understanding of the technical terminology used in subsequent chapters.

3.2.1 Reliability

Reliability refers to the consistency of a test, or how reliable a test will be after it is repeated by the same or another clinician. Reliability can be categorised as intra or inter-rater reliability; the former refers to the consistency and ability of the test to produce the same results on more than two occasions by the same assessor, while the latter is the consistency between different assessors' assessments of the same patient.

Common statistical analyses for reliability include the kappa coefficient (k) and the intra-class correlation coefficient (ICC). Cohen's kappa coefficient is used for determining intra-rater and inter-rater reliability and indicates the agreement between two sets of collected data while considering the possibility of chance. Prevalence-adjusted bias-adjusted kappa (PABAK) is also used to measure inter-rater reliability. It adjusts kappa values to account for any imbalances caused by the differences in the prevalence and bias (Byrt et al., 1993). K-values can range from –1 to 1, where 1 represents perfect agreement between the raters, 0 indicates the level of agreement

no better than that expected from a random chance, and –1 indicates great disagreement between the raters. The strength of agreement will be described according to Landis and Koch (1977), with k values <0.00 classified as poor, 0.00-0.20 slight, 0.21-0.40 fair, 0.41-0.60 moderate, 0.61-0.80 substantial and 0.81-1.0 almost perfect. The ICC is an index that determines reliability by reflecting the degree of correlation, as well as the agreement, between measurements (Koo & Li, 2016). It refers to correlations within a class of data, e.g. between repeated assessments (Liljequist et al., 2019), and typically ranges from 0 to 1. If the ICC is below 0.5, it is considered to have poor reliability. Conversely, ICC values above 0.8 or 0.9 are indicative of measurements with good or excellent reliability, respectively (Koo & Li, 2016). For the purpose of this review, the threshold of acceptable ICC and k-values are set at 0.80 and 0.40, respectively.

3.2.2 Diagnostic accuracy

'Diagnostic accuracy' refers to the ability of a test to determine the presence or absence of a targeted condition (Šimundić, 2009). There are several different measures of diagnostic accuracy, including sensitivity, specificity, likelihood ratios and predictive values.

Sensitivity

Sensitivity values refer to the results in cases where patients were correctly diagnosed through the screening test, as having the stated diagnosis. A sensitivity test reflects a positive result in patients who are known to have the specified condition (Trevethan, 2017). In perfect sensitivity (100%), the result is always positive if the patient has the condition (it will never be negative if they have the condition). Therefore, a negative test infers exclusion of the condition. For example, with a sensitivity of 80% for 100 patients with the condition, 80 patients will have the condition, and 20 patients will have a false-negative test result. A test with high sensitivity is useful for 'ruling out' or excluding a diagnosis if the screening test is negative. The SNOUT ('Sensitive test when Negative rules OUT the disease') acronym is a useful tool for remembering the key features of sensitivity for diagnostic tests. Using the method indicated by SNOUT can indicate if a test has high sensitivity and, accordingly, if a negative result is obtained using the test, the condition can be ruled out (Davidson, 2002).

Specificity

Specificity values identify individuals without the identified condition who have been correctly identified by a screening test having a negative diagnosis (Trevethan, 2017). A test with high specificity aids in 'ruling in' or confirming a diagnosis. A specific test will be negative in patients known not to have the condition. In perfect specificity (100%), a negative test always means the condition is excluded, and will never be positive in a patient who does not have the condition. This assures that if the test is positive, it is a true positive. For example, with a specificity of 80%, in 100 patients without the condition, 80 patients will not have the condition, and 20 patients (i.e., 20%) will have a false-positive result. The SPIN ('Specific test when Positive rules IN the disease') acronym denotes that if a test has high specificity and yields a positive result, a condition can be ruled in (Davidson, 2002).

Agreement on acceptable sensitivity and specificity values has not been established, as the threshold is dependent on the required context. As a general rule, the higher the sensitivity and specificity values, the more accurate a test will be.

Likelihood ratio

Likelihood ratios assist in determining the usefulness of a positive test for ruling in a condition, or the usefulness of a negative test for ruling out a condition (Deeks & Altman, 2004). They are considered a more sophisticated measure of accuracy, compared to sensitivity and specificity, because they provide information about changes in the probability of a condition being present, given the specific test result. Likelihood ratios are derived from information based on specificity and sensitivity values (McGee, 2002).

Positive likelihood ratios (LR+) represent changes in the odds of the condition being present, based on a positive test result. A higher LR+ indicates a bigger shift in the probability that the targeted condition will be present in the event of a positive test (Deeks & Altman, 2004). An LR+ of >5 will be useful diagnostically, with true positives being more likely than false positives. Conversely, an LR+ of 1.0 is not helpful, as this will indicate the likelihood of both false and true positives.

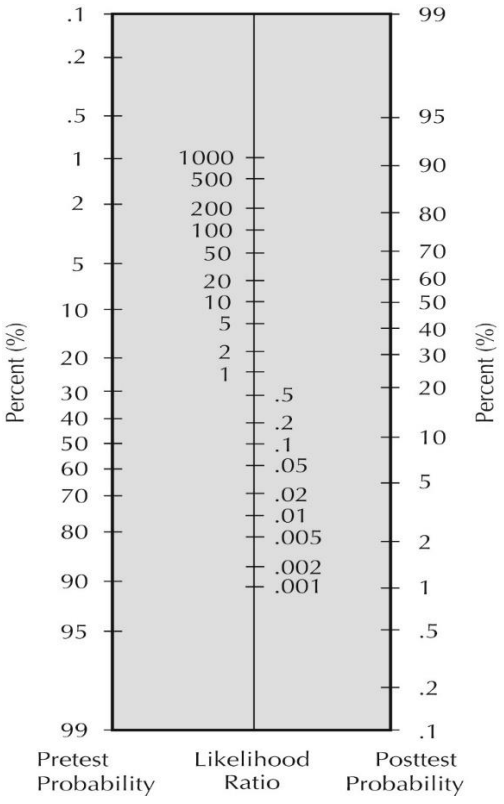
Negative likelihood ratios (LR–) represent changes in the odds of the condition being absent, based on a negative test result. The smaller the LR–, the larger the shift in

probability will be that the targeted condition is absent in the event of a negative test (Deeks & Altman, 2004). A LR– of <0.2 is clinically relevant because the lower the likelihood of a negative test, the more information the test will provide for ruling out a condition Whereas, a LR– of 1.0 indicated that false-negative results will be as likely as true negative results.

It has been reported that an accepted threshold value of 10.0 and 0.1 for positive and negative likelihood ratios, respectively, is recommended for a clinical test (Davidson, 2002; Stengel et al., 2003). However, other authors suggest that these values are unlikely to be attainable in clinical trials or musculoskeletal medicine, and suggest that LR+ ratios above 5.0 or LR– below 0.2 are acceptable for clinical use (Jaeschke et al., 1994). These values generate a moderate shift in probability from pre- to post-test. Fagan's nomogram (Fagan, 1975) is a graphical tool used to quantify post-test probability-based change following diagnostic accuracy test results (see Figure 11).

Figure 11.

Fagan's nomogram

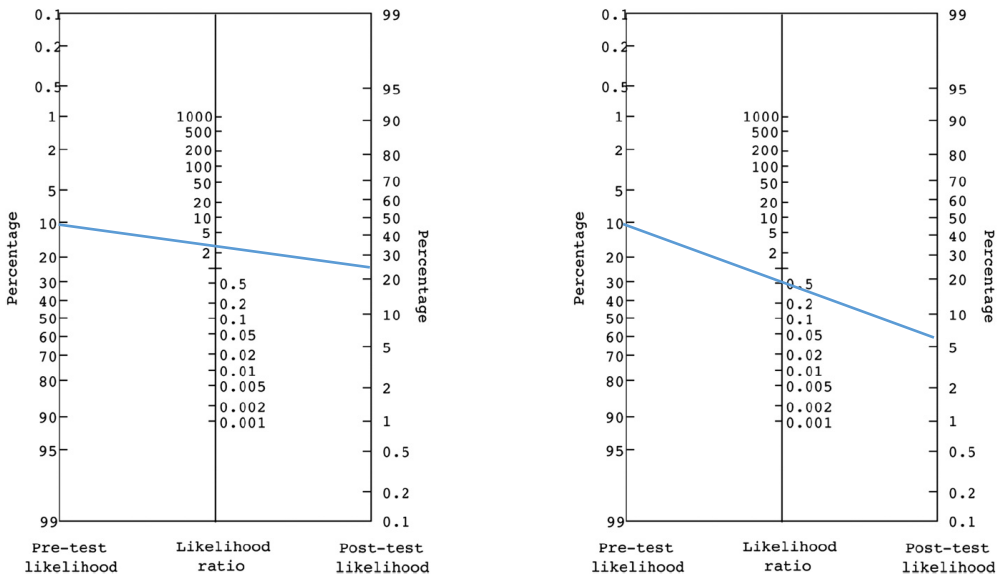


Note: Reproduced with permission from (Fagan TJ. Nomogram for Bayes theorem [letter]. New England Journal of Medicine. 1975; 293-275), Copyright Massachusetts Medical Society

The starting point, known as 'pre-test probability', is based on patients' subjective history, expert opinion and known prevalence data on the suspected condition. Using a diagnostic test with recognised likelihood ratios, the shift in probability for a targeted condition can be determined. As an example, Valdes and LaStayo (2013) reported that carpal tunnel syndrome had a prevalence rate of 5%–15%, and in their systematic review identified that Tinel's test for carpal tunnel syndrome had a mean LR+ of 2.95, and a LR– of 0.57. Using 10% as a pre-test probability starting point, and drawing a line to the likelihood ratio, Fagan's nomogram indicated a shift in probability from 10% to 24% if the Tinels test result was positive. If the Tinels test was negative, the probability rate shifted from 10% to 6% in a negative test, as shown in Figure 12. These shifts are considered relatively minor, given that the likelihood ratios did not meet the acceptable thresholds.

Figure 12.

A shift in probability using Fagan's nomogram for carpal tunnel syndrome



Note: Reprinted from: The value of provocative tests for the wrist and elbow: A literature review. Valdes, K., & Lastayo, P. *Journal of Hand Therapy*, 26(1), 32–43. Copyright (2013), with permission from Elsevier.

McGee (2002) summarised the approximate change in probability shown by Fagan's nomogram (shown in Table 2), where values that ranged from 0 to 1, indicated a lower probability of the condition being present, and a likelihood ratio of 1 indicated no change in probability. Values greater than 1 implied a higher probability of the condition being present. For example, a LR- of 0.2 generates an approximate –30%

shift in probability and a LR+ of 5 generates a +30% shift. In the previous example (Tinels test for carpal tunnel syndrome) in Valdes and LaStayo (2013), there was an approximately 14% and 4% shift, respectively, which in an isolated test will not yield confidence in terms of either confirming or excluding a diagnosis of carpal tunnel syndrome. This highlights that, to observe a substantial shift in probability from pre to post-test, an acceptable threshold of likelihood ratios is required; therefore, for the purpose of this review, the acceptable threshold was established as LR+ >5.0 and LR– <0.2.

Table 2.
Likelihood ratios and associated changes in probability

Likelihood ratio	Approximate change in probability (%)
0.1	–45
0.2	–30
0.3	–25
0.4	–20
0.5	–15
1	0
2	+15
3	+20
4	+25
5	+30
6	+35
8	+40
10	+45

Note: Adapted from McGee, S. Simplifying Likelihood Ratios. *Journal of General Internal Medicine,* (2002). *17*(8), 647–650.

Predictive values

Predictive values describe the probability of patients having a condition once their test results become known (Altman & Bland, 1994). Positive predictive values (PPV) refer to the proportion of people with a positive screening test result who have the condition (i.e., true positives). Conversely, negative predictive values (NPV) is the proportion of people with a negative screening test result who do not have the condition (i.e. true negatives) (Akobeng, 2007). For example, if 1,000 patients' test results were positive, but only 150 patients had the condition, the PPV would be 15% (150 / 1,000 x 100),

indicating a 15% chance of the patient having the condition in the event of a positive test result. Conversely, if 1,000 patients' test results were negative, and 900 patients did not have the condition, the NPV would be 90% (900 / 1,000 x 100). Accordingly, the probability of the patient being condition free in the event of a negative test finding would be 90%.

Predictive values are significantly affected by the prevalence rates of the condition. If this prevalence increases, the PPV will also increase. Similarly, as the prevalence of the condition decreases, the NPV will increase (Akobeng, 2007; Altman & Bland, 1994). For example, in a population of 1,000 patients, if the prevalence of a condition is 5%, there will be 50 patients with the condition and 950 without it. If the diagnostic test has sensitivity and specificity values of 90%, the test will correctly identify 45 patients with the condition and 855 without it. The remaining 5 patients will be classified as false negatives, and 95 patients will be false positives. If the condition prevalence is 20%, 200 patients will have the condition and 800 will not. Using the same test with 90% sensitivity and specificity rates will correctly identify 180 patients with the condition, 720 patients without the condition, 20 patients with a false negative and 80 patients having a false-positive result. With a prevalence rate of 5%, the PPV will be 32%, whereas with a prevalence rate of 20% the PPV will increase to 69%.

Acceptable thresholds for predictive values have to date not been established. Some studies have reported that values of 95% are required to be considered clinically satisfactory (Andersson et al., 2015). Accordingly, 95% will be used in this thesis.

3.3 Background

Previous literature reviews looking at the efficacy of diagnostic tests and MRI to diagnose TFCC injuries have been undertaken. Two systematic reviews, which focused on multiple upper limb provocation tests were conducted by Andersson et al. (2015) and Valdes and LaStayo (2013). While these reviews were well-conducted, they were broad in scope and included multiple pathologies and upper limb regions, including the wrist, hand, thumb, and elbow. Additionally, these reviews were completed more than five years ago and additional studies may have been undertaken since their completion. It was therefore deemed beneficial to undertake an up-to-date review that focused on TFCC diagnostic tests.

Five systematic reviews have evaluated the accuracy of MRI to diagnose TFCC (Andersson et al., 2015; Hobby et al., 2000; Smith et al., 2012; Treiser et al., 2018; Wang et al., 2015). Overall, those reviews showed that MRI had adequate accuracy for confirming and excluding TFCC injuries. The diagnostic accuracy data derived from all the reviews are shown in Table 3.

Table 3.

The pooled MRI diagnostic accuracy data for diagnosing TFCC injuries

Paper	Pooled PPV	Pooled NPV	Pooled Sn	Pooled Sp
Andersson et al. (2015)	Range: 71%–100%	Range: 0.37%–90%	Range 0.44–0.93	Range 0.54–1.0
Hobby et al. (2000)			0.83 (95% CI: 0.77–0.88)	0.80 (95% CI: 0.71–0.86)
Smith et al. (2012)			0.75 (95% CI: 0.76–0.86)	0.81 (95% CI: 0.40–0.97)
Treiser et al. (2018)			0.76 (95% CI: 0.72–0.80)	0.82 (95% CI: 0.77–0.86)
Wang et al. (2015)			0.83 (95% CI: 0.75–0.89)	0.82 (95% CI: 0.71–0.89)

Note: CI, confidence interval; Sn, sensitivity; Sp, specificity; PPV, positive predictive value; NPV, negative predictive value.

The reviews conducted were for the most part high quality, but had some limitations, including lack of quality assessment and detailing of MRI protocols. One of the limitations was that many of the reviewed studies were conducted over an extensive time range thereby including MRI scans with various field strengths, and changes in MRI technology. For example, the magnetic strength of MRI machines has changed over time and has had an impact on image quality. With the development of 3.0-Telsa MRI scanners, greater spatial resolution and a higher image resolution has provided better contrast detection and, accordingly, a better image (Saupe et al., 2005). The increased diagnostic accuracy of 3.0T MRI has been reported by multiple authors (Anderson et al., 2008; Magee, 2009; Smith et al., 2012). The study by Anderson et al. (2008), compared 1.5T against 3.0T MRI field strength scans, reporting sensitivity and specificity values of 0.82 and 0.59, respectively, in 1.5T MRI, and of 0.9 and 0.74 in 3.0T MRI. With the development of MRI technology, and the use of 3.0T MRI scans becoming standard field strengths for MRI scans within New Zealand populations, it

was considered that a review of the current literature on 3.0T MRI efficacy would be beneficial.

3.4 Aims

The purpose of the following literature review was to identify and evaluate research that investigated diagnostic tests and MRI in the diagnosis of TFCC injuries. This review has three components with three specific aims as follows.

1. To determine the reliability of TFCC diagnostic tests by identifying and evaluating published studies that investigate this topic.
2. To determine the diagnostic accuracy of TFCC diagnostic tests by identifying and evaluating published studies that investigate this topic.
3. To determine the efficacy of 3.0 Tesla MRI in diagnosing TFCC injuries by identifying and evaluating published studies that investigate this topic.

3.5 Methods

3.5.1 Data sources and search strategy

The preferred reporting items for systematic review and meta-analysis (PRISMA) statement was used to guide the literature search and report its findings. In June 2019 and January 2022, a search of the SCOPUS, Medline, Cinahl, SPORTDiscus, Web of Science, and AMED databases was conducted to identify studies that investigated diagnostic tests and 3.0T MRI in the diagnosis of TFCC injuries.

Three separate searches were conducted, one focusing on the reliability of provocation tests, one on diagnostic accuracy, and a third on the efficacy of a 3.0T MRI scan for diagnosing TFCC injuries. The first search separated key concepts and conducted separate searches in three categories. The search terms and strategy used for all databases are shown in Table 4.

Table 4.

Systematic review search terms

Search one: TFCC diagnostic test reliability	Search two: TFCC diagnostic test accuracy	Search 3: Diagnostic accuracy of MRI for TFCC injuries
TFCC OR triangular fibrocartilage* OR 'ulna* wrist'	TFCC OR triangular fibrocartilage* OR 'ulna* wrist'	TFCC OR triangular fibrocartilage* OR 'ulna* wrist'
AND	AND	AND
provocat* OR test OR sign OR diagnos* OR clinical OR exam*	provocat* OR test OR sign OR diagnos* OR clinical OR exam*	MRI OR magnetic resonance OR magnetic resonance imaging*
AND	AND	AND
reliab*	accura* OR sensitivity OR specificity OR validity	accura* OR sensitivity OR specificity OR validity

Note: * truncation for variant spellings of term used

3.5.2 Study selection

Studies that investigated the reliability or accuracy of diagnostic tests, or the efficacy of 3.0T MRI scans for TFCC injuries, were included. The three searches had minor differences in the inclusion and exclusion criteria, as shown in Table 5. An early date limit was not set, as a preliminary search highlighted a limited amount of research on the topic and the author did not want to exclude potentially relevant studies.

Table 5.

The inclusion and exclusion criteria of the literature reviews

TFCC diagnostic test reliability	TFCC diagnostic test accuracy	Diagnostic accuracy of MRI for TFCC injuries
Inclusion criteria		
Adults aged ≥18 years	Adults aged ≥18 years	Adults aged ≥18 years
Assessment of the reliability of a TFCC diagnostic test	Assessment of the validity of a TFCC diagnostic test	Assessment of the validity of MRI for TFCC injuries
Studies that used wrist or TFCC injured cohorts	Studies that used wrist or TFCC injured cohorts	Studies that used wrist or TFCC injured cohorts
English-language studies	English-language studies	English-language studies
	Reference standard of arthroscopy, open surgical findings or MRI	Reference standard of arthroscopy or open surgical findings
		Index test, 3.0 Tesla MRI
Exclusion criteria		
Systematic reviews	Systematic reviews	Systematic reviews
Studies that included participants with the following conditions	Studies that included participants with the following conditions	Studies that included participants with the following conditions
- Neurological conditions	- Neurological conditions	- Neurological conditions
- Arthritis of the DRUJ or RUCJ	- Arthritis of the DRUJ or RUCJ	- Arthritis of the DRUJ or RUCJ
- Rheumatological conditions	- Rheumatological conditions	- Rheumatological conditions
- Diagnosis of chronic pain or CRPS	- Diagnosis of chronic pain or CRPS	- Diagnosis of chronic pain or CRPS
Cadaveric studies	Cadaveric studies	Cadaveric studies

Note: CRPS: complex regional pain syndrome. DRUJ, distal radioulnar joint; RUCJ: radioulnocarpal joint; MRI: magnetic resonance imaging.

For all literature searches, the following approach was implemented. The results from each search were exported into Endnote version X9. Duplicates were removed using Endnote's filter setting. The identified studies were then screened by title and abstract. If this did not provide the information required to determine whether the paper met the inclusion/exclusion criteria, the full-text article was reviewed and evaluated. For studies that were deemed inappropriate for inclusion, the reason for their exclusion was noted. Finally, a manual search of the reference lists of all the included studies and pre-identified systemic reviews was conducted to ensure that no relevant studies were overlooked.

3.5.3 Data extraction

Details of the study design, methodology, participant characteristics, test procedure, and research findings were extracted from each study. These details were collated in an Excel spreadsheet for subsequent analysis, alongside the index and reference tests. As possible in studies that included data for tests on other wrist pathologies, data that pertained to TFCC injuries were extracted and reported separately.

The extracted statistical data differed for the three different searches. An ICC or Cohen's kappa coefficient (k) values were extracted for the reliability studies. Sensitivity, specificity, likelihood ratios and predictive values were extracted for the diagnostic accuracy studies. Confidence intervals were reported where available.

3.5.4 Data analysis

Quality evaluation

The quality of the included studies was assessed using the quality appraisal tool for studies of diagnostic reliability (QAREL) scale (Lucas et al., 2010) and the Quality Assessment of Diagnostic Accuracy Studies (QUADAS-2) tool (Whiting et al., 2011).

The QAREL tool was developed specifically to assess the quality of reliability studies (Lucas et al., 2010). This 11-item checklist evaluates seven principles, including the appropriateness of subjects and examiners, the blinding of examiners, the order of examination, the timing between tests, test application and statistical analysis. Three questions relate to factors that influence external validity, and the remaining questions evaluate internal validity. Internal validity refers to the degree that the results are trustworthy and did not result from methodological issues, external validity relates to the extent to which the results are generalisable (Patino & Ferreira, 2018). The QAREL items were scored as 'yes', 'no' or 'unclear'. In one question (question four; blinding from own findings) could be scored as 'not applicable', depending on the type of research performed, in this instance it creates a total of 10 questions. The QAREL tool has previously been shown to have good test/retest reliability (Lucas et al., 2013) and was recently used in several systematic reviews for diagnostic reliability studies (Rubio-Ochoa et al., 2016; Simopoulos et al., 2012). The tool was not originally designed with an indication or cut-off point to determine quality. However, to determine the quality of some studies, authors have used a modified QAREL version, in which a point system

was adopted in which a ‘yes’ answer equated to 1 point, and a ‘no’ or unclear answer scored 0. If question four; blinding of own findings is not applicable, then the total number of questions reduces from 11 to 10. A percentage was then calculated from the total number of answers given. There was no single accepted cut-off point, but QAREL scores ranging from 50% to 70% were considered to be of good quality (Moran et al., 2016). Following the Powden et al. (2019) example, the present review used a cut-off point of 60% as an indication of good quality.

The QUADAS-2 tool is recommended by the Cochrane Collaboration for assessing the quality of primary diagnostic studies (Reitsma et al., 2009). It is not designed to score or classify studies but rather to allow for making comparisons between studies by discussing areas of concern. The tool is divided into four domains to determine bias in the following: (i) patient selection, (ii) the index test, (iii) the reference standard, and (iv) flow and timing (Whiting et al., 2011). The QUADAS-2 tool asks the user to determine if they consider that there is a ‘low’ or ‘high’ risk of bias. The qualitative nature of the QUADAS-2 means that it does not have a recommended overall cut-off point or numerical value to indicate if a study was of good, moderate or low quality.

Categorisation of the diagnostic tests

Because the same test is often referred to by different names, tests were renamed in some cases from those used in the included articles for clarity and consistency. The diagnostic tests were labelled according to the anatomical location and the biomechanical stress applied. Table 6 details the tests used in this review, the various names of the tests and the label used in this review.

Table 6.

TFCC diagnostic test categorisation

Test name used in included review	Biomechanical stress description	Alternative test names used in the studies
Grind test	The axial load applied from the carpus to the ulna while performing a rotational movement (supination to pronation)	Ulnar grind Ulnocarpal stress test Ulnocarpal meniscoid-test Waiter's test
Shear test	Posterior-anterior stress applied to the UCJ	Articular disc shear test Ulnomeniscotriquetral dorsal glide test (UMTDG)
DRUJ ballottement test	Posterior-anterior stress applied to the DRUJ	DRUJ stress test Radioulnar stress test
Ulnar fovea test	Palpation to the ulnar fovea region, between the pisiform and ulnar head	N/A
Peak rotational force test	Rotational (supination and pronation) torque strength measured by dynamometer with shovel handle attachment	N/A
Piano key sign	Visual inspection of the DRUJ to observe its alignment	N/A
Piano key test	Applying a dorsal to volar load across the ulna, 4 cm proximal to the DRUJ	N/A
Push-off test	Weightbearing while leaning, with the hands behind the body, on a hand-held Jamar dynamometer	N/A
Press test	In a sitting position, pressing down on the hands to lift the weight of the body off the chair	N/A
Wrist weightbearing test	Weightbearing with the hands in front of the body, leaning on an analogue scale	N/A
Gripping impaction test (GRIT)	Grip strength measured by a handheld dynamometer is measured in forearm neutral (mid-rotation), pronation, and supination positions	N/A

Note: DRUJ: distal radioulnar joint. N/A: not applicable. UCJ: ulnocarpal joint.

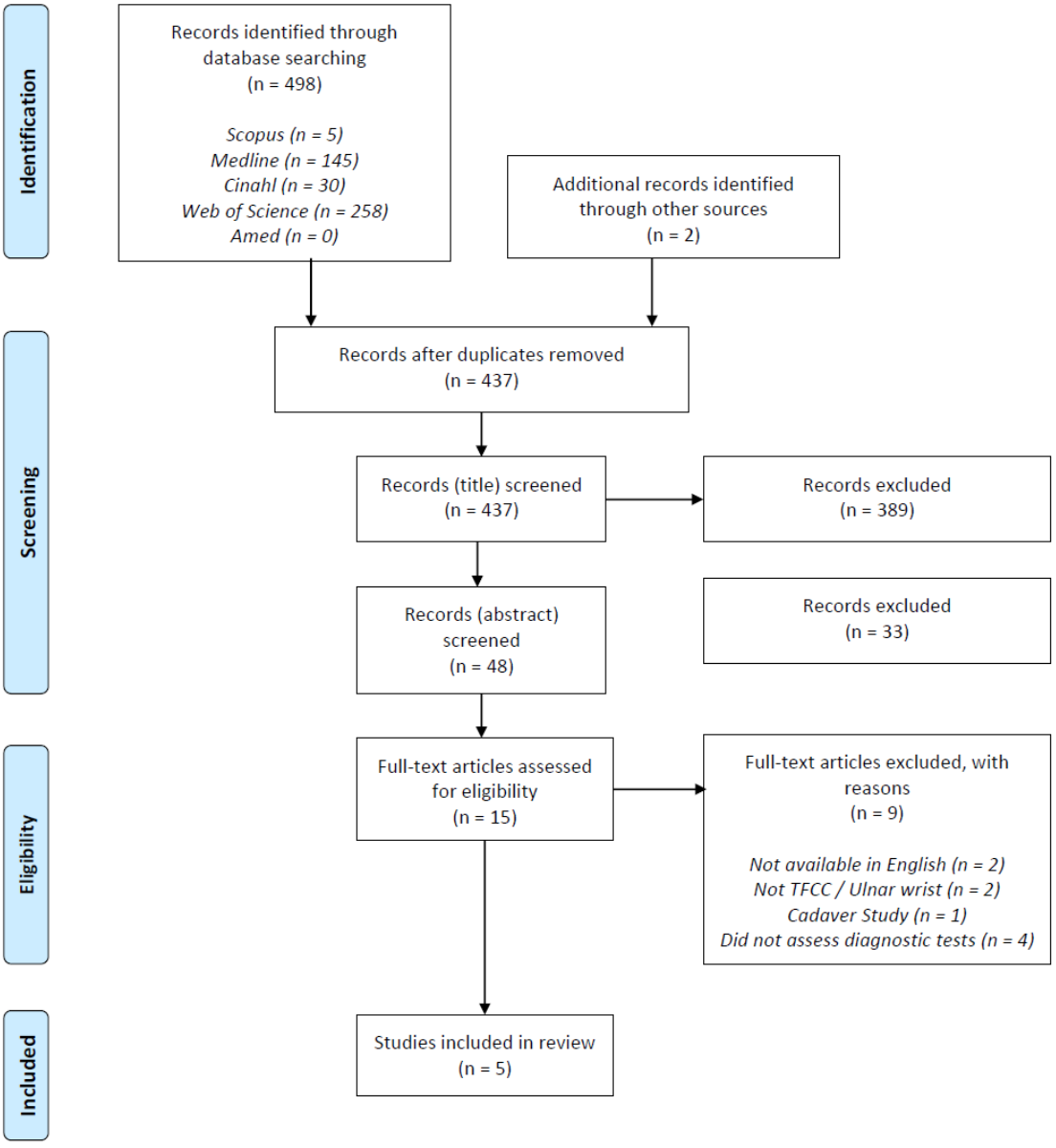
3.6 Results

3.6.1 Studies that investigated the reliability of TFCC provocation tests

A total of 498 articles were identified using the search terms with a final of five articles being included in this review. Figure 13 presents the results for the search and Appendix B: Systematic search results details the results for each database.

Figure 13.

PRISMA flow diagram for reliability of TFCC diagnostic tests



Note: N: number. TFCC: Triangular Fibrocartilage complex

Quality assessment

The quality of the studies that were included in this review was measured using the QAREL score. The results of the QAREL are summarised in Table 7. Four studies (Andersson et al., 2016; Lindau et al., 2002; Mehta et al., 2019; Scheer et al., 2010) met the 60% QAREL score threshold (the percentage of questions answered 'yes' among the total number of questions answered); this indicated high quality. The remaining study (Vincent et al., 2014) was below this threshold (55%). Quality of the majority studies was impacted due to a lack of blinding. The external validity portion of the QAREL ranged from 33% to 100% with a median of 86%, and the internal validity section ranged from 33% to 71%, with a median of 46%. This indicated that the results were highly generalisable, but that methodological issues had potentially impacted the study's results.

Table 7.

A summary of the reliability literature quality using the QAREL critiquing tool

Question		Andersson et al. (2016)	Mehta et al. (2019)	Scheer et al. (2010)	Lindau et al. (2002)	Vincent et al. (2014)
1	Representative sample	Y	Y	Y	Y	Y
2	Representative rater	Y	Y	Y	Y	U
3	Blinding (other raters)	Y	U	Y	U	Y
4	Blinding (own findings)	U	N/A[1]	N/A[1]	N/A[1]	U
5	Blinding (reference/disease)	Y	U	U	Y	U
6	Blinding (clinical information)	Y	U	U	Y	U
7	Blinding (additional cues)	Y	U	Y	Y	U
8	Examination order varied	N	Y	N	N	Y
9	Appropriate time interval	Y	Y	U	U	Y
10	Test appropriate	Y	Y	Y	Y	Y
11	Appropriate statistics	Y	Y	Y	Y	Y
	Internal validity (%) (Q: 3–9)	5/7 (71%)	2/6 (33%)	2/6 (33%)	3/6 (50%)	3/7 (43%)
	External validity (%) (Q: 1–2, 10)	3/3 (100%)	3/3 (100%)	3/3 (100%)	3/3 (100%)	2/3 (33%)
	Percentage of 'yes' answers (%)	9/11 (82%)	6/10 (60%)	6/10 (60%)	7/10 (70%)	6/11 (55%)

Note: Y = yes. N = No. U = unclear. N/A not applicable.

[1] if question not applicable, then total number of questions reduces from 11 to 10

Design and methodology

The primary aim in most of the studies was to investigate the reliability of diagnostic tests. The study conducted by Scheer et al. (2010) differed in this regard, as the primary aim was to establish the reliability of a radioulnar ratio, a statistic calculated from measurements made via a CT scan. The study was included in this review because the authors also examined the reliability of the DRUJ ballottement test as a preliminary requirement for establishing the accuracy of their criterion measure.

Participant characteristics

The characteristics of the participants included in the five studies (Andersson et al., 2016; Mehta et al., 2019; Scheer et al., 2010; Vincent et al., 2014) are detailed in Table 8. A total of 140 participants were included across the five studies. All studies included relatively small cohorts, ranging from 20 to 50 participants, and they all included participants who were more than six months post-injury. The participant cohorts in Mehta et al. (2019) and Vincent et al. (2014) were not wrist or pathology specific, and included both wrist and elbow injuries. Andersson et al. (2016) included individuals who were scheduled to undergo arthroscopic investigation for suspected TFCC injuries. Scheer et al. (2010) and Lindau et al. (2002) conducted their studies on a post distal radius fracture cohort.

The age range across the studies was from 16 to 64 years. The mean age reported in four studies (Andersson et al., 2016; Lindau et al., 2002; Mehta et al., 2019; Vincent et al., 2014) ranged from 31-48 years. Gender was reported in four studies, with percentages varying between studies. Andersson et al. (2016) and Lindau et al. (2002) both reported a 40:60 male to female ratio, compared to a 65:35 ratio in Vincent et al. (2014) and 30:70 in Mehta et al. (2019).

Table 8.

A summary of the reliability literature search: an overview of research characteristics

Study	Index tests		Participant demographics	Patient characteristics
	Diagnostic test	Additional tests		
Lindau et al. (2002)	DRUJ ballottement test	X-ray Pain (VAS) Modified Garland & Werley wrist score	N = 20: Gender: 8 males; 12 females Age: mean 40 years. Range, 20–56 Hand dominance: not reported	Injury duration: Average 5.6 years Mechanism of injury: 100% had a history of significant trauma (distal radius fracture) Treatment history: 18/20 casted, 1/20 closed reduction & casted, 1/20 surgical fixation
Scheer et al. (2010)	DRUJ ballottement test	X-ray radioulnar ratio	N = 48 Gender: not reported Age range: 18–50 Dominant hand injury: yes: no 52%; 47%	Injury Duration: minimum 6 months Mechanism of injury: 100% had a history of significant trauma (distal radius fracture) Treatment history: Surgical intervention in 40% (19/48) participants
Mehta et al. (2019)	Push-off test	Isometric wrist extension strength Static grip strength Pain (NPRS) QuickDASH	N = 50 Gender: 15 males, 35 females Age: mean 48.1 years (SD: 16.6 years) Dominant hand injury: yes: no 58%; 42%	Injury duration: Mean duration of symptoms: 28.2 months Injury location: wrist: elbow injury, 38 (76%):12 (24%)

Study	Index tests		Participant demographics	Patient characteristics
	Diagnostic test	Additional tests		
Vincent et al. (2014)	Push-off test	Wrist & elbow ROM Isometric wrist extension strength Static grip strength DASH & WLQ-26	N = 22 Gender: 15 males, 7 females Age: mean, 42 years. Range, 22–61 Dominant hand injury: yes: no 45%: 54%	Injury duration: Mean post-injury period = 32 weeks Injury location: Wrist: elbow injuries, 12 (54%):10 (45%)
Andersson et al. (2016)	Forearm peak rotation torque	MRI Foveal sign	N = 20 Gender: 8 males, 13 females Age: mean 31 years (SD:11.3 years) Dominant hand injury: yes: no 35%: 65%	Injury duration: more than 6 months old Mechanism of injury: 17/20 (85%) had a history of significant trauma

Note: DRUJ: distal radioulnar joint; TFCC: triangular fibrocartilage complex; N: number: NPRS: numerical pain rating scale; VAS: visual analogue scale; MRI: magnetic resonance image; quickDASH: Quick version of the disability of arm, shoulder, hand questionnaire; WLQ-26: Work Limitations questionnaire; ROM: range of motion; SD: standard deviation

Diagnostic tests

Three diagnostic tests were included in the five studies. These were the push-off test (Mehta et al., 2019; Vincent et al., 2014), forearm peak rotation torque test (Andersson et al., 2016), and the DRUJ ballottement test (Lindau et al., 2002; Scheer et al., 2010). All of the reviewed studies evaluated the inter-rater reliability of the diagnostic tests, and two studies also reported on intra-rater reliability (Andersson et al., 2016; Vincent et al., 2014). These two studies reported intra- and inter-rater reliability in healthy individuals and injured cohorts. A summary of the results is provided in Table 9.

Table 9.

Statistical analysis results concerning the reliability of the reviewed studies

Study	Diagnostic test	Inter-rater reliability		Intra-rater reliability	
Lindau et al. (2002)	DRUJ ballottement	Affected limb	K: 0.66, 90% CI [0.36, 0.95]	NR	
Scheer et al. (2010)	DRUJ ballottement test		K: 0.84 95% CI [0.68, 0.99]	NR	
Andersson et al. (2016)	Peak torque strength	Wrist injury cohort	ICC 0.95 95% CI [0.91, 0.96]	Wrist injury cohort	ICC 0.95, 95% CI [0.93, 0.97]
				Healthy individuals	ICC 0.96, 95% CI [0.93, 0.97]
Mehta et al. (2019)	Push-off test	Affected side	ICC: 0.96 95% CI [0.93, 0.98]	NR	NR
		Unaffected side	ICC 0.93 95% CI [0.89, 0.96]	NR	NR
Vincent et al. (2014)	Push off test	Affected limb	ICC 0.97, 95% CI [0.93, 0.99]	Affected limb	ICC 0.96, 95% CI [0.92, 0.97]
		Unaffected limb	ICC 0.85, 95% CI [0.68, 0.94]	Unaffected limb	ICC 0.92, 95% CI [0.85, 0.97]

Note: thresholds: kappa values: 0.40. ICC: 0.80

CI: confidence interval; K: kappa value. ICC: intra-class correlation; NR: not reported

Peak rotational torque strength test

The intra- and inter-rater reliability for the peak rotational torque strength test was evaluated by Andersson et al. (2016). Their results were almost perfect with intra-rater reliability reported kappa value of 0.95 (95% CI 0.93, 0.97) and inter-rater reliability kappa value was 0.95 (95% CI 0.91, 0.96).

DRUJ ballottement test

Scheer et al. (2010) reported agreement between two examiners in 44/48 of the cases and inter-rater agreement as a kappa value of 0.84 (95% CI 0.68, 0.99). Lindau et al. (2002) reported that the inter-rater reliability of the DRUJ ballottement test had a kappa value of 0.66 (90% CI 0.36, 0.95).

Push-off test

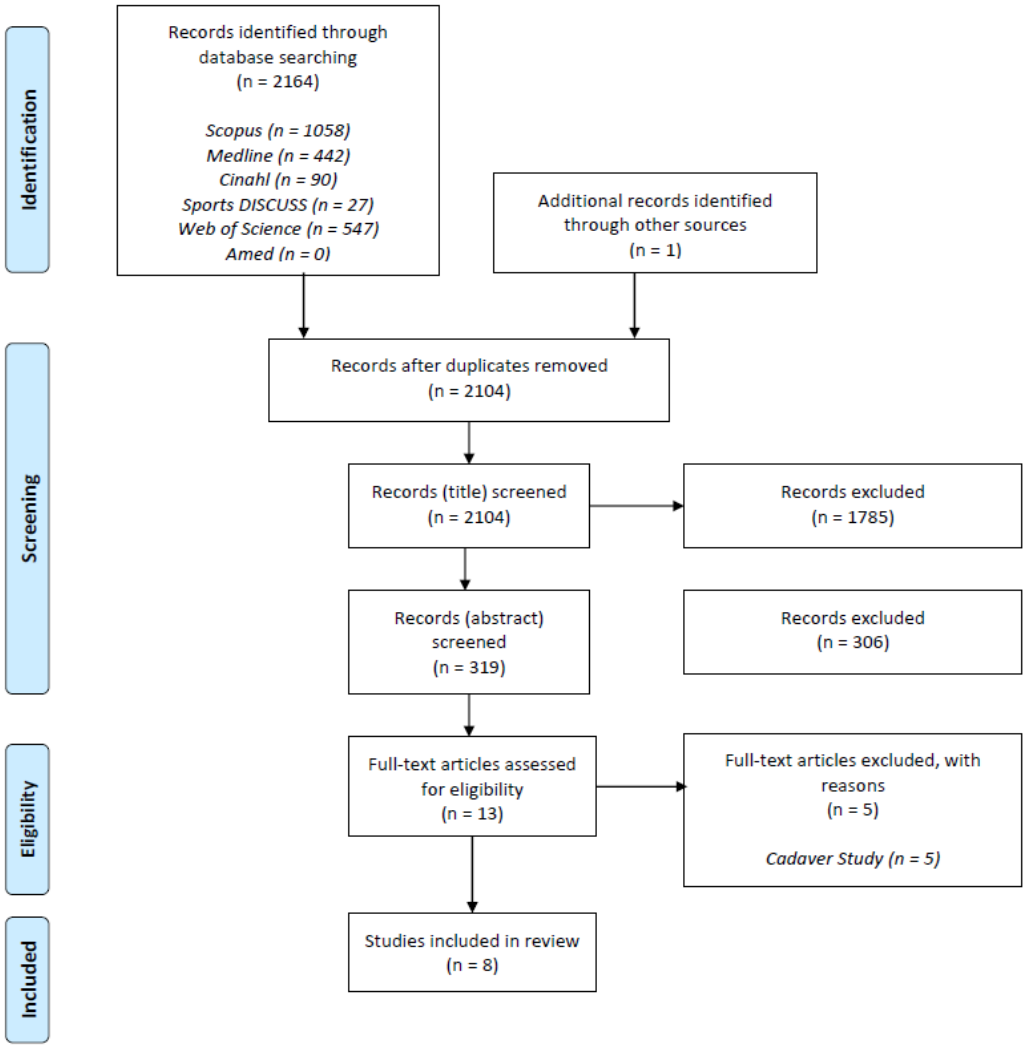
Vincent et al. (2014) evaluated the intra- and inter-rater reliability of the weightbearing push-off test for both the affected and the unaffected limb. Intra- rater reliability of the affected limb (ICC) was 0.96 (CI 95% 0.92, 0.97) and 0.92 (CI 95% 0.85, 0.97) for the non-affected limb. The inter-rater reliability of the affected limb (ICC) was 0.97 (CI 95% 0.93, 0.99) and 0.85 (CI 95% 0.68, 0.94) for the unaffected limb. Mehta et al. (2019) also evaluated the inter-rater reliability of the push-off test. Inter-rater reliability results were an ICC of 0.96 for the affected limb and 0.93 for the non-affected limb.

3.6.2 Studies investigating the diagnostic accuracy of TFCC provocation tests

The literature search generated 2,164 studies that matched the search strategy. After screening and assessing eligibility, eight studies were included in this review. Figure 14 presents the results of the search and Appendix B details the results for each database.

Figure 14.

PRISMA flow diagram for diagnostic accuracy of TFCC diagnostic tests



Note: N: Number. TFCC: Triangular fibrocartilage complex.

Quality assessment

The results of the assessment using the QUADAS-2 critiquing tool are reported in Table 10. Overall, the majority of the studies that addressed the criteria outlined by the QUADAS-2 indicated a low risk of bias or concern regarding applicability. The majority of studies included an appropriate population and the diagnostic tests were correctly and independently applied from additional investigations. The reporting of the reference and index tests was completed to a high standard, particularly in terms of outlining the test descriptions and the execution of reference standard tests. None of the studies blinded the examiner from the outcomes, and participant withdrawals were only explained in two studies (Prosser et al., 2011; Ruston et al., 2013). Other

reported issues included a lack of reporting of the time frames between the reference standard and clinical provocation test. This detail was only provided in three studies (LaStayo & Howell, 1995; Prosser et al., 2011; Schmauss et al., 2016). In Lindau et al. (2000), there was a long delay between the reference standard and index tests, with arthroscopy having been conducted at the time of the injury (an average of three days; range, one to fifteen days), and the TFCC provocation test conducted at a median follow up of 12 months (range, 11–27 months).

Table 10.

A summary of the TFCC diagnostic accuracy literature quality using the QUADAS-2 critiquing tool

	Risk of bias				Applicability concerns		
	Patient selection	Index test	Reference standard	Flow and timing	Patient selection	Index test	Reference standard
LaStayo and Howell (1995)	L	U	U	U	L	L	L
Lester et al. (1995)	H	L	L	H	H	L	H
Lindau et al. (2000)	L	L	L	H	L	L	L
Nakamura et al. (1997)	L	U	U	U	L	L	L
Prosser et al. (2011)	L	L	L	L	L	L	L
Ruston et al. (2013)	U	U	U	U	L	L	L
Schmauss et al. (2016)	L	U	U	H	L	L	L
Tay et al. (2007)	L	U	U	L	L	L	L

Note: L, low risk of bias or concern regarding applicability; H, high risk of bias or concern regarding applicability; U, unclear risk or concern regarding applicability.

Design and methodology

Five of the reviewed studies (LaStayo & Howell, 1995; Lester et al., 1995; Lindau et al., 2000; Nakamura et al., 1997; Prosser et al., 2011) adopted prospective and cross-sectional designs. The remaining three studies (Ruston et al., 2013; Schmauss et al., 2016; Tay et al., 2007) were retrospective audits. The relevant inclusion criteria were reported in all the studies. Some studies excluded specific pathologies; three studies (LaStayo & Howell, 1995; Schmauss et al., 2016; Tay et al., 2007) excluded participants with comorbidities that could alter carpal anatomy or biomechanics, including previous surgery, wrist fracture, arthritis or congenital conditions. Conversely, Lindau et al.

(2000) specifically used a cohort of participants' post-distal radius fractures. All studies used arthroscopy as the reference standard to confirm or exclude TFCC injuries. Magnetic resonance imaging was used in 71% (5/7) of studies (Lester et al., 1995; Nakamura et al., 1997; Prosser et al., 2011; Ruston et al., 2013; Schmauss et al., 2016) as an additional radiographic investigative tool.

Participant characteristics

The study design and demographics of the eight original studies included in this review are outlined in Table 11 below. A total of 1,417 participants were included, among whom 876 had diagnostic tests performed. This difference arose primarily from the fact that in Schmauss et al. (2016), there was a large disparity between the number of overall participants (908) and the number of participants for whom provocation tests had been performed (255). The mean age was relatively similar across all the studies, ranging from 35-41 years. Across the seven studies that reported gender, 57.5% of participants were male and 42.5% were female. In all the studies, the included participants had a primary complaint of wrist pain. The percentage of participants who had a traumatic cause for their symptoms varied greatly between studies. Nakamura et al. (1997) reported that 46.6% participants had a history of trauma, compared to 75.4% in Tay et al. (2007), and 96% in Lester et al. (1995). Lindau et al. (2000) conducted an assessment on patients post distal radius fractures, in which 78% were caused by a fall onto an outstretched hand.

Table 11.

The diagnostic accuracy characteristics of the reviewed studies, based on the literature search

Study	Index tests	Criterion measure	Participant demographics	Patient characteristics
LaStayo and Howell (1995)	Shear test	Arthroscopy	N = 50 Age: mean 38 years (range 16–67) Gender: 26 males, 24 females Hand dominance: not reported	Included: Unspecified wrist pain Excluded: previous wrist surgery, systemic inflammatory arthritis, CRPS Mechanism of injury: not reported Symptom duration: not reported.
Lester et al. (1995)	Press test	Arthroscopy	N = 27 Age: mean 31 (range 20–49 years) Gender: 16 males, 9 females Hand dominance: not reported	Included: ulnar-sided wrist pain aggravated by forceful use Mechanism of injury: 96% (26/27) history of trauma Symptom duration: not reported
Lindau et al. (2000)	DRUJ ballottement	Arthroscopy	N = 51 Age: mean 41 years (range 20–57) Gender: 24 males, 27 females Hand dominance: not reported	Included: distal radius fractures Mechanism of injury: 100% (51/51) history of trauma. 78% (40/51) fall Symptom duration: not reported. Median follow up timeframe 12 months (range 11-27months).
Nakamura et al. (1997)	Grind test	Arthroscopy	N = 45 Age: mean 36 years (range 15–67) Gender: 27 males, 18 females Hand dominance: not reported	Included: persistent ulnar-sided wrist pain for more than three months Mechanism of injury: 53% (24/45) spontaneous onset. 47% (21/45) history of trauma Symptom duration: not reported

Study	Index tests	Criterion measure	Participant demographics	Patient characteristics
Prosser et al. (2011)	Shear test Shear test with compression DRUJ ballottement	Arthroscopy	N = 105 Age: mean 37 years (SD 12) Gender not reported Hand dominance: 87% right hand dominant. Dominant hand injury: not reported	Included: undiagnosed wrist pain of at least four weeks duration Excluded: wrist fractures, previous carpal surgery, rheumatoid athritis, CRPS Mechanism of injury: not reported Symptom duration: mean 9.6 months (range 3.9, 14.8 months)
Ruston et al. (2013)	Grind test	Arthroscopy	N = 66 Age: mean 35 years (SD 12.7) Gender: 32 males, 34 females Hand dominance: not reported	Included: those with intra-articular wrist pathology Mechanism of injury: not reported Symptom duration: not reported
Schmauss et al. (2016)	Ulnar fovea test Grind test	Arthroscopy	N = 908, (diagnostic tests conducted in 255) Age: mean 40 years (range, 18–78) Gender: 539 males, 369 females Hand dominance: not reported	Included: wrist pain Excluded: congenital variations and established post-traumatic or degenerative arthritis Mechanism of injury: not reported Symptom duration: mean 2.5 months (range 1 day, 56 months)
Tay et al. (2007)	Ulnar fovea test	Arthroscopy	N = 272 Median age: 33.7 years (range, 12.6–74.7) Gender: 146 males, 126 females Hand dominance: 90.8% (248/272) right hand dominant. Dominant hand injury: yes: no 58%: 42%	Included ulnar sided wrist pain Excluded: those with clearly demonstrated altered carpal anatomy Mechanism of injury: 75% history of trauma Symptom duration: not reported

Note: DRUJ, Distal radioulnar joint; CRPS, complex region pain syndrome; MRI, magnetic resonance imaging; N: number. SD: Standard deviation

Diagnostic accuracy results

A total of five TFCC diagnostic tests were investigated over the eight studies included in this review. These were the shear test (LaStayo & Howell, 1995; Prosser et al., 2011), the press test (Lester et al., 1995), ulnar fovea sign (Schmauss et al., 2016; Tay et al., 2007), grind test (Nakamura et al., 1997; Schmauss et al., 2016) and the DRUJ ballottement test (Lindau et al., 2000; Prosser et al., 2011). The tests are described in Table 5. Six studies investigated a single provocation test and in two studies (Prosser et al., 2011; Schmauss et al., 2016), multiple TFCC diagnostic tests were examined. Estimates of diagnostic accuracy were reported using various statistical metrics. Table 12 details the diagnostic accuracy results for the five investigated tests.

Table 12.

The statistical analysis results of diagnostic accuracy in the TFCC diagnostic tests overview

Study	Test	Sn	Sp	LR+	LR-	PPV	NPV
Lester et al. (1995)	Press test	1.0	-	-	-	-	-
LaStayo and Howell (1995)	Shear test	0.66. CI not stated	0.64	1.83[2]	0.55[2]	0.58	0.69
Prosser et al. (2011)	Shear test	0.58 (95% CI 0.49, 0.71)[2]	0.69 (95% CI 0.53, 0.82)[2]	1.88 (95% CI 1.15, 3.04)	0.53 (95% CI 0.33, 0.86)	0.71[2]	0.59[2]
	DRUJ ballottement	0.53 (95% CI 0.28, 0.77)[2]	0.70 (95% CI 0.60, 0.80)[2]	1.79 (95% CI 1.03, 3.11)	0.30 (95% CI 0.11, 0.86)	0.26[2]	0.89[2]
Lindau et al. (2000)	DRUJ ballottement	0.59 (95% CI 0.33, 1.0)[1,2]	0.96 (95% CI 0.82, 1.0)[1,2]	14.75 (95% CI 2.31 to 117.56)[2]	0.43 (95% CI 0.24, 0.76)[2,]	0.91	0.78
Tay et al. (2007)	Ulnar fovea sign	0.95 (95% CI 0.90, 0.98)	0.87 (95% CI 0.79, 0.92)	7.06 (95% CI 4.53, 11)	0.055 (95% CI 0.03, 0.11)	-	-
Schmauss et al. (2016)	Ulnar fovea sign	0.73 (95% CI 0.68, 0.78)[2]	0.44 (95% CI 0.39, 0.50)[2]	1.32 (95% CI 1.17, 1.48)[2]	0.60 (95% CI 0.48, 0.75)[2]	0.53	0.66
	Grind test	0.90 (95% CI 0.85, 0.94)[2]	0.20 (95% CI 0.15, 0.26)[2]	1.12 (95% CI 1.04, 1.22)[2]	0.50 (95% CI 0.30, 0.77)[2]	0.54	0.65
Ruston et al. (2013)	Grind test	0.40. CI not stated	0.93	5.48[2]	0.65[2]	0.77	0.72
Nakamura et al. (1997)	Grind test	-	-	-	-	0.55	

Note: Sn: sensitivity. Sp: specificity; LR+, positive likelihood ratio; LR–, negative likelihood ratio; PPV, positive predictive value. NPV, negative predictive value. CI: confidence interval; [1] : for diagnosing complete peripheral tear of the TFCC; [2] : calculated by researcher from raw reported data.

Shear test

The shear test was investigated by LaStayo and Howell (1995) and Prosser et al. (2011). Both studies failed to meet acceptable diagnostic accuracy thresholds. Prosser et al. (2011) combined the results from both tests (shear tests and shear test with compression) but did not report the results of the two individual tests. LaStayo and Howell (1995) reported LR+ of 1.83 and specificity value of 0.64, but did not report confidence intervals. Prosser et al. (2011) reported similar LR+ 1.88 and whilst these LR+ values indicate an approximate 15% shift in probability, but this is below acceptable thresholds to be used as an isolated test. In excluding TFCC injuries, LaStayo and Howell (1995) reported LR- of 0.55 and sensitivity of 66%, and Prosser et al. (2011) reported LR- of 0.53. Interestingly, Prosser et al. (2011) reported that when the shear test was used in isolation, 73% of participants were correctly classified, and this increased to 86% when provocative tests were combined with MRI investigation. This finding was of statistical significance with a P-value <0.0001.

Ulnar fovea sign

The ulnar fovea sign was examined by Schmauss et al. (2016) and Tay et al. (2007). The two studies reported contradictory findings of high (Tay et al., 2007) and low (Schmauss et al., 2016) accuracy. The results by Tay et al. (2007) indicated that the ulna fovea sign had high levels of accuracy to confirm TFCC injuries (accompanied with confidence intervals), with high specificity of 0.87, and LR+ of 7.06, indicating nearly a 40% shift in predictability. Comparatively, Schmauss et al. (2016) reported low specificity of 0.44 and LR+ of 1.30. Tay et al. (2007) also reported high sensitivity values of 0.95 and LR- of 0.05 indicating high levels of accuracy to exclude TFCC injuries. Schmauss et al. (2016) reported limited ability to exclude TFCC injuries with sensitivity value of 73% and LR- of 0.61

Both studies conducted statistical analysis on subgroup classifications, as seen in Table 13. Schmauss et al. (2016) looked at participants with ulnocarpal pain, i.e., those with ulnocarpal pain who had a history of trauma, and TFCC injury according to the Palmer classification. They showed that the accuracy of the ulnar fovea sign was influenced by the location of pain, history of trauma and degree of injury. Tay et al. (2007) looked at subgroup analysis of specific TFCC injuries, showing a decrease in sensitivity values but

an increase in specificity values when using the ulnar fovea test with specific TFCC-associated injuries.

Table 13.

Ulnar fovea sign subgroup analysis

Subgroup	Sensitivity		Specificity	
	Schmauss et al. (2016)	Tay et al. (2007)	Schmauss et al. (2016)	Tay et al. (2007)
All participants	0.73	0.95	0.44	0.87
Participants with ulnar wrist pain	0.88		0.09	
Participants with ulnar wrist pain and a history of trauma	0.90		0.08	
Participants with confirmed TFCC 1A lesions (central TFC perforation)	0. 86		0.09	
Participants with foveal disruptions only		0.90		0.86
Participants with UT ligament injuries only		0.74		0.97
Participants with UT ligament injuries and clinically stable DRUJ		0.90		0.88

Note: UT, ulnotriquetral ligament; DRUJ, distal radioulnar joint.

Grind test

The grind test was investigated in three studies (Nakamura et al., 1997; Ruston et al., 2013; Schmauss et al., 2016). There was a large discrepancy in the results between Ruston et al. (2013) and Schmauss et al. (2016). Ruston et al. (2013) reported specificity values of 0.93 and LR+ of 5.48, and PPV of 0.77, indicating reasonable ability to confirm TFCC injuries. Conversely, Schmauss et al. (2016) reported that the grind test had limited ability to confirm TFCC injuries with a sensitivity of 0.90, specificity of 0.20, a PPV of 0.54 and an NPV of 0.65. Nakamura et al. (1997) reported PPV values of 0.55, similar to that of Schmauss et al. (2016), but did not provide sensitivity or specificity values.

Subgroup analysis was undertaken by both Ruston et al. (2013) and Schmauss et al. (2016). Ruston et al. (2013) compared the accuracy of the clinical examination, as well as MRI scans, against the reference standard of arthroscopy; both groups had comparable accuracy values, with clinical examination reported at 72.7% and MRI at 71.7%. Schmauss et al. (2016) investigated subcategories, including participants with

symptomatic ulnar wrist pain, a history of trauma, and TFCC injury based on Palmer classification, as shown in Table 1. This showed similar statistical values throughout all the subcategories.

Table 14.

Grind test subgroup analysis

Subgroup	Sensitivity	Specificity
All participants	0.90	0.20
Participants with ulnar wrist pain	0.93	0.12
Participants with ulnar wrist pain and a history of trauma	0.93	0.12
Participants with confirmed TFCC 1A lesions (central TFC perforation)	0.93	0.12

Note: Adapted from Schmauss, D., Pöhlmann, S., Lohmeyer, J., Germann, G., Bickert, B., Megerle, K., Pöhlmann, S., & Lohmeyer, J. A. (2016). Clinical tests and magnetic resonance imaging have limited diagnostic value for triangular fibrocartilaginous complex lesions. *Archives of Orthopaedic and Trauma Surgery, 136*(6), 873-880. https://doi.org/https://doi.org/10.1007/s00402-016-2441-9

DRUJ ballottement

The DRUJ ballottement test was assessed in two studies (Lindau et al., 2000; Prosser et al., 2011), which showed conflicting results. Lindau et al. (2000) reported high levels of accuracy to confirm TFCC injuries, and minimal usefulness of excluding TFCC injuries, with a sensitivity of 59%, specificity of 96%, a PPV of 0.91 and an NPV of 0.78. The LR+ of 14.75 seen in Lindau et al. (2000) creates a substantial shift (<45%) in predictability, however, the confidence intervals around this mean estimate were very wide (2.31-117.56), suggesting the estimate lacks precision. Conversely, Prosser et al. (2011) reported a LR+ of 1.79 and LR- of 0.30 to confirm or exclude TFCC injuries, which the authors indicated as being mildly useful in comparison to arthroscopic investigations.

Press test

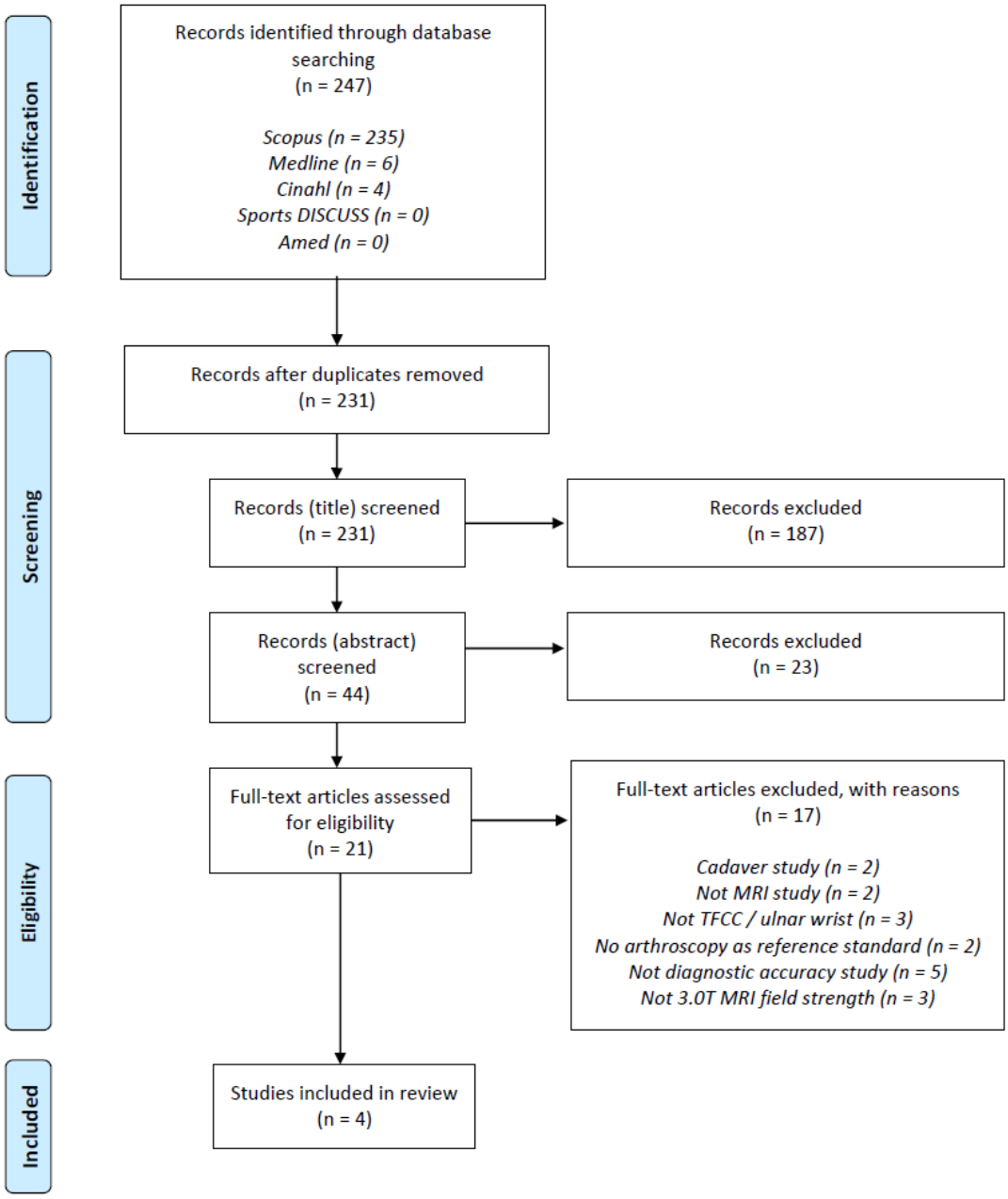
Among the included studies, the press test was only investigated by Lester et al. (1995). Their statistical analysis was limited to sensitivity calculation, which reported a 100% sensitivity rate, with all the study's 27 participants had a positive press test. The authors also investigated the accuracy of the press test in comparison to MRI findings, for which they reported a 79% accuracy rate.

3.6.3 Studies that investigated the efficacy of 3.0Tesla MRI for TFCC injury diagnosis

A total of 249 articles were identified matching the search strategy, with a final of four studies being included in this review. Figure 15 presents the results for the search and Appendix B details the results for each database.

Figure 15.

PRISMA flow diagram for diagnostic accuracy of the 3.0T MRI literature search



Note: N: Number. T: Tesla. MRI: Magnetic resonance imaging. TFCC: Triangular fibrocartilage complex.

Quality assessment of the studies

All four studies indicated a low risk of bias or concern regarding their applicability, based on the QUADAS-2 tool, as shown in Table 15. All studies detailed the MRI procedure, including technical considerations, such as patient position, angles, section thickness and the use of wrist coils. Aspects that were of concern included a lack of documenting the timing between MRI and arthroscopy (Anderson et al., 2008; Ochman et al., 2017), and failing to detail the patient selection process in Ochman et al. (2007).

Table 15.

A summary of the MRI diagnostic accuracy literature quality using the QUADAS-2 critiquing tool

Study	Risk of bias				Applicability concerns		
	Patient selection	Index test	Reference standard	Flow and timing	Patient selection	Index test	Reference standard
Anderson et al. (2008)	L	L	L	U	L	L	L
Eladawi et al. (2022)	L	L	L	L	L	L	L
Magee (2009)	L	L	L	L	L	L	L
Ochman et al. (2017)	U	L	L	U	U	L	L

Note: L, low risk of bias or concern regarding applicability; H, high risk of bias or concern regarding applicability; U, unclear risk or concern regarding applicability.

Participant characteristics and MRI protocols

A total of 145 participants were included in the four studies. The study design, participant demographics and study protocols of the four studies included in this review are outlined in Table 16. Minimal participant characteristics were reported in these studies; only two studies referred to age (Eladawi et al., 2022; Ochman et al., 2017), and only one study (Eladawi et al., 2022) reported on gender. All of the studies used arthroscopy as their reference standard.

The overall aim of MRI protocols is to maximise the information provided by a scan, which can be achieved by manipulating several variables. The technical considerations that were routinely reported included patient position, slice thickness, the presence of a wrist coil and scan views. Overall, the MRI protocols between the four studies were similar, therefore comparison of results between the results was possible. However,

some studies failed to document certain technical aspects. Ochman et al. (2017) was the only study that failed to report on patient position during scanning. All the remaining studies used the same standardised 'superman' position, where the patient is lying pronated with the affected arm in an overhead and elevated position and the elbow joint in pronation. All studies used coronal, sagittal and axial planes of view. The inclusion of wrist coils, which were used in all four of the studies that reviewed 3.0T MRI, aided in optimizing imaging by improving the signal-to-noise ratio. Slice thickness impacts scan resolution, i.e., a small thickness resulted in an increased resolution but a reduced signal, and a larger slice thickness reduced resolution but increased the scan signal. The slice thickness was not reported in Anderson et al. (2008) and varied in the other three studies; 1.0 mm in Eladawi et al. (2022), 1.5 mm in Ochman et al. (2017) and 2.0 mm in Magee (2009) , which was within the standardised and recommended range of <2.0 mm.

Table 16.

The MRI diagnostic accuracy characteristics, based on the studies derived from the literature search

Study	Participant demographics	MRI protocol					Criterion measure
		Field strength	Views	Position	Wrist coil	Slice thickness	
Anderson et al. (2008)	N = 32 Gender: not stated Age: not stated	3 Tesla	Coronal, sagittal, and axial planes	Superman position	At scanner isocentre	Not reported	Arthroscopy
Eladawi et al. (2022)	N = 46 Gender: not stated Age: mean 37.6 years (SD 12 years)	3 Tesla	Coronal, sagittal, and axial planes	Not stated	At scanner isocentre	1.0mm	Arthroscopy
Magee (2009)	N = 49 Gender: not stated Age: not stated	3 Tesla	Coronal, sagittal, and axial planes	Superman position	At scanner isocentre	2 mm; 10% interslice gap	Arthroscopy
Ochman et al. (2017)	N = 18 Gender: 6 females, 12 males Age: Mean 34.8 years (range 17–51)	3 Tesla	Coronal, sagittal, and axial planes	Not stated	At scanner isocentre	1.5mm	Arthroscopy

Note: N: number. mm, millimetre. SD: Standard deviation, Superman position: prone position, elbow extended overhead, wrist pronated

The diagnostic accuracy of 3.0T MRI

The diagnostic accuracy results for all studies that investigated the use of 3.0T MRI for detecting TFCC injuries are outlined in Table 17. The two reviewers in Anderson et al. (2008) were reported as a combined result, whilst in Ochman et al. (2017) was reported individually.

Table 17.

Statistical results for the diagnostic accuracy of 3.0T MRI for diagnosing TFCC injuries

Study	Sn	Sp	PPV	NPV
Anderson et al. (2008)	0.90 95% CI [0.72, 0.95]	0.74 95% CI [0.54, 0.85]		
Eladawi et al. (2022)	1.0	0.86	0.89	1.0
Magee (2009)	0.86	1.0		
Ochman et al. (2017)	Reviewer 1: 0.83	0.42	0.42	0.83
	Reviewer 2: 0.83	0.63	0.45	0.63

Note: CI, confidence interval; NPV, negative predictive value; PPV, positive predictive value; Sn, sensitivity; Sp, specificity.

The data suggests that 3.0T MRI has moderate to high diagnostic accuracy for diagnosing TFCC injuries. Specificity values varied from 0.42–to 1.0; high specificity values were reported by Anderson et al. (2008) (0.74), Eladawi et al. (2022) (0.86) and by Magee (2009) (1.0). Conversely, low-to-moderate values were reported in Ochman et al. (2017), based on two reviewers, at 0.42 and 0.63, respectively. Eladawi et al. (2022) reported a reasonable PPV of 0.89; however, this was not consistent with the two reviewers in Ochman et al. (2017), who reported a PPV of 0.42 and 0.45, respectively. Positive likelihood ratios were not reported by any study.

Conversely, 3.0T MRI has high utility for excluding TFCC injuries. Eladawi et al. (2022) demonstrated that perfect sensitivity and negative predictive values indicated the non-detection of TFCC injuries on MRI is strong evidence that there is not any injury to the TFCC. This was also observed in Ochman et al. (2017), who reported high levels of sensitivity (0.83, as reported by both of their two reviewers) and moderate negative predictive values (0.83 and 0.63). Although Anderson et al. (2008) and Magee (2009) did not report on NPV, these studies also reported high sensitivity values of 0.9 and

0.86, respectively. Negative likelihood ratios were not reported by any study. The reported high specificity and negative predictive values shown indicated reasonable confidence for the ability of 3.0T MRI scans to exclude TFCC injuries.

3.7 Discussion

The review examined the literature that investigated the reliability and accuracy of provocative tests, and the accuracy of 3.0T MRI to diagnose TFCC injuries. Overall, TFCC diagnostic tests exhibited high inter and intra-rater reliability, however was limited in its accuracy to detect TFCC injuries. Based on four high quality studies, 3.0T MRI, was shown to be an accurate investigative tool to detect TFCC injuries. The review highlighted that many of the diagnostic tests have not been investigated for either their reliability or diagnostic accuracy as it relates to TFCC injuries thereby limiting their clinical utility.

3.7.1 Reliability and diagnostic accuracy of the diagnostic tests

The following section discusses the review findings for individual diagnostic tests to provide the reader with a summary of the clinical utility of each test.

The ulnar fovea sign

The ulnar fovea sign has not been evaluated for its reliability. It was, however, investigated for its accuracy by Tay et al. (2007) and Schmauss et al. (2016), with the two studies reporting high (Tay et al., 2007) and low (Schmauss et al., 2016) levels of accuracy. The usefulness of the ulnar fovea sign therefore remains contentious. The quality of the two above studies would also have impacted the results they provided. In this regard, the study by Tay et al. (2007) scored well on the QUADAS-2 and provided robust data. Conversely, the QUADAS-2 tool highlighted some concerns regarding the research conducted by Schmauss et al. (2016) in relation to the risk of bias and missing reported data. The fact that the ulnar fovea sign's reliability has not been assessed may play a role in the lack of consensus reported between the two studies. However, the ulnar fovea manoeuvre is a static test, with its target zone clearly identifiable using prominent anatomical landmarks. These factors will assist in test reproducibility and may positively impact inter-rater reliability. Conversely, the force transmission that is applied when conducting this test potentially negatively impacts reliability, as it may vary between therapists and is individualised to the

patient due to variability of subjective pain intensity and level of irritability, or if associated swelling or anatomical differences limited access into the testing zone.

The grind test

The grind test has not been evaluated for reliability. It has been investigated by three studies (Nakamura et al., 1997; Ruston et al., 2013; Schmauss et al., 2016) for accuracy. The lack of statistical analysis undertaken in the research conducted by Nakamura et al. (1997) impacted the ability to compare results between studies. The study by Ruston et al. (2013) indicated that the grind test had reasonable ability to confirm TFCC injuries. Unfortunately, this was not supported by other studies investigating the grind test, with Schmauss et al. (2016) and Nakamura et al. (1997), reporting limited ability to confirm TFCC injuries. Nakamura et al. (1997), summarised that a positive grind test may indicate several various ulnar-sided wrist pathologies, but it was not highly specific to a particular pathology (e.g., TFCC injuries); as such, they indicated that a positive test was sufficient for warranting further investigative methods. Given the high variations and conflicting results reported between these three studies, the clinical utility of the grind test for diagnosing TFCC injuries is contentious and cannot be recommended.

The shear test

The reliability of this test has not been investigated. The shear test was evaluated by both LaStayo and Howell (1995) and Prosser et al. (2011) for its accuracy in diagnosing TFCC injuries. Both studies reported similar results, despite Prosser et al. (2011) only reporting one statistical metric, in that the accuracy of shear test for diagnosing TFCC injuries was limited, with low levels of accuracy to confirm TFCC injuries, which failed to meet acceptable thresholds to be used as an isolated test. Based on the results of the review the shear test cannot currently be recommended.

The DRUJ ballottement test

The DRUJ ballottement test was evaluated by two studies for inter-rater reliability (Lindau et al., 2002; Scheer et al., 2010). Both studies used a kappa value to report the reliability indicating an almost perfect and substantial strength of agreement according to Landis and Koch (1977). Although there was a difference in kappa values between the two studies, both achieved accepted thresholds and, as such, advocated for the

inter-rater reliability of the DRUJ ballottement test. Intra-rater reliability has not been evaluated.

The DRUJ ballottement was evaluated for diagnostic accuracy by two studies, but there was a lack of consistency between the studies. The results by Lindau et al. (2000) reported indicated high levels of accuracy to confirm TFCC injuries, and minimal usefulness of excluding TFCC injuries. In contrast, Prosser et al. (2011) showed limited usefulness. However, the calculated confidence intervals in Lindau et al. (2000) were wide indicating poor precision for the estimates of accuracy. The findings of these studies suggest that DRUJ ballottement test should not be relied on to be used as a stand-alone test.

Peak torque strength

The peak torque strength was evaluated for reliability by Andersson et al. (2016), who reported excellent intra- and inter-rater reliability. Its diagnostic accuracy for TFCC injuries has not been determined.

The press test

The press test has not been investigated for Its reliability. Its diagnostic accuracy was investigated by Lester et al. (1995), who reported that it had 100% sensitivity. These authors did not report other measures of diagnostic accuracy. This, together with methodological issues with the study, makes it very difficult to interpret their results. Therefore, the press test cannot be conclusively relied upon for ruling in a TFCC diagnosis.

The push-off test

The push-off test was evaluated for its reliability by Vincent et al. (2014) and Mehta et al. (2019). Both of these studies reported similar high inter-rater reliability with ICCs that met acceptable thresholds, the push-off test is indicated as being a reliable test between therapists. Intra-rater reliability has not been investigated. No studies have been found that investigated for accuracy, so the ability of the push-off test to detect or exclude TFCC injuries is unknown.

The quality of the included studies

The QAREL tool was used to evaluate the quality of the reliability studies that were included in this review, which four studies (Andersson et al., 2016; Lindau et al., 2002; Mehta et al., 2019; Scheer et al., 2010) achieved the threshold to indicate good quality. One study (Vincent et al., 2014) was slightly below this threshold, indicating it as being of lower quality.

All of the diagnostic accuracy studies reflected being of a moderate quality. In particular studies that were conducted by Prosser et al. (2011), Nakamura et al. (1997) and Andersson et al. (2016) reflected a lower risk of bias compared to Ruston et al. (2013), Vincent et al., (2014) and Scheer et al. (2010). This was to some degree influenced by the methodological approach.

Design

Prospective and retrospective study designs were both utilised in the included studies. Retrospective studies in particular are subject to both internal and external validity threats which can impact the reliability, interpretation and generalisability of research results (Tofthagen, 2012). Retrospective studies can capture data involving large populations, which in prospective studies is often considered unfeasible due to time, recruitment and financial limitations. However, they are reliant on the record-keeping of multiple clinical staff, which can lead to issues such as incomplete data, test selection bias, differences in test personnel as well as in the interpretation of results. This was seen in the studies completed by Schmauss et al. (2016) and Tay et al. (2007), both of which included more than 250 participants each, but had the largest percentage of participant dropouts, due to insufficient data.

Participant selection

The target population and inclusion/exclusion criteria were clearly stated in all of the reviewed studies. A few studies looked beyond suspected TFCC injuries or ulnar wrist pain. Four studies (LaStayo & Howell, 1995; Prosser et al., 2011; Ruston et al., 2013; Vincent et al., 2014) included participants who had a range of upper limb complaints and used multiple diagnostic tests. Prosser et al. (2011), Ruston et al. (2013) and LaStayo and Howell (1995) assessed multiple wrist diagnostic test for TFCC, LT and SL ligament injuries, in participants with wrist pain. In Vincent et al. (2014) the same diagnostic test was used if participants had elbow or wrist pain. Subsequently, given

that the participant cohorts were not isolated to ulnocarpal pain or suspected TFCC injuries, the generalisability of the results obtained by these studies for the population with TFCC injuries was reduced. Participants with known alterations to carpal anatomy due to previous surgery or trauma were routinely excluded from participant cohorts. The exception for this occurred in the study conducted by Scheer et al. (2010), who specifically recruited participants following a distal radius fracture to assess DRUJ instability. Considering the focus of this study on a particular cohort, its reported results are highly relevant to those with a post-distal radius fracture; however, this means it has less relatability for those without this particular pathology. Accordingly, care should be taken where these results are applied to different populations.

Participant selection in two studies (Schmauss et al., 2016; Tay et al., 2007) only included those who were under specialist care and were undergoing arthroscopic investigation. This may potentially have reduced the generalisability of the results to the primary care cohort. By only including this population group, studies may have excluded participants with no or low-grade traumatic TFCC injuries from their data, thereby creating bias.

Participant demographics were relatively well-described by the majority of the reviewed studies. However, in a few studies, these were not identified (LaStayo & Howell, 1995; Tay et al., 2007); some studies also did not clarify whether their patients were solely limited to those who had suffered a traumatic event. The implication of this is that participants may have had confounding co-morbidities, and TFCC-related pain may have been attributed to degenerative pathological changes. Thus, including this population within study cohorts will impact the results, and statistical analyses may be inaccurate and misleading.

Reference standard

In the accuracy studies, arthroscopy was used as the criterion measure for diagnosing TFCC injuries; however, a few studies also included MRI. The use of arthroscopic investigation in these studies echoes the widely regarded notion of it being the gold-standard approach for diagnosing TFCC injuries. The use of MRI in these studies reflected its application in emergent research literature in musculoskeletal injury

imaging (Crues & Bydder, 2007; Deyle, 2011; Heiss-Dunlop; Potter et al., 1997; Skalski et al., 2016; Smith et al., 2012).

Reporting

Dropouts were not reported in any of the diagnostic accuracy studies, nor in the majority of the reliability studies. Only Andersson et al. (2016) reported an excluded participant following data collection, which had been due to inconclusive imaging of the reference standard arthroscopy, which could not be used for a secondary review. Incomplete data was a common theme throughout the retrospectively designed studies. The inconsistency of data restricted statistical analysis, thus reducing the power of the results. Ruston et al. (2013) excluded a large percentage of participants (25%) (n = 22/88) due to incomplete data when auditing their research notes. In Schmauss et al. (2016), among 908 arthroscopies, the authors identified 603 patients that had ulnocarpal pain and suspected TFCC injuries, however, only 255 of these had both an ulnar fovea test and an MRI scan; accordingly, 57.7% of participants were calculated as having had incomplete data sets.

Statistical analysis

In the reliability literature review, all studies reported on inter-rater reliability, but only two studies (Andersson et al., 2016; Vincent et al., 2014) reported intra-rater reliability. Some studies only reported the inter-rater reliability for the affected limb, (Andersson et al., 2016; Lindau et al., 2002), and others reported both affected and contralateral limbs (Mehta et al., 2019; Vincent et al., 2014). In the study by Scheer et al. (2010), the DRUJ ballottement test was not the primary focus of evaluation, and an intra-rater reliability investigation was only undertaken to determine the reliability of the authors' reference standard.

A lack of reported statistical analysis was a common issue throughout several of the studies reviewed for diagnostic accuracy. To a degree, this was addressed by this researcher by using raw data provided by the authors to calculate missing measures associated confidence intervals. Unfortunately this was not able to be done across all papers, with three papers not providing raw data (Lester et al., 1995; Nakamura et al., 1997; Ruston et al., 2013).

Comparison with other reviews

No systematic reviews were identified that purely investigated ulnar-sided wrist pain or TFCC injuries specifically. However, two systematic reviews were identified that assessed diagnostic tests for a range of upper limb joints, including the ulnar wrist and the TFCC. Andersson et al. (2015) conducted a systematic review of MRI and clinical provocative tests for wrist injuries, including radial, central and ulnar wrist regions. However, only one of their included studies assessed a TFCC diagnostic test (shear test), which failed to reached standard thresholds and therefore was on limited benefit for determining TFCC injuries. The review by Valdes and LaStayo (2013) focused on diagnostic tests for wrist and elbow joints for both ligamentous, muscular and neural structures. Among the 13 provocative tests included, four specifically assessed the TFCC region. They reported that only ulnar fovea sign and the press test were deemed of reasonable quality and fit their criteria of recommended tests. However, both the shear and grind tests were classified into a neutral/no decision category due to their low likelihood ratios. These results are similar to the results shown in this literature review and therefore are supportive of its conclusions, which identified that ulnar fovea sign was shown to have some value in determining TFCC injuries. The shear has low recommendation for use. However, the grind test may have some clinical utility but uncertain with conflicting evidence.

Literature gaps

The review highlighted several gaps in the literature regarding diagnostic tests to determine TFCC injuries. These include the multiple number of TFCC diagnostic tests, the limited number of diagnostic tests investigated, the lack of combined assessments, and the populations that were recruited.

Many of the tests located test identical structures, with slight changes in technique or test outcome. To accommodate this, to a certain degree, TFCC diagnostic test were categorised according to mechanical action. For those tests with differing test responses, whether that was presence of pain, or laxity, or quantification of score of weight or strength, this was not possible. For example, the piano key test and the DRUJ ballottement test, which both assess the DRUJ, fall into this category. The DRUJ ballottement test typically assesses the amount of laxity, while the piano key test is purely a pain provoking test and is considered positive if familiar pain can be

reproduced. No studies evaluating the piano key test, nor any variation of this test that met the review's inclusion/exclusion criteria were located for either reliability or accuracy.

Intra- and inter-rater reliability were investigated for a limited number of TFCC diagnostic tests. However, the tests that did undergo reliability assessment were not the same tests that were investigated for accuracy, thus limiting their recommendation for clinical practice. If these diagnostic tests are proven to be reliable, this data will be particularly beneficial for indicating confirmation or exclusion of diagnoses and the progression of injuries.

Many additional TFCC diagnostic tests have not been investigated for either reliability or diagnostic accuracy, despite their frequent clinical use. The wrist weightbearing test was an alternative method to the push-off test for assessing weightbearing. This test was previously investigated, determining the standardised values in a normal population (Barlow et al., 2020) and in terms of the effect of wrist bracing on weightbearing capacity in TFCC injured populations (Asmus et al., 2021). The study by Asmus et al. (2021) showed a significant reduction in weightbearing capacity in TFCC injured populations but failed to report the diagnostic accuracy or reliability of this test as a diagnostic method in TFCC-injured populations. The current review did not identify any study that investigated the gripping rotatory impaction test (GRIT) and its diagnostic accuracy or reliability for determining TFCC injuries. The GRIT is a provocative wrist test that was originally intended for the assessment of ulnocarpal impaction (between the articular surface of the ulna, triquetrum and lunate bones) (LaStayo & Weiss, 2001; Prosser et al., 2011). However, the GRIT is commonly clinically used as an assessment tool for determining a traumatic TFCC injury, given that its mechanical aim is to impinge the articular TFCC disc (Kirchberger et al., 2015; Skirven et al., 2011). The rationale for using the GRIT as a TFCC diagnostic test is that during rotation, the gap between the ulna and carpal bones reduces, causing impingement of the ulnocarpal joint, which is likely to provoke pain in an individual with a traumatic TFCC injury. In the original GRIT validity study by LaStayo and Weiss (2001), the justification for the use of a ratio as a positive or negative test outcome was that during pronation with gripping, there is an increase in force transmission, with the ulna migrating distally; this forces the articular disc against the carpal bones, compared to

the decrease that occurs during supination with gripping. Therefore, with TFCC injuries, gripping in pronation will reproduce pain and grip strength will hypothetically reduce. Additionally, the radioulnar ligaments contract during rotation to provide stability to the distal radioulnar joint (Altman, 2016). Thus, when the TFCC is injured, the patient's ability to produce pain-free grip strength at end-range rotation will be impaired (LaStayo & Lee, 2006; LaStayo & Weiss, 2001). This was further confirmed in the study by Andersson et al. (2015), who investigated rotational torque in TFCC injuries. The authors found on average a 30% reduction in torque strength in the case of arthroscopically diagnosed TFCC injuries.

The common clinical practice of utilising multiple aspects of the clinical examination in combination, such as patients' history, or using multiple diagnostic tests has to date not been investigated. The premise of using multiple variables aims to increase the accuracy or predictability of TFCC injuries and, in doing so, reflects the known accuracy limitations of the tests and the multi-structure complexity of the TFCC. No studies were identified that investigated a combination of diagnostic tests or clinical factors as a method to increase predictability of TFCC injuries. Only the study by Schmauss et al. (2016) investigated the diagnostic accuracy of two tests (the ulnar fovea sign and grind tests, respectively); this was because this paper was retrospective in nature, and the tests were performed on separate participant cohorts. As such, the authors were unable to perform statistical analysis calculations concerning the effects of these tests when combined because not every participant underwent both tests.

The populations that were included in the reviewed studies were those that often underwent arthroscopic investigation. This implied that the included participants had a significant or prolonged injury and symptoms; this is because arthroscopic investigation is not routinely performed in cases of acute or low-grade injuries. This indicated that these participants had significant or chronic injuries, as opposed to acute or low-grade injuries. In the current author's experience and clinical practice, a referral to orthopaedic specialists would be considered for patients that present with acutely significant instability, the failure of progression based on conservative treatment, or chronic non-improving symptoms. Depending on the severity of an injury, including clinical signs and pain intensity, this may happen in the acute stages, e.g., the first few weeks; more commonly, however, this will take place after 8–12

weeks post-date of injury, following a period of rehabilitation. However, the population of patients that require onward referrals does not represent the bulk of clinical caseloads, which frequently comprise low to moderate sprains that successfully resolve with time and a comprehensive rehabilitation programme. Therefore, the accuracy and reliability in this low-grade population have not been thoroughly investigated, and it is yet to be determined whether these values differ within this population.

3.7.2 The diagnostic accuracy of 3.0 Tesla MRI for TFCC injuries

Four studies of high quality that investigated the diagnostic accuracy of 3.0T MRI scans for detecting TFCC injuries were reviewed. The results indicated that 3.0T MRI scans have reasonable levels of accuracy to determine TFCC injuries.

Quality of included studies

Overall, the studies included in the present review were well-conducted and the QUADAS-2 tool indicated a low risk of bias and appropriate application of study protocols. Specifically, their description of the technical considerations of MRI, including position, slice thickness, views and patient positions were well-reported, enabling direct comparisons and replication. The technical considerations may have impact upon accuracy, such with wider slice thickness, potentially this may miss smaller tears. The scanning position that is often required is the standardised superman position, in which patients are placed in a prone position, with the elbow extended overhead and the wrist pronated. It is noted, however, that this position relies on patients' ability to tolerate full shoulder flexion and elbow extension, which may not be achievable by all patients with wrist pain.

Participant selection

One of the main limitations of the MRI review studies was that the majority failed to report participant characteristics. One of the variables that were reported was age. In both Eladawi et al. (2022) and Ochman et al. (2017), the average age of participants was relatively young (37.6 and 34.8 years, respectively). Gender was only reported by Ochman et al. (2017); the research reported that 66.6% of the participants had been male. These factors concerning gender and a younger age range could potentially

reflect a mechanism of injury; however, as none of the studies reported on this aspect, this could not be determined.

Comparison with other reviews

There are no other reviews specifically evaluating the accuracy of 3.0T MRI for TFCC injuries. Previous reviews have included various MRI field strengths (Andersson et al., 2015; Hobby et al., 2000; Smith et al., 2012; Treiser et al., 2018; Wang et al., 2015), which indicated that MRI is accurate method to detect and exclude TFCC injuries. The results from this review correlate well with these previous reviews. Despite the increase in magnetic strength and hypothesis that increased field strength may yield higher rates of accuracy a literature review was conducted on 3.0T MRI accuracy for TFCC injuries, the results of this review showed that accuracy of 3.0T MRI was comparable with existing reviews of MRI studies at lower field strengths. However further research of 3.0T field strength and direct comparison would be beneficial.

3.7.3 Clinical relevance

In clinical practice diagnostic tests are widely used to diagnose ulnar wrist injuries. Often these tests are clinically used with an infallible belief, in that a positive test correlates to a positive diagnosis and a negative test response subsequently rules out diagnosis. This notion and clinical approach may be due to therapist lack of awareness of current literature, or not understanding the metrics of diagnostic accuracy. The results of this review challenges that clinical practise and highlights the significant failings of these tests, which indicates they are less conclusive in regards to their diagnostic ability than widely believed. The results shown in this review, is not too dissimilar to diagnostic tests of the glenohumeral joint, in which recent studies have highlighted the limited ability of diagnostic tests to accurately detect shoulder joint pathology (Hegedus et al., 2008)

3.7.4 Limitations of the reviews

The included participant cohorts in the reviewed studies were primarily those who were receiving specialist care and required a high level of investigation or intervention, such as arthroscopy. This indicated that this population had substantial and/or chronic injuries/symptoms, which was to likely include participants with degenerative TFCC

pathologies. It is therefore not possible to determine diagnostic accuracy of TFCC diagnostic tests on a solely acute traumatic TFCC injury population.

Other limitations of this review, included that the requirement of including only studies that were reported in English led to the exclusion of some papers. To ascertain the risk of bias within individual studies, the QUADAS-2 critiquing tool and QAREL scores were used. Both of these quality assessment tools have associated limitations, however, including a lack of a quantitative score to indicate levels of quality. They do not report on the methodological quality of the study, nor do they place increased importance or weight on particular essential questions.

Finally, a meta-analysis was not undertaken in this thesis, due to lack of available papers and variable statistical reporting, and the constraints of a master's level thesis. Being able to compare results between papers could provide more robust support for the use of TFCC diagnostic tests and the accuracy of 3.0T MRI scans.

3.7.5 Future direction

Considering the limitations reported in the current review of the body of literature included herein, in conjunction with the clinical importance placed on diagnostic TCCC tests, it will be beneficial to prospectively establish the reliability and effectiveness of individual, as well as a cluster of diagnostic tests, in a homogenous population for which a TFCC injury is suspected, while also considering and accounting for methodological inconsistencies. Given that no one conclusive test was identified for diagnosing TFCC injuries, a combination of relevant tests or other elements of the clinical examination may increase predictability, which could provide clinicians with certainty regarding diagnosis.

3.8 Conclusions

In summary, the review found that clinical tests have limited ability to accurately diagnose a TFCC injury. In addition, the accuracy of MRI to detect TFCC injuries was shown to have high levels of accuracy for both confirming and excluding TFCC injuries, thereby supporting its suitability as a reference standard.

The results of the TFCC diagnostic test review suggested that the diagnostic tests had high levels of intra- and interrater reliability. This reinforces their ability to consistently

reassess at the same level between sessions and therapists if a standardised protocol is followed. The clinical utility of using diagnostic tests to diagnose TFCC injuries was limited, with a small number of studies of moderate to excellent quality, showing frequently conflicting results. Often the included studies failed to meet the standardised threshold values for validating their use in TFCC injury diagnoses; nonetheless, they may generate small changes in the probability to do so. Based on the current literature review, no single test is conclusively useful for making a TFCC injury diagnosis. The ulnar fovea sign has some value for ruling in and excluding TFCC injuries. The grind test and DRUJ ballottement may have some clinical utility but given the conflicting evidence, caution should be used. The shear test reflects low recommendation and the push-off test is not recommended for TFCC diagnosis. However, there are significant limitations and gaps in the current literature, which has investigated the diagnostic accuracy of provocative tests in a TFCC injury. In particular, these limitations relate to the methodological approach, including participant recruitment, statistical analysis, and the reported participant characteristics. Furthermore, the tests that were assessed for validity were not assessed for reliability, which was likely a compounding factor in the conflicting results, and reduced the ability for recommendation in clinical practice.

The lack of consensus and the methodological issues of the existing evidence show a clear need for a prospective study that investigates the diagnostic accuracy of clinical tests in an acute ulnar sided injury population. The following chapter presents a study that investigates the accuracy of clinical examination, specifically five diagnostic tests to determine TFCC injuries.

Chapter 4: The diagnostic accuracy and inter-rater reliability study of TFCC injuries

4.1 Introduction

This chapter outlines the methodological process and considerations undertaken for the main study in this thesis. The purpose of this study was to establish the inter-rater reliability and diagnostic accuracy of TFCC diagnostic tests. Statistical analysis was conducted for individual diagnostic tests and various combinations of individual elements within the clinical examination. The study also considered the value of information obtained from the patient interview such as the mechanism of injury and patient symptoms.

4.2 Methods

4.2.1 Ethics

The Auckland University of Technology Ethics Committee (AUTEC) (reference number, 19/74) (see Appendix C) granted ethical approval for conducting the study.

4.2.2 Study design

This study was a prospective study of participants who were suspected of having sustained traumatic TFCC injuries. The study had two components, a diagnostic accuracy component and an inter-rater reliability component. These were conducted in parallel using a single cohort of participants.

4.2.3 Sample-size calculation

Sample-size calculations were determined in conjunction with Associate Professor Alain Vandal, a biostatistician from The University of Auckland. The sample size was informed by the results of a four-month audit of a central Auckland private hand therapy clinic (Handworks) performed by the researcher prior to the start of this study. This audit revealed that 150 patients had been assessed and treated for acute ulnar-sided wrist pain, of whom 38 (25%) underwent MRI scanning. Findings from the MRI scan demonstrated that approximately 1 in 4 individuals had a TFCC injury. Initial sample size calculations estimated that data on approximately 80 participants would need to be collected over 12 months, taking into account consent and retention rates

of 70%, (Hintze, 2014). Regrettably, due to the impact of the global Coronavirus 2019 pandemic and subsequent lockdowns in 2020, a sample size of this magnitude was impossible to achieve within the timeframe of a Master's thesis. Hence, the sample size was recalculated based on this study being a pilot study. The final sample size was to include a minimum of 16 participants. The expected precision of the study estimates was quantified by auditing the clinical prevalence estimate and the expected number of participant calculations. The authors defined 'imprecision' as the expected half-width of 90% confidence intervals for the estimate. Assuming values of 80% for both sensitivity and specificity, the imprecisions were 8.5% and 14.4% for these quantities, respectively. These values increased to 9.8% and 16.5%, respectively, under an assumed sensitivity and specificity of 70% each, and decreased to 6.8% and 10.4% for a common value of 90%. These values were considered sufficiently reasonable for justifying a pilot study that addressed the research questions.

4.2.4 Referring specialists

Participants were recruited from Auckland-based orthopaedic hand specialists. The specialist orthopaedic hand surgeons who were included for participant recruitment were Mr Wolfgang Heiss-Dunlop, Mr Christopher Taylor, Mr Adam Durrant, Mr Tom Maxwell, Mr Albert Yoon, and Mr John Mutu-Grigg. Privately, all specialists working within the Auckland region who also routinely accepted referred patients from the greater Auckland and Northland regions. Mr Heiss-Dunlop, Mr Taylor, Mr Durrant and Mr Maxwell also worked at Counties Manukau Health as senior consultants as part of a specialist hands team, while Mr Yoon was a senior consultant for the Waitamatā District Health Board. All specialists had international training and experience, and were fellows of the Royal Australasian College of Surgeons.

4.2.5 Examiners

All participants were assessed by the primary researcher (Rebecca Tuhi), a physiotherapist and registered hand therapist with 10 years of clinical experience who has completed a Masters of Health Practice in Rehabilitation. As part of the inter-rater reliability portion of this study, a select number of participants were also assessed by a second researcher (known as a 'research assistant' henceforth), either Sarah Waldin or Rochelle Molloy, both of whom are physiotherapists and registered hand therapists with, respectively, 25- and 15-years' clinical experience.

4.2.6 Participants

Participants with ulnar-sided wrist pain were recruited from the hand orthopaedic specialists described above. The inclusion criteria were patients over the age of 18 years with ulnar-sided wrist pain that had resulted from a traumatic incident. Participants had to have had symptoms over four weeks, but there was no upper limit on time from injury to specialist referral. Potential participants had to have a good understanding of the English language or have an interpreter available. They were all required to be under the care of an orthopaedic hand specialist and to have been referred for MRI scans as part of their diagnostic work-up. Potential participants were excluded if they had a history of significant upper limb trauma or had any medical conditions that impacted their functional ability, including either neurological or arthritic conditions such as stroke, spinal cord injuries, or rheumatoid arthritis. Patients with a history of previous wrist fractures or wrist surgery were not excluded.

4.2.7 Reference standard

The reference standard for confirmation of a TFCC injury was the diagnosis made by the participants' specialist. Specialist diagnoses were based on their clinical assessment of participants in combination with MRI results. TFCC injuries had to be confirmed by MRI, and any other pathology present was also noted. All specialists used radiology services that utilised T2-weighted 3.0T-MRI scans. Positive reference test (PRT) will be used to denote a confirmed TFCC injury. Negative reference test (NRT) will be used to denote an excluded TFCC injury.

Contact was made with the participants' respective orthopaedic specialist by the primary researcher to confirm their diagnosis following their MRI appointment. All specialists completed a patient diagnosis form (see

Appendix O), which included information about their diagnosis and confirmed MRI results. Any confirmed TFCC injuries were also classified according to the Palmer classification scale, by the specialist. Radiology services were contacted by the primary researcher to request the formal MRI reports, which were summarised as part of the radiology report (see Appendix P).

4.2.8 Procedure

Participant recruitment

The recruitment of participants was facilitated through hand-orthopaedic specialists. Prior to starting this project, all participating surgeons were advised about the study aims, recruitment procedures, and participation criteria. Appropriate patients were provided with the study pamphlet, study information sheet and an expression of interest form by their specialist (see Appendix D). Patients who expressed a desire to participate in this study, completed the expression of interest form and left it with the hand specialists' administrative team. This was then emailed to the primary researcher who then contacted the patient.

Screening of potential participants

Potential participants were contacted via telephone by the primary researcher. The study was explained, that participation was voluntary and it would not impact their current treatment plan. Participants were given the opportunity to ask any questions or concerns they may have had. The primary researcher asked all questions from the screening questionnaire (see Appendix G) to determine their appropriateness for the study and determined their current level of pain and degree of irritability. Following this conversation, if participants were considered appropriate for inclusion and were happy to participate in the study, they were given an appointment for data collection that was made to fall within the four weeks before or after their upcoming MRI scan. The four-week timeframe was determined to ensure that the participants' radiological findings and assessment findings were based on similar levels of injury, irritability, and possible degree of pathology. All participants were emailed confirmation of their data collection appointment time and location, as well as copies of the study information sheet and consent form (see Appendix H). Twenty-four hours before the data collection appointment a confirmation text message was sent.

Data collection

The data collection appointment was conducted at one of the Handworks clinics located in central and eastern Auckland, or at the AUT Integrative Health clinic in Auckland's North Shore. This appointment lasted approximately 45–60 minutes. On arrival, participants were advised about research study, process and that participation was voluntary. They were given the opportunity to ask any questions or concerns they had. Participants completed written consent forms, which included both the diagnostic accuracy and reliability studies. Participants firstly underwent a physical examination. Following this, a patient interview was conducted and standardised questionnaires completed. For participants that were included as a part of the inter-rater reliability study, based on participants consent and level of irritability, the clinical assessment was performed twice, once by the primary researcher and once by the research assistant. For this group of participants, there was a minimum 30-minute gap between the two physical assessments.

Blinding

Participants were instructed not to provide any information about their condition until the data collection had been completed. The patient interview was purposely conducted the physical examination by the primary researcher, in order to not influence the physical examination results. The research assistants were blinded to the information obtained by the patient interview. The researchers were also blinded from each other's findings. All researchers were blinded to findings of the MRI and to the specialist's diagnosis at the time of the assessment.

Data Collected

Patient interview

Information collected (for detail, see Appendix I) on participant demographics were age, gender, ethnicity, and occupation. Also, injury details, such as time since injury, mechanism of injury, symptoms, and aggravating and easing factors were collected. To quantify pain, the numerical pain rating scale (NPRS) was utilised. To determine functional ability and limitations, standardised questionnaires were employed. These comprised the global rate of change (GRoC), the patient-rated wrist hand evaluation (PRWHE) and the QuickDASH questionnaires (see Appendix J).

Physical examination

The physical examination (for detail, see Appendix L) comprised of standardised active and passive range of movement tests for the wrist and forearm, including wrist flexion, wrist extension, ulna deviation, radial deviation, supination, and pronation using standard goniometry techniques. Five TFCC diagnostic tests were performed, these were the ulnar fovea sign, piano key, grind, shear and the GRIT tests. Detail regarding the performance and interpretation of all procedures performed are provided in Appendix M. The order in which the diagnostic tests were conducted was randomised using an online computer based random number generator (Haahr, 1998).

4.2.9 Standardisation between research personnel

To ensure standardisation of the techniques and reliability among the research team (primary researcher and the research assistants), a training session was conducted before the start of the study. This included reviewing the study procedure and setting a standardised method of testing and interpretation of test results (see Appendix L, Appendix M, and Appendix N). The training session also included a practice data collection session involving a consenting patient, who had been receiving treatment at the time, to ensure that the techniques were correctly performed. Following the assessment of this patient, the primary researcher and research assistants met to discuss their findings to ensure consensus about their interpretation of the test findings.

4.3 Statistical analysis

Statistical analysis was undertaken with the assistance of Auckland University's biostatistician, Associate Professor Alain Vandal. The statistical analyses were conducted using the SPSS Statistics 24.0 software program (IBM, 2016, Armonk, NY), and R version 3.6 (R Core Team, 2022).

4.3.1 Inter-rater reliability

Inter-rater reliability regarding categorical variables was measured using unweighted Cohen's kappa (Cohen, 1960), prevalence-adjusted bias-adjusted kappa (PABAK) (Byrt et al., 1993), and intraclass coefficient (ICC) (Koo & Li, 2016) as well as percentage of agreement. ICC values below 0.5, or kappa-values (k-values) of 0.2 was considered to reflect reliability too poor for the test to be retained for the diagnostic accuracy

component of this study. Threshold for ICC and k-values to determine acceptable reliability was set at 0.80 and 0.40, respectively.

For continuous measures, notably range of motion and GRIT variables, a linear mixed model using 'participant' as random effect and 'assessor' as fixed effect was fitted using R package *lme4* (Bates et al., 2015). The ICC was estimated using the ratio of the estimated between-participant and total variance. Ninety-five percent confidence intervals for the true ICCs were obtained using the bootstrap (Efron & Tibshirani, 1993) on 1000 bootstrap replicates and identifying the 2.5 and 97.5 centiles.

4.3.2 The diagnostic accuracy of individual TFCC diagnostic tests

Key diagnostic accuracy statistical measures were calculated to determine the reliability and diagnostic accuracy of individual tests. Various measures of diagnostic accuracy were calculated including sensitivity, specificity, positive and negative likelihood ratios and predictive values. Each candidate predictor was examined in turn concerning its relationship with the reference standard (specialist diagnosis). The statistical significance of the predictors was assessed from simple logistic regression models fitted with a bias-reducing penalised likelihood (Firth, 1993).

4.3.3 The diagnostic accuracy of combinations of information obtained from the clinical examination

A set of 45 predictors was established a priori, from demographic characteristics and the results of the clinical examination and diagnostic tests. Binary predictors with fewer than four participants in one or the other category were excluded. Other predictors with descriptive variables were also excluded due to individual variations and inability to compare between participants. The remaining predictors were included in a logistic regression model using the lasso (Tibshirani, 1996). The logistic regression model had the form

$$\text{logit}(p_i) = \sum_{k=1}^{q} \beta_k x_{ik},$$

where $i = 1, \dots, n$ represents the participant, p_i the probability that participant i has a TFCC tear, x_{ik} the k^{th} predictor of participant i, β_i a coefficient to be estimated from the data, q is the number of non-excluded predictors and $\text{logit}(p) = \ln\left(\frac{p}{1-p}\right)$, also

known as the log-odds of p. The predictors x_{ik}, in our case were either binary ($x_{ik} \in \{0,1\}$), as in the result of a test, or non-negative continuous, as with age or pain scales.

The coefficients were estimated from the predictor data x_{ik} and the outcome data y_i, denoting presence ($y_i = 1$) or absence ($y_i = 0$) of a TFCC tear. When aiming for an explanatory model, estimation is affected using maximum likelihood, or equivalently maximum log-likelihood. However, the lasso penalises the log-likelihood by subtracting from it the penalty term $\lambda \times \sum_{k=1}^{q} |\beta_k|$, for some $\lambda > 0$. The maximum penalised-log-likelihood estimate $\hat{\beta} = [\hat{\beta}_1, \dots, \hat{\beta}_q]$ is thus shrunken towards zero, which reduces overfit and in so doing improves the predictive properties of the fitted value (Copas, 1997). The lasso has the property that increasing the value of λ will cause some, and eventually all, of the fitted values $\hat{\beta}_k$ to take on the value 0, thus effectively eliminating some predictors from the model.

The value of λ was selected to minimise a predictive criterion, in our case the proportion of misclassified diagnoses of TFCC tear or no TFCC tear. A fitted value $\hat{p}_i$ correctly classifies a diagnosis y_i if $\text{logit}(\hat{p}_i) < 0$ and $y_i = 0$, or if $\text{logit}(\hat{p}_i) > 0$ and $y_i = 1$. The estimated predictive criterion, for each λ, was obtained via ten-fold cross-validation, which involved partitioning the data randomly into ten subsets of approximately equal size. Holding out each of the subsets in turn, the model of interest was fitted on the remaining nine and the predictive criterion assessed in the subset that was held out. The results from the ten fits were then brought together to estimate the predictive criterion unbiasedly for the model in question and for a particular value of λ. The procedure was repeated for values of λ covering a fine grid, and the λ yielding the smallest misclassification proportion was selected. This implementation of the lasso was carried out using the *glmnet* package (Friedman et al., 2010) for the R statistical environment (R Core Team, 2022).

It is worth noting that, with the lasso, statistical significance does not play a role in the selection of the predictors: only prediction-related criteria are considered, and overfitting is mitigated by the use of cross-validation.

The result of the lasso-penalised model was an estimated coefficient vector $\hat{\beta} = [\hat{\beta}_1, \dots, \hat{\beta}_q]$, with several of the $\hat{\beta}_k$ potentially set to 0. From this $\hat{\beta}$, a predictive score

$s_j = \sum_{k=1}^{q} \hat{\beta}_k \, x_{jk}$ could be computed for any individual j, within or outside the study sample, with the property that higher values of s_j correspond to a larger probability of a TFCC tear. Further, the score can be converted to an estimated probability of a TFCC tear $\hat{p}_j = \frac{\exp(s_j)}{1+\exp(s_j)}$.

4.3.4 Sample size determination for a definitive study

To produce a definitive predictive model of TFCC tear, we used recently published methods (Riley et al., 2019). Predictive modelling sample size determination does not use the concept of power, but rather the concept of minimal global shrinkage, which can be estimated from the likelihood ratio statistic of a large model involving all potential predictors and a null model, given by $r = 2(\ell_{\text{Full}} - \ell_{\text{Null}})$.

To form the large model, we needed to limit the list of potential predictors to a number substantially smaller than the number of available observations. The set of potential predictors was therefore formed by the union of the lasso-selected predictors, as well as those lasso-excluded predictors with a significance level smaller than 0.3 in the simple penalised logistic regression models described in section 4.3.2.

The minimal sample size (N) to obtain global shrinkage s can then be computed as

$$N = \frac{q+1}{(s-1)} \log\left(\frac{s}{s-1+\exp\left(-\frac{r}{n}\right)}\right),$$

where q is the number of potential predictors and n the size of the training data (Riley et al., 2019).

4.4 Results

4.4.1 Participants

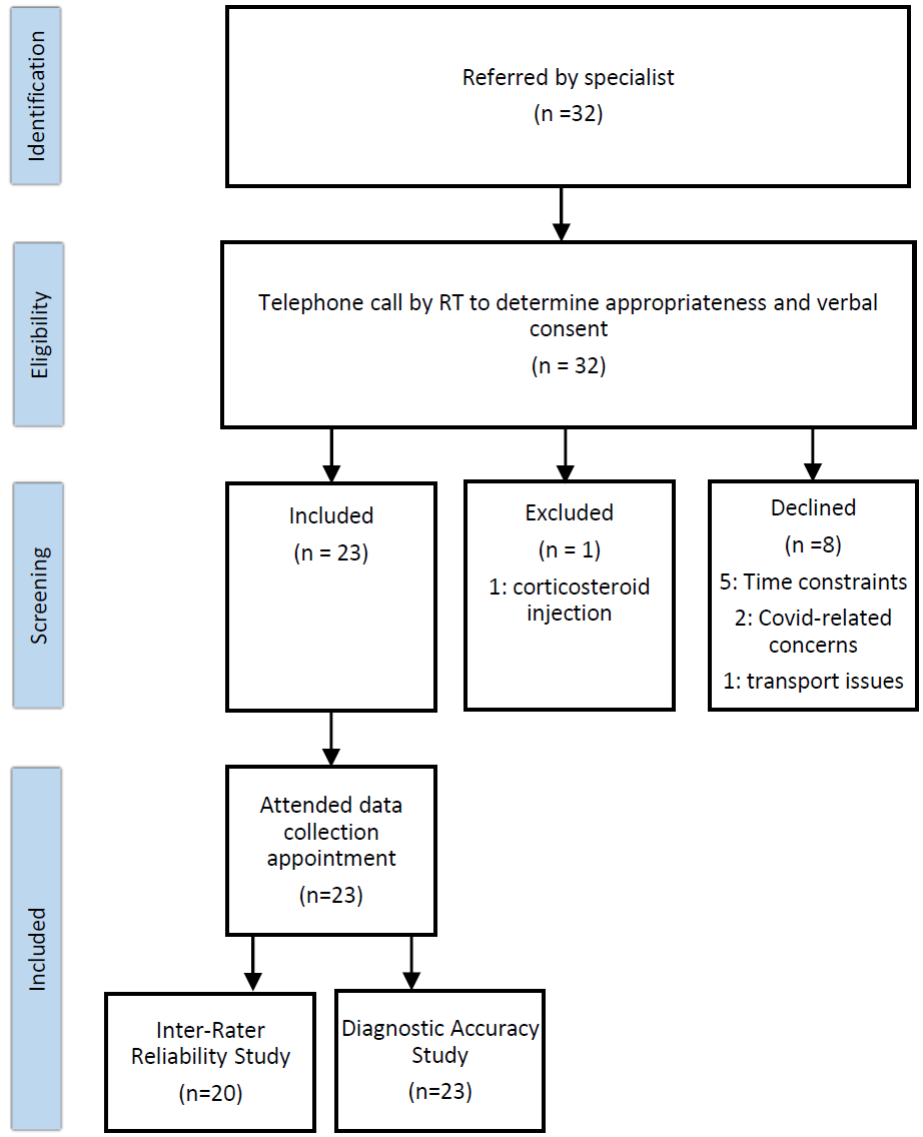
A total of 23 participants were recruited. All participants completed both the data collection appointment and had an MRI scan. Twenty participants also underwent a second clinical examination by the research assistant as part of the inter-rater reliability study. Of the 23 participants, 16 participants had a positive reference test (PRT) which was defined as a TFCC injury as determined by specialist diagnosis. Hence,

the pre-test probability of a proven TFCC injury in this cohort was 70% (16/23 x 100 = 69.6). Seven participants had a negative reference test (NRT).

As outlined in Figure 16 below, eight potential participants declined to participate in the study. Five of these indicated that the main reason for not participating was time constraints around family and work commitments, which was exacerbated by the pandemic-associated restrictions. Two participants voiced concerns over an additional appointment during the height of the pandemic, and anxiety related to the potential exposure of covid by attending a data collection appointment that was not a part of usual treatment. One participant had no transport to a local clinic in order to undergo the assessment. Finally, one further participant was ineligible after undergoing a corticosteroid injection the week prior to the appointment. Given that the desired effect of the corticosteroid injection is to reduce pain, it would have been unethical to perform pain provoking diagnostic tests following this. It would have also likely impacted the results of both the subjective questions, standardised questionnaires, and the clinical assessment.

Figure 16.

Study Flow Chart



Note: N: Number. NRT: Negative reference test. PRT: Positive reference test. RT: Rebecca Tuhi (primary researcher).

Participant demographics

Participant characteristics are outlined in Appendix R. There was no statistically significant difference in the demographic variables found between the PRT and NRT groups. The participant cohort included 13 males and 10 females, with a mean age of 41.39 years (range 18–62). Participant ethnicity was varied; the majority of participants (11 participants, 47.8%) identified as New Zealand European/Pākehā, three (13%) identified as South African, two participants (8.6%) identified as English, and one participant each (4.3%) that identified as New Zealand Māori, Tongan, Samoan, Filipino, Indian, English, Scottish or German. The majority of participants (20

participants, 86.96%) were right-hand dominant, and 13 participants (56.5%) had injured their right hand. A dominant hand injury occurred in 14 (60.87%) participants.

Nearly all participants (95.7%) were employed, one participant (4.3%) was not in paid employment as they were a full-time university student. In terms of occupational roles, office-based and physical roles were evenly spread between the participants (ten and twelve participants, respectively). Occupational workload categorisation was varied, with ten participants (43.5%) in light work, four participants (17.4%) in moderate work, one participant (4.3%) in heavy work and seven participants (30.4%) in very heavy work roles, as classified by ACC guidelines (Accident Compensation Corporation, 2004).

All participants took part in recreational activities that involved the upper limbs, but the load involved in these varied from domestic-based activities like cooking and gardening, to more strenuous hobbies such as gym-based exercise, martial arts, or mountain-biking. Racquet-based sports, such as tennis, badminton and cricket were also reported.

Mechanism of injury were classified as trauma, strain, or overuse. Trauma was defined as an impactful force such as in a fall or high velocity impact. A strain mechanism, was a defined as a one-off loaded activity such as lifting, twisting or carrying causing onset of symptoms. Overuse, in which repeated mechanical activities or forces caused onset of symptoms. Traumatic forces were the most common mechanism of injury in 16 (69%) participants and one-off strain mechanisms were reported in six (26%) participants. Eleven (47.3%) participants sustained injuries directly relating to a fall. Nine (38.7%) participants indicated the involvement of a pronated upper limb (four participants fell sideways and five participants fell forwards). The mean participant-estimated height of the fall was 0.47 meters but ranged from standing height (0-meters) to 3-meters; with seven participants falling from a standing height.

Participant symptoms

Table 18 provides detail regarding participants' reported symptoms and symptom behaviour. The duration of participants' symptoms ranged from 80 days to more than three years. Sixteen (69.5%) participants had symptoms lasting less than a year, and seven (30.4%) participants over one year.

Pain was the most common symptom, with participants often reporting a combination of sharp pain and dull aching pain. Twenty-one (91.3%) participants reporting a sharp pain, and 16 (69.5%) participants reporting dull aching pain. Commonly, pain was associated with either movement, position or loading tasks. Pain was most commonly (22 participants, 95.6%) intermittent in nature. When pain was aggravated, the majority of participants (18 participants, 78.3%) reported that this settled within a few hours. However, for five (21.7%) participants it took more than a day to settle. There was no statistically significant difference between participants with PRT and NRT.

Weakness was the second most reported symptom (86.9%), but there was no statistically significant difference between PRT and NRT groups. More than half of the participants (52.2%) reported crepitus. The presence of crepitus was the only symptom that demonstrated a statistically significant difference ($p = 0.002$), between NRT and PRT groups, with higher number reported with those participants with a PRT.

Table 18.

Participants' reported symptoms and symptom behaviour

	All participants (n = 23)		PRT (n = 16)	NRT (n = 7)	p-value (NRT & PRT)
	Number of participants (percentage)		Number of participants	Number of participants	
Pain					
- Constant (yes)	13	(56.5%	10	3	0.38
- Intermittent (yes)	22	(95.6%)	15	7	-
Sharp pain	21	(91.3%)	15	6	0.53
Dull aching pain	16	(69.6%)	11	5	0.90
Locking	2	(8.7%)	1	1	0.53
Clicking/crepitus	12	(51.6%)	9	3	0.002*
Giving way	9	(39.1%)	4	5	0.55
Weakness	20	(86.9%)	15	5	0.14
Duration of symptoms					
- >3 months	4	(17.2%)	3	1	0.80
- 3-6 months	6	(26.1%)	5	1	0.39
- 6-9 months	3	(12.9%)	3	0	-
- 9-12 months	3	(12.9%)	2	1	0.91
- <12 months	7	(30.1%)	3	4	0.07
Time for symptoms to settle					
- Within 30 minutes	8	(34.8%)	4	4	0.14
- Within 2 hours	10	(43.5%)	8	2	0.34
- Within 24 hours	3	(12.9%)	3	0	-
- More than 48 hours	2	(8.7%)	1	1	0.53

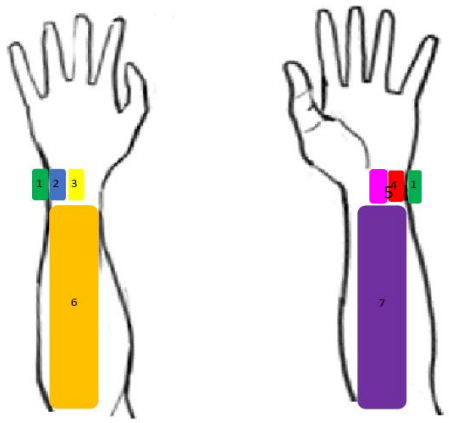
Note: - Incalculable. * Significant difference between PRT and NRT ($p < 0.05$)

NRT: Negative reference test. N: Number. PRT: Positive reference test.

Symptoms were also categorised according to region. Figure 17 illustrates the zones across the wrist and forearm in which participants reported experiencing symptoms. As outlined in Table 19, there was no statistical significance in pain locations between those participants with a PRT and those with a NRT. Most commonly, pain was reported across the dorsal aspect of the wrist, followed by the medial ulnar aspect and then over the dorsal DRUJ. Fourteen (60.9%) participants had symptoms across the dorsal ulnar aspect of the wrist, ten (43.5%) participants had medial ulnar symptoms across the ulnar fovea region, eight (34.8%) participants had dorsal central DRUJ symptoms and nine (39.1%) participants had symptoms across the dorsal forearm.

Figure 17.

The location of symptom



Key	
Zone	Location
1	Medial ulnar
2	Dorsal ulnar
3	Dorsal DRUJ
4	Volar ulnar
5	Volar DRUJ
6	Dorsal forearm
7	Volar forearm

Note: DRUJ: distal radioulnar joint

Table 19.

The region of symptoms

	All participants (n = 23) Number of participants (percentage)		PRT (n = 16) Number of participants	NRT (n = 7) Number of participants	p-value (PRT vs NRT)
Dorsal ulnar	14	(60.9%)	9	5	0.49
Volar ulnar	6	(26.1%)	4	2	0.86
Lateral ulnar	10	(43.5%)	8	2	0.34
Dorsal DRUJ	8	(34.8%)	4	4	0.14
Volar DRUJ	2	(8.7%)	1	1	0.53
Dorsal forearm	9	(39.1%)	8	1	0.11
Volar forearm	0	(0%)	0	0	-

Note: - Incalculable. PRT: Positive reference test. NRT: Negative reference test. N: Number. DRUJ: Distal radioulnar joint.

Table 20 provides details regarding factors that influence pain intensity. There were no statistically significant differences between PRT and NRT groups for any of the factors included in this table. Pain was more commonly aggravated by activity than related to a specific time of day. Weight-bearing through the wrist, and gripping and twisting were the most provocative (5.4/10 and 4.8/10 respectively) activities. They were also the most common reported aggravating activity.

Table 20.

Pain intensity scores (NPRS)

Aggravating Factors	All participants (n = 23)				PRT (n = 16)		NRT (n = 7)		P value
	Mean NPRS (SD)		Number of participants (%)		Mean NPRS (SD)		Mean NPRS (SD)		
Time of Day									
- Upon waking	1.4	(2.1)	N/A		1.63	(2.32)	0.86	(1.12)	0.42
- In the afternoon	3.1	(3.0)	N/A		3	(2.98)	3.43	(2.92)	0.75
- In the evening	3.5	(3.1)	N/A		3.38	(3.08)	3.86	(2.90)	0.29
- With ADLs	6.1	(2.5)	N/A		6.4	(2.58)	5.57	(2.06)	0.46
Specific activities									
- Pain with gripping ADLs	2.8	(2.8)	15	(65.2%)	2.44	(2.89)	3.86	(2.03)	0.25
- Pain when twisting the wrist	3.4	(3.0)	17	(73.9%)	2.75	(2.80)	4.71	(2.76)	0.14
- Pain with gripping & twisting the wrist	4.8	(2.7)	20	(87.0%)	4.75	(6.10)	5	(2.62)	0.91
- Pain when leaning on hands	5.4	(3.1)	20	(87.0%)	5.38	(3.20)	5.43	(2.72)	0.97
- Pain with ADLs with the forearm in a pronated position	3.6	(3.1)	17	(73.9%)	3.88	(3.28)	4.86	(2.20)	0.48
- Pain with ADLs with the forearm in a neutral position	2.4	(2.9)	13	(56.5%)	2.06	(2.44)	3.43	(3.29)	0.28
- Pain with ADLs with the forearm in a supinated position	3.3	(3.1)	16	(69.6%)	3.06	(2.75)	3.86	(3.56)	0.50

Note: ADLs: activities of daily living. N/A: not applicable. NRT: Negative reference test. N: number. NPRS: Numeric pain rating scale (rated from 0 to 10). PRT: Positive reference test. SD: standard deviation.

Functional status

Standardised questionnaires were utilised to assess baseline functional ability (see Table 21). The mean score on the global rate of change (GROC) scale for all participants included in the study was 1.04 (range, -4 to +4). The mean score for all the participants on the patient-rated wrist hand evaluation (PRHWE) questionnaire was 34.2 (range, 12-69). For the QuickDASH, the mean score was 36.9 (range, 4.5–88.6). While the mean scores were slightly higher for both the PRWHE and QuickDASH in the PRT group, these differences were not statistically significant

Table 21.

Functional outcome measures

	All participants (n = 23)		PRT (n = 16)		NRT (n= 7)		p-value
	Mean (SD)		Mean (SD)		Mean (SD)		
GROC Scale	1.04	(2.8)	1	(2.9)	1.1	(2.2)	0.91
PRWHE	34.2	(16.8)	35.6	(17.1)	30.9	(15.4)	0.54
QuickDASH	36.9	(22.4)	40.6	(21.7)	28.2	(19.7)	0.21

Note: GROC, global rate of change; PRWHE, patient-rated wrist hand evaluation; QuickDASH, a rapid version of the disabilities of the arm, shoulder and hand questionnaire. N: Number. SD: Standard deviation.

Assessment and treatment history

Participants typically presented to primary care services, including general practitioners or Accident and Emergency clinics (78.3%) following injury. Only 21.7% of participants presented directly to physiotherapy or hand therapy clinics. Most participants (69.5%) presented within the first week of the injury, but five participants (17.4%) took longer than a month to present to a health professional. The majority (82.6%) of participants had undergone either physiotherapy or hand therapy-based conservative treatment strategies prior to participation in this study. Splints were prescribed for 94.7% of participants, 84.2% completed a home exercise programme and 63.2% received manual therapy that included massage and joint mobilization techniques performed on their wrist. Both primary care doctors and hand-therapists referred participants to orthopaedic hand specialists for review (43.4% and 52.2% respectively). In most cases, this was due to ongoing symptoms and/or the failure of standard conservative treatment. See Appendix S: for further detail.

MRI Findings

TFCC injuries were reported by the radiologist in 16 participants, and excluded in seven participants. The Palmer classification was used to classify TFCC injuries, based on MRI images. Appendix T provides detail of the number of participants within each of the categories included in this classification system (see Table 1 for detail of this Palmer classification). The majority were classified as 1B (9 participants, 39.1%), or 1A (5 participants, 21.7%) indicating injury to the central disc, or a tear at the base of the ulnar styloid, or a radial avulsion tear of the TFCC. No participants were categorised as type 2.

Reference Standard Diagnoses for Participants without a TFCC Injury

Additional pathologies were observed on the MRI and determined by their specialist to be their cause of symptoms (see Appendix T for detail). There was a mixture of traumatic and degenerative conditions observed. The most common of these were carpal pathologies which were present in 11 participants (four with pisotriquetral joint pathologies, three with scapholunate ligament pathologies, three with lunate impaction). Extensor Carpi Ulnaris tendinopathy were reported in four participants, and Extensor Pollicus Longus pathologies, including a tear and tendinopathy was reported in two participants.

4.4.2 Inter-rater reliability

Table 22 provides detail of the inter-rater reliability of the TFCC provocation tests. There was ‘moderate’ strength of agreement, as indicated by Landis and Koch (1977), between examiners for the grind, ulnar fovea sign and piano key tests with k-score scores of 0.57, 0.57 and 0.51, and PABAK of 0.7, 0.7 and 0.5 respectively. Notably, the shear test had both the lowest degree of agreement at 40%, and lowest reliability with a k score of 0.01 and a PABAK score of –0.2.

Reliability for most measurements of passive (PROM) and active range of motion (AROM) were ‘substantial’. PROM measurement of extension, flexion and supination movements had the highest levels of inter-rater reliability (ICC of 0.86, 0.76, 0.85). Ulnar deviation PROM and AROM demonstrated the lowest ICC levels (ICC of 0.50 and ICC 0.58 respectively). The grip strength in forearm neutral rotation demonstrated almost perfect reliability, with ICC of 0.88.

Table 22.

Inter-rater Reliability of Physical tests and Measurements

Test	ICC (95% CI)	unweighted K (95% CI)	PABAK (95% CI)	% Agreement (95% CI)
Grind		0.57 (0.14, 1)	0.7 (0.24, 0.94)	0.85 (0.62, 0.97)
Shear		0.01 (0.24, 0.25)	–0.2 (0.62, 0.28)	0.40 (0.19, 0.64)
Ulnar fovea sign		0.57 (0.14, 1)	0.7 (0.24, 0.94)	0.85 (0.62, 0.97)
Piano key		0.51 (0.15, 0.87)	0.5 (0.50, 0.99)	0.75 (0.52, 0.91)
GRIT	0.60 (0, 0.68)			
AROM				
Flexion	0.81 (0.69, 0.91)			
Extension	0.81 (0.51, 0.95)			
Radial Deviation	0.78 (0.53, 0.89)			
Ulna Deviation	0.58 (0.29, 0.77)			
Supination	0.87 (0.52–0.95)			
Pronation	0.77 (0.42, 0.94)			
PROM				
Flexion	0.76 (0.51, 0.92)			
Extension	0.86 (0.54, 0.96)			
Radial Deviation	0.77 (0.50, 0.99)			
Ulna Deviation	0.50 (0.16, 0.08)			
Supination	0.85 (0.49, 0.95)			
Pronation	0.56 (0, 0.88)			
Grip strength (in neutral)	0.88 (0.69, 0.97)			

Note: AROM, active range of motion; CI, confidence interval; K: kappa. ICC: intraclass coefficient. PABAK: Prevalence-adjusted bias-adjusted kappa. PROM, passive range of motion.

4.4.3 Diagnostic accuracy of individual variables obtained from the clinical examination

The diagnostic accuracy of the information obtained from the patient assessment are detailed in Table 23, Table 24 and Table 25. Overall, no factor met any of the acceptable thresholds for indicating clinical utility outlined in Chapter 3 on page 23. Neither pain location, any specific provocative functional movement nor specific clinical test had a statistically significant association with the diagnosis of a TFCC injury. These results showed that no single test or symptom demonstrated diagnostic accuracy values that suggest they have clinical utility as a stand-alone test.

The accuracy of pain location and pain with activities is outlined in Table 23. The sensitivity and specific values look reasonable for a few tests, but the associated likelihood ratios suggest that they have a limited effect on the probability of a TFCC tear being either present or absent, and was not of statistical significance. The best estimates of sensitivity were seen in pain with gripping and twisting activities, weightbearing, and with activities with forearm pronated (0.88, 0.88 and 0.89), however this did not correlate with LR- values that met the 0.2 threshold, therefore have no diagnostic value. Pain over the dorsal forearm had one of the best point estimates of specificity, and correlated with a LR+ of 3.50. The LR+ of 3.50 is just below the target threshold of 5.0, suggests an approximate 22% increase in the probability that a positive test would predict the presence of a TFCC tear. However, the confidence intervals of 0.53 to 22.93 are wide-ranging, as expected with a pilot study, and includes values below and above one indicating that this finding is not of statistical significance.

Pain with AROM (seen in Table 24) had poor accuracy metrics which failed to meet any a priori thresholds, alongside wide-ranging confidence intervals and insignificant p-values. therefore, as a standalone factor, pain with AROM testing has limited ability to confirm or exclude TFCC injuries.

Table 23.

Diagnostic accuracy for TFCC injuries, from clinical examination: patient information

Variable	TP[1]	FP	FN[1]	TN[1]	Sn (95% CI)	Sp (95% CI)	PPV/NPV	LR+ (95% CI)	LR- (95% CI)	*p*-value
Pain location dorsal ulnar	9	5	7	2	0.56 (0.30, 0.80)	0.29 (0.04, 0.71)	0.64 / 0.22	0.79 (0.42, 1.49)	1.53 (0.42, 5.60)	0.49
Pain location, volar ulnar	4	2	12	5	0.25 (0.07, 0.52)	0.71 (0.29, 0.96)	0.67 / 0.29	0.88 (0.21, 3.72)	1.05 (0.61, 1.82)	0.86
Pain location, medial ulnar	4	2	12	5	0.25 (0.07, 0.52)	0.71 (0.29, 0.96)	0.67 / 0.29	0.88 (0.21, 3.72)	1.05 (0.61, 1.82)	0.86
Pain location, dorsal DRUJ	4	4	12	3	0.25 (0.07, 0.52)	0.43 (0.10, 0.82)	0.50 / 0.20	0.44 (0.15, 1.27)	1.75 (0.71, 4.31)	0.73
Pain location, volar DRUJ	1	1	15	6	0.06 (0.02, 0.30)	0.86 (0.42, 1.0)	0.50 / 0.29	0.44 (0.03, 6.04)	1.09 (0.79, 1.52)	0.53
Pain location, dorsal forearm	8	1	8	6	0.50 (0.25, 0.75)	0.86 (0.42, 1.0)	0.89 / 0.43	3.50 (0.53, 22.93)	0.58 (0.33, 1.04)	0.79
Pain location, volar forearm	0	0	16	7	0.03 (0.0, 0.21)	1.0 (0.59, 1.0)	- / 0.30	0.45 (0.01, 21)	1.04 (0.84, 2.28)	0.81
Pain with gripping	8	7	8	0	0.50 (0.24, 0.75)	0 (0.0, 0.41)	0.53 / -	0.50 (0.31, 0.82)	7.50 (0.49, 114)	0.47
Pain with twisting	11	6	5	1	0.69 (0.41, 0.89)	0.14 (0.04, 0.58)	0.65 / 0.17	0.80 (0.51, 1.26)	2.19 (0.31, 15.45)	0.37
Pain with gripping & twisting	14	6	2	1	0.88 (0.62, 0.98)	0.14 (0.04, 0.58)	0.70 / 0.33	1.02 (0.72, 1.46)	0.88 (0.09, 8.14)	0.75
Pain with weight-bearing	14	6	2	1	0.88 (0.62, 0.98)	0.14 (0.04, 0.58)	0.70 / 0.33	1.02 (0.72, 1.46)	0.88 (0.09, 8.14)	0.99
Pain with activities with supinated forearm	11	5	5	2	0.69 (0.42, 0.89)	0.29 (0.04, 0.71)	0.69 / 0.29	0.96 (0.54, 1.71)	1.09 (0.28, 4.34)	0.15
Pain with activities with neutral forearm	9	4	7	3	0.56 (0.30, 0.80)	0.43 (0.10, 0.82)	0.69 / 0.30	0.98 (0.45, 2.13)	1.02 (0.37, 2.83)	0.87
Pain with activities with pronated forearm	11	6	5	1	0.89 (0.41, 0.89)	0.14 (0.04, 0.58)	0.65 / 0.17	0.80 (0.52, 1.26)	2.19 (0.31, 15.45)	0.24

Note: [1] 0.5 added to cells with zero values to allow estimations of accuracy. - Incalculable. * Statistically significant. Thresholds: PPV / NPV 95%. LR+ >5.0. LR- <0.2

AROM: Active range of motion. DRUJ: CI: Confidence intervals. Distal radioulnar joint. FP: False positive. FN: False negative. NPV: Negative predictive value. LR+: Positive likelihood ratio. PPV: Positive predictive value. TN: True negative. TP: True positive. LR- Negative likelihood ratio.

Table 24.

Diagnostic accuracy of clinical examination: physical assessment

Variable	TP	FP	FN	TN[1]	Sn (95% CI)	Sp (95% CI)	PPV/NPV	LR+ (95% CI)	LR- (95% CI)	*p*-value
Pain with extension AROM	2	7	14	0	0.13 (0.02, 0.38)	0.01 (0, 0.41)	0.22 / 0	0.12 (0.05, 0.50)	13 (0.90, 192)	-
Pain with flexion AROM	3	7	13	0	0.19 (0.04, 0.46)	0.01 (0, 0.41)	0.30 / 0	0.19 (0.08, 0.57)	12 (0.83, 179)	-
Pain with ulnar deviation AROM	3	7	13	0	0.19 (0.04, 0.46)	0.01 (0, 0.41)	0.30 / 0	0.19 (0.08, 0.57)	12 (0.83, 179)	-
Pain with radial deviation AROM	3	6	13	1	0.19 (0.04, 0.46)	0.14 (0.04, 0.58)	0.33 / 0.07	0.22 (0.08, 063)	5.69 (0.91, 35.45)	0.99
Pain with supination AROM	2	6	14	1	0.13 (0.02, 0.38)	0.14 (0.04, 0.58)	0.25 / 0.07	0.15 (0.04, 0.55)	6.12 (0.99, 37.96)	0.92
Pain with pronation AROM	2	7	14	0	0.13 (0.02, 0.38)	0.01 (0, 0.41)	0.22 / 0	0.12 (0.05, 0.50)	13 (0.90, 192)	-

Note: [1] 0.5 added to cells with zero values to allow estimations of accuracy. - Incalculable. * Statistically significant. Thresholds: PPV / NPV 95%. LR+ >5.0. LR- <0.2

TP: True positive. FP: False positive. TN: True negative. FN: False negative. PPV: Positive predictive value. NPV: Negative predictive value. LR+: Positive likelihood ratio. LR- Negative likelihood ratio. CI: Confidence intervals. AROM: Active range of motion.

Table 25.

Diagnostic accuracy of clinical examination: TFCC diagnostic tests

Test	TP	FP[1]	FN	TN	Sn (95% CI)	Sp (95% CI)	PPV/NPV	LR+ (95% CI)	LR- (95% CI)	*p*-value
Ulna fovea sign	8	3	8	4	0.50 (0.25, 0.75)	0.57 (0.18, 0.90)	0.73 / 0.33	1.17 (0.44–3.13)	0.88 (0.39, 1.96)	0.75
Piano key	2	0	14	7	0.13 (0.16, 0.38)	1.0 (0.59, 1.0)	1.0 / 0.33	1.88 (0.10–37)	0.88 (0.73, 1.05)	-
Shear	7	1	9	6	0.44 (0.20, 0.70)	0.86 (0.42, 1.0)	0.88 / 0.40	3.06 (0.46, 20.43)	0.66 (0.39, 1.11)	0.17
Grind	8	1	8	6	0.50 (0.25, 0.75)	0.86 (0.42, 0.99)	0.89 / 0.43	3.50 (0.53, 22.93)	0.58 (0.33, 1.904)	0.11
GRIT	9	6	7	1	0.56 (0.30, 0.58)	0.14 (0.36, 0.58)	0.60 / 0.13	3.06 (0.46, 20.43)	0.66 (0.39, 1.11)	0.17

Note: [1] 0.5 added to cells with zero values to allow estimations of accuracy. - Incalculable. * Statistically significant. Thresholds: PPV / NPV 95%. LR+ >5.0. LR- <0.2

TP: true positive. FP: False positive. FN: False negative. TN: True negative. Sn, sensitivity; Sp, specificity; PPV, positive predictive value; NPV, negative predictive value; LR+, positive likelihood ratio; LR–, negative likelihood ratio; CI, confidence interval.

The diagnostic accuracy of the TFCC diagnostic tests is detailed in Table 25. The piano key test had the highest specificity value of 1.0 and PPV of 1.0 suggesting that this test may have some value for identifying a TFCC tear. However, the corresponding LR+ of 1.88 demonstrates that a positive test does not effectively increase the probability of this injury. The piano key test had low sensitivity of 0.13, a NPV of 0.33 and LR- of 0.88, indicating that this test has little diagnostic utility for excluding TFCC injury.

The GRIT test had a sensitivity of 0.56, the highest shown between the diagnostic tests. But the corresponding LR– of 0.66 and an NPV of 0.13 suggests that a negative test result does not reduce the post-test probability of a TFCC injury. The GRIT had low estimates of specificity of 0.14 but a moderate LR+ of 3.06. This value indicates an approximate 30% shift in post-test predictability, however, the wide confidence intervals (0.46 - 20.43) that include 1 demonstrate that this finding is not significant.

The ulnar fovea sign had specificity value of 0.57, an LR+ of 1.17 and PPV of 0.73, indicating limited ability to confirm TFCC injuries with a positive ulna fovea sign test. Again, confidence intervals (0.44 – 3.13) indicate that this finding is not statistically significant. The ulna fovea sign had low rates of sensitivity of 0.50, an LR– of 0.88 and a NPV of 0.33, indicating limited accuracy for excluding TFCC injuries.

The shear test showed some potential in confirming TFCC injuries, with high levels of specificity (0.86), PPV (0.88) and a LR+ of 3.06, close to the a priori thresholds of PPV 95% and LR+ of 5.0. However, the confidence intervals (0.46 - 20.43) indicate that the LR+ is not of statistical significance.

The grind test had high specificity of 0.86 (0.42-0.99), high PPV of 0.89, and moderate LR+ of 3.50 values, indicating reasonable ability to confirm TFCC injuries with a positive test result. However, the wide-ranging confidence intervals seen (0.53 - 22.93) indicate a less precise estimation and one that is not of statistical significance.

4.4.4 Diagnostic accuracy of combination of clinical examination findings

The diagnostic accuracy of various combinations of information obtained from the clinical examination was explored using regression analysis. This analysis identified a model that include nine predictors, as shown in Table 26. Using the lasso regression statistical analysis, coefficients were identified that produced the smallest estimated

misclassification rate to predict a TFCC tears. Those retained (nine variables) by the model are shown in Table 26, and those not retained (31 variables) are located in Appendix S.

This analysis investigated all elements of the clinical examination, considering a total of 46 variables. Eleven variables where not included in subsequent analysis as there were too few positives or negatives. It identified nine variables that would improve the predictability of TFCC injuries. These factors included gender, mechanism of injury, indicator of constant symptoms, presence of crepitus, pain intensity with pronation-based ADLS, pain indicator with supination-based ADLS, the degree of passive radial deviation and pronation range of motion, and the amount of grip strength in a neutral position. None of the TFCC diagnostic tests were identified as having sufficient value in predicting a TFCC tear to be included in the final model.

The lasso regression method was perfect within sample, correctly predicting all TFCC tears in the cohort. Out of sample, the cross-validated misclassification error estimate was calculated to be 17.4%, indicating an 17% chance of getting an incorrect result using this method (the same nine predictors) in a different population.

Table 26.

Predictability (retained)

Test	TP	FP	FN[1]	TN	Sn (95% CI)	Sp (95% CI)	PPV/NPV	LR+ (95% CI)	LR- (95% CI)	SFPLR (95% CI)	*p*-value
Male gender	9	4	7	3	0.56 (0.30, 0.80)	0.43 (0.10, 0.82)	0.69 / 0.30	0.98 (0.45, 2.13)	1.02 (0.37, 2.83)	0.73 (-0.97, -2.51)	0.39
Strain mechanism of injury	4	3	12	4	0.25 (0.07, 0.52)	0.57 (0.18, 0.90)	0.57 / 0.25	0.58 (0.17, 1.95)	1.31 (0.65, 2.65)	0.99 (-0.89, -3.41)	0.32
Presence of constant pain	10	4	6	3	0.63 (0.35, 0.85)	0.43 (0.10, 0.82)	0.71 / 0.33)	1.09 (0.52, 2.30)	0.88 (0.30, 2.54)	-0.79 (-2.71, 0.93)	0.37
Presence of crepitus	8	4	8	3	0.50 (0.25, 0.73)	0.43 (0.10, 0.82)	0.67 / 0.27	0.88 (0.39, 1.96)	1.17 (0.44, 3.13)	-3.45 (-8.3, -1.07)	0.002*
Presence of pain with ADLS in supination	11	5	5	2	0.69 (0.42, 0.89)	0.29 (0.04, 0.71)	0.69 / 0.29	0.96 (0.54, 1.71)	1.09 (0.28, 4.34)	1.60 (-0.18, 3.55)	0.08
Pain intensity (NPRS) with ADLS in pronation (range 0-10)										0.17 (-0.11, 0.52)	0.25
Degree of PROM radial deviation (range 5-38)										-0.19 (-0.40, -0.04)	0.01
Degree of PROM pronation (range 66-95)										-0.03 (-0.25, 0.096)	0.70
Grip strength in neutral (range 16-65)										0.04 (-0.03, 0.12)	0.29

Note: [1] 0.5 added to cells with zero values to allow estimations of accuracy. * Statistically significant. Thresholds: PPV / NPV 95%. LR+ >5.0. LR- <0.2

TP: true positive. FP: False positive. FN: False negative. TN: True negative. Sn, sensitivity; Sp, specificity; PPV, positive predictive value; NPV, negative predictive value; LR+, positive likelihood ratio; LR–, negative likelihood ratio; CI, confidence interval. SFPLR: Simple firth-penalised logistic regression. NRPS: numerical pain rating scale. PROM: passive range of motion. ADLS: activities of daily living

Table 27 provides details that enable an understanding of how each predictor contributes to the final model. The coefficient factors demonstrate that individual predictors do not have the same weighting in terms of importance on the predictability of the model. Also, the range for some included predictors is much larger than others. Predictors with larger ranges will have a greater impact on predictability, compared to those with binary factors, or those with a small range. It is also worth noting that some predictors have a positive effect on the probability of a TFCC tear being present (e.g., male gender) and others have a negative effect (e.g., the presence of crepitus).

Table 27.

Lasso coefficients

Factors	Range of the predictor	Coefficients
Male Gender	0, 1	0.173
MOI strain or overuse	0, 1	0.097
Presence of constant symptoms	0, 1	-0.462
Presence of crepitus	0, 1	-1.943
Pain intensity with pronation-based ADLS	0, 10	0.061
Presence of pain with supination-based ADLs	0, 1	0.495
Passive radial deviation ROM	5, 38	-0.126
Passive pronation ROM	66, 95	0.043
Grip strength in neutral	16, 65	0.036

Note: MOI: Mechanism of injury. ADLs: activities of daily living. ROM: range of motion

To obtain a final score, each coefficient must be multiplied by the value of the corresponding variables and all the results added. This then can be transformed to obtain an estimated probability of a TFCC tear using the following equation, where e^x refers to the coefficient multiplied by the corresponding variable value:

$$Probability\ (p) = \frac{e^x}{1 + e^x}$$

A score over 50% is the threshold to indicate those predicted to have a TFCC injury, and less than 50% indicates those predicted not to have a TFCC injury. A participant example of using the lasso coefficient and probability equation is seen in Table 28. In this example, the participant had a linear score of 3.040. After applying the probability equation, this resulted in a predicted probability score of 0.95, indicating that this participant had a 95% chance of a confirmed TFCC injury. This model of prediction was

accurate when correlated against specialist diagnosis. In this participant example, they had a positive reference standard (a confirmed TFCC injury). A summary of all participant calculated scores is provided in Table 29. Full results of all participants are located in Appendix U.

Table 28.

Participant example of Lasso coefficients

Co-efficient factors		Patient results	
Factors	score	Answer	score
Male Gender	0.173	No (0)	0
MOI strain	0.097	Yes (1)	0.097
Presence of constant symptoms	-0.462	No (0)	0
Presence of crepitus	-1.943	No (0)	0
Pain intensity with pronation-based ADLs (0-10)	0.061	5	0.306
Presence of pain with supination-based ADLs	0.495	Yes (1)	0.495
Passive radial deviation ROM (degree)	-0.126	20	-2.518
Passive pronation ROM (degree)	0.043	88	3.806
Grip strength in neutral (kilogram)	0.036	23.5	0.854
Linear score			3.040
Predicted probability score			0.95

Note: MOI: Mechanism of injury. ADLs: Activities of daily living. ROM: range of motion.

Table 29.

Summary of all participants lasso coefficient scores and diagnosis

Participant	Lasso coefficient score	Predicted probability of a TFCC tear	Confirmed TFCC injury
1	3.04	0.95	yes
2	3.04	0.34	no
3	1.32	0.24	no
4	0.98	0.27	no
5	3.56	0.97	yes
6	3.41	0.97	yes
7	1.66	0.83	yes
8	0.31	0.54	yes
9	2.35	0.92	yes
10	0.63	0.69	yes
11	-1.48	0.17	no
12	1.25	0.76	yes
13	-0.04	0.42	no
14	2.28	0.91	yes
15	2.53	0.91	yes
16	1.76	0.84	yes
17	2.65	0.93	yes
18	-0.66	0.32	no
19	-0.97	0.26	no
20	2.58	0.93	yes
21	2.08	0.89	yes
22	1.54	0.82	yes
23	3.18	0.96	yes

4.5 Discussion

This study provides new evidence on the inter-rater reliability and diagnostic accuracy of information obtained from the clinical examination for TFCC injuries. This is the first known study that has investigated both the reliability and diagnostic accuracy of diagnostic tests on the same cohort of patients with ulnar sided wrist pain and suspected TFCC injuries. This study investigated other variables obtained from the clinical examination to determine if any individual, or combination of variables,

improved the probability of correctly diagnosing a symptomatic TFCC injury. Nine predictors, including male gender, strain mechanism of injury, presence of constant pain, presence of crepitus, present of pain with activities in supination, pain intensity of activities in pronation, the amount of grip strength, as well as the degree of passive radial deviation and pronation movement, are shown to accurately predict TFCC injuries when used in a combined model.

4.5.1 The TFCC diagnostic tests

The ulnar fovea sign is routinely used by therapists in clinical practise to determine the presence of TFCC injuries, but little is known about its reliability. This is the first study that to have investigated the inter-rater reliability of the ulnar fovea sign. Clinical observations suggest that therapists frequently interpret pain produced by this test equating to confirmation of a TFCC injury and a negative test excluding TFCC injury. This study demonstrated that the ulna fovea sign is reliable, but showed poor diagnostic accuracy as a stand-alone test, suggesting that therapists should be judicious in using such an interpretation. In fact, clinicians should be wary of using the ulnar fovea sign to diagnosis or exclude TFCC injuries, with a LR+ of 1.17 and LR- of 0.88 indicating a very small shift (3%) with either a positive or negative rest result (McGee, 2002). The confidence intervals associated with the estimates of likelihood ratios (LR+ 0.44-3.13 and LR- 0.39-19.96) were not statistically significant with both LR+ and LR- including 1 in their results. Our results were similar to those of Schmauss et al. (2016) who reported it had limited clinical utility, but conflicts with those of Tay et al. (2007) who reported more favourable results with LR+ of 7.06 and LR- of 0.055. The study by Tay et al. (2007) had low levels of bias, and reported confidence intervals which indicated that their findings were statistically significant. They did have a much larger sample size of 272 participants, which would add weight to the strength of their finding compared to those of this pilot study. However, the retrospective methodology used in Tay et al. (2007) may explain the differences between the results seen, as retrospective studies can have potential issues in regards to missing data and differing interpretations of tests.

The piano key test showed a moderate level of inter-rater agreement, highlighting that this test is reliable between therapists. The systematic review showed that no other studies have investigated the piano key test for reliability. However, in respect to

diagnostic accuracy, the current study indicates that this test has limited ability to either identify or rule out a TFCC injury. LR+ values of 1.88 was found, but wide-ranging confidence intervals indicating this was not statistically significant. The piano key test was limited to exclude TFCC injuries with a negative test result, with LR- of 0.88. No other study has explored the diagnostic accuracy of this test in symptomatic populations.

This is the first known study that has investigated the inter-rater reliability of the grind test. The moderate levels of inter-rater reliability found in this study, might help to explain the various results reported in the diagnostic accuracy reported for the test across multiple studies. The mechanism behind the grind test is complex in that it applies an axial force during rotation movement, potentially resulting to alterations in force transmission and technique. This study found a LR+ of 3.50, indicating an approximately 22% shift in probability to supporting a TFCC injury. However, the wide confidence intervals (0.53 to 22.93) include 1 indicating that this point estimate is not statistically significant. However, this result suggests that this test maybe worth investigating in a larger study, which with larger study size is likely to led to narrow confidence intervals, and possible a statistically significant estimate. The three previous studies that investigated the diagnostic accuracy (Nakamura et al., 1997; Ruston et al., 2013; Schmauss et al., 2016) reported variable results. The results of this pilot study were more similar but not as favourable to those of Ruston et al. (2013) who reported specificity of 0.93 and LR+ of 5.48. However Ruston et al. (2013) failed to report confidence intervals so potentially their results are not statistically significant. Our results with LR- of 0.58 were similar to those of Schmauss et al. (2016), who reported LR- of 0.5, and Ruston et al. (2013) who reported LR- of 0.65, all indicating that the grind test had limited ability to exclude TFCC injuries. Our findings demonstrated that this test has poor utility and suggests that it should not be used as a stand-alone diagnostic test to exclude or to confirm TFCC injuries.

This study showed that the shear test had low (slight) levels of inter-rater agreement. No previous studies that have investigated its reliability for comparison. Given its relatively simple mechanics and its common use clinically it would have been assumed to have better reliability. The results found suggest that it should not be used as it is unreliable. Further investigation into its technique or application needs to be done to

better standardise this test, in order to see if its reliability can be improved. The diagnostic accuracy of the shear test is limited. This pilot study found LR+ value of 3.06, while the LR+ did not reach a priori threshold of 5.0 (Deeks & Altman, 2004), its level would create a reasonable (approximately +20%) shift in predictability (McGee, 2002). However, confidence intervals were not statistically significant and therefore its ability to confirm TFCC injuries cannot be stated. Previous studies by LaStayo and Howell (1995) and Prosser et al. (2011) reported limited diagnostic accuracy. LaStayo and Howell (1995) reported LR+ of 1.83 but did not report confidence intervals, and Prosser et al. (2011) reported LR+ of 1.88 which was statistically significant. The lower reliability levels for this test may explain the differences in our results compared to previous studies and the low numbers associated with a pilot study give way to wide-ranging confidence intervals. Overall, the shear test has limited ability to confirm or exclude TFCC injuries.

The GRIT is a test that was designed to detect ulnocarpal impaction. LaStayo and Weiss (2001) investigated the GRIT diagnostic accuracy for identifying ulnar carpal impaction. It has not been investigated for reliability or diagnostic accuracy for detecting TFCC injuries. The GRIT was included in the current study due to anatomical influence that ulnar positive variance and impaction has upon the TFCC. The findings from this study suggest that the GRIT has substantial level of agreement between therapists. It may have some clinical utility in diagnosing a TFCC injury but the results must be interpreted with caution. The GRIT test had minimal ability to exclude TFCC injuries, however its ability to confirm TFCC injuries was uncertain because of contradictory results, i.e., low specificity of 0.14 but a moderate LR+ of 3.06. The LR+ creates a 30% shift in probability of a TFCC injury, the 0.14 specificity value indicates a high false-positive rate. However, the confidence intervals were not statistically significant, and its ability to diagnose TFCC injuries cannot be confirmed. A larger sample size may potentially give rise to narrow confidence intervals, and possible statistically significant results.

4.5.2 The diagnostic accuracy of combinations of information obtained from the clinical examination

This study has shown that a specific combination of multiple findings based on the information obtained from the clinical examination, can substantially improve

clinicians' ability to predict the presence of a TFCC injury. This study has presented a model that can predict TFCC injuries. This model contains nine predictors which were identified from the clinical examination. These were: being of male gender, strain mechanism of injury, the presence of constant symptoms, presence of crepitus, pain intensity with pronation-based ADLS, presence of pain with supination-based ADLS, passive radial deviation and pronation range of motion, and grip strength in a neutral position. None of the TFCC diagnostic tests were included in the model, indicating that there are better indicators of determining TFCC injuries than the diagnostic tests that are currently used by clinicians.

This is the first known study that has investigated predictability of TFCC injuries based on combinations of findings. This provides new evidence around important clinical factors that will help in determining or excluding TFCC injuries. Within-sample, the fit was predictably nearly perfect: the in-sample misclassification is 0% with a cut-off of 50% probability, indicating that the model was 100% accurate in diagnosing TFCC injuries, in those confirmed with TFCC injury on MRI scan, in this cohort. The 50% probability cut-off refers to the 50% threshold of model score that was required in order to determine a TFCC injury. This model has a cross-validation-estimated misclassification of 17.4% out of sample, indicating that it might give an incorrect answer in 17% of patients in another cohort. It is important to note that despite the lasso being used, overfitting to such a small data set cannot be ruled out, if only by chance. Other approaches (e.g., fitting an intercept, or including weights), yielded only two predictors of importance, which were crepitus and the amount of passive pronation range of motion.

While some predictors included in the model have face validity others were not expected. Some of these predictors contradict current clinical understandings. Others contradict proposed mechanisms and aggravating factors of TFCC injuries. Typically, patients with TFCC injuries report pain location over the medial ulnar aspect of the wrist, pain with gripping and twisting, pain and restricted ulnar deviation movement, and pain with weightbearing. Interestingly, none of these symptoms were included in the final predictive model. Ulnar deviation movement, both active and passive, narrows the ulnocarpal joint space and compresses the TFC articular disc, and often results in pain. Neither the presence of pain during motion, or the degree of active or

passive ulnar deviation range of movement was specific to TFCC injuries, and therefore not included in the model.

Weightbearing causes compression through position or load through the ulnocarpal joint and one would expect this to cause pain in the presence of TFCC injury (Jawed et al., 2020; Palmer & Werner, 1981). Despite this, this study has shown that the presence of pain or level of pain intensity in this position was not a predictor of TFCC injuries. It has been reported that patients with confirmed TFCC injuries have a reduced weightbearing capacity (Asmus et al., 2021). A quantifiable weightbearing test was not performed in this study, such as wrist weightbearing test or push-off test. Additionally, there has been no diagnostic accuracy studies looking the ability of such a test to predict TFCC injuries. This therefore could be considered in future research to see if this test has any diagnostic value. The non-inclusion of these classic TFCC symptoms and clinical signs within the model suggests that whilst these activities and movements may cause pain, they have no diagnostic value for TFCC injuries. Potentially this may reflect that the biomechanics of these actions involve multiple joints and anatomical structures, and that they are likely to be provocative for a number of wrist injuries or pathologies and therefore not specific to TFCC injuries.

Variables included in the model, such as pain with pronation-based ADLs and the presence of pain with supination-based ADLs make sense in terms of the biomechanical forces placed upon the TFCC with these movements. Rotational movement is influenced by volar and dorsal DRUJ ligament length and stability, and the addition of force or load with functional activities requires dynamic stabilising from ECU tendon, therefore it is likely to exacerbate pain with TFCC injuries. Passive pronation range of motion will stretch the dorsal DRUJ ligaments and ECU tendon components of TFCC, so with an TFCC injury is likely to be limited. The degree of passive radial deviation is a negative predictor, which from a biomechanical perspective opens up the ulnocarpal joint, which in a TFCC injury potentially relieving pain and pressure through the ulnocarpal joint and TFC disc, and may allow normal ranges of movement.

There were some variables included in the final model that were not expected. The most common mechanism of injury reported in the literature for traumatic TFCC

injuries is a fall on outstretched hand in a pronated position. However, in this study a strain mechanism was associated with an increase in probability of a TFCC injury. This study also demonstrated that an increase in grip strength in a neutral position was a predictor of TFCC injuries. This was surprising given the role that the TFCC plays in wrist stability, which is required with a gripping action. An injury to the TFCC would be expected to result in a corresponding decreased grip capacity. Furthermore, grip strength in a pronated forearm position places more load through the TFCC with the migration of the ulnar distally. This, theoretically, would create aggravation of pain and a reduction in grip strength, but in this study was not found to be a predictor of TFCC injury.

Some of the predictors had positive, and some had negative correlations with the presence of a TFCC tear. A positive correlation indicates that the presence of that symptom/sign increased the probability of a TFCC injury, where as a negative correlation decreased the probability. Those that had a positive correlation and increased probability of a TFCC injury were being of male gender, having a strain mechanism of injury, higher pain intensity with pronation-based ADLs, and the greater the amount of grip strength in neutral wrist position. Those with a negative correlation were the presence of crepitus, constant symptoms, and the greater the degree of passive radial deviation movement. Furthermore, the binary predictors can be interpreted from the opposite perspective, either reducing or increasing predictability. A binary predictor that has a positive effect on the presence of a TFCC injury, such as male gender, not being male has a negative effective on the overall likelihood of a TFCC tear. As will having a traumatic mechanism of injury such as a fall, or being pain-free with supination-based activities will decrease predictability of TFCC injuries. And have no crepitus or intermittent symptoms would increase predictability of TFCC injuries.

It is important to note however, the impact each predictor has on the models ability to predict the presence or absence of a TFCC tear is not equal. Binary predictors (i.e., those with yes or no results) will either have zero effect or a maximum of 1-times the respective coefficient. In contrast, for predictors with continuous measures such as pain intensity (0-10) and passive ROM of pronation (0-95) the weighting co-efficient associated with that predictor is multiplied by the value of measured ‘test’. For

example, as seen in Table 28, this participant had 88 degrees of passive pronation. The co-efficient score for this predictor is 0.043 per degree of range so that with 88 degrees of movement, the contribution of this predictor to the final score is 3.806. In comparison, whilst the coefficient for a strain mechanism of injury (0.097) is larger than that for a degree of movement in the direction of pronation, this predictor is only counted once.

4.5.3 Demographics

Gender ratio found in this cohort was thirteen males to ten females. The model found that being of male gender increased predictability of TFCC injuries. There have been no known previous studies that have investigated gender on TFCC injuries. This may reflect the occupational roles or recreational activities that are more likely to induce TFCC injuries through strain-type mechanisms.

This study reported an age range of 18 to 62 years of age, with a mean age of 41.8 years. This age range reflects the population presenting with ulnar sided wrist pain clinically. However, the age range in this cohort limits the generalisability of model, and is likely to be less relevant in children and geriatric populations. Previous studies have reported increased prevalence rates of TFCC injuries with older age (Chan et al., 2014; Lordache et al., 2012). In patients under 30-years of age, Chan et al. (2014) reported a 27% prevalence rate, compared to 49% in those over 70-years. This study reveals differing prevalence rates, to those reported by Chan et al. (2014), with the majority of (11/16, 68.75%) participants with a confirmed TFCC injury were seen in those under 50- years. Four (25%) participants under the age of 30-years, three (18.75%) participants in 31–40-year age group, four (25%) participants in 41-50-year age group being diagnosed as having a confirmed TFCC injury. Five (31.25%) participants that had a confirmed TFCC were over the age of 50-years. The higher prevalence rate seen in under 50-year age groups may be attributed to the reported mechanisms of injury, most of which occurred during recreational activities (52.2% of participants). There were no participants recruited over the age of 70-years, so therefore unable to comment on TFCC injury prevalence in this age group, but it might suggest a lower prevalence rate in this age group. If more participants were recruited in the older age groups, potentially the fall onto outstretched hand mechanism of injury may be a more commonly reported cause of symptoms and injury. Potentially,

this age group may be seen in hospital-based clinics rather than the private orthopaedic clinics that participants were recruited from. This could be attributed a more traumatic force of injury and possibility associated fractures from a fall mechanism of injury, or alternatively symptoms could be associated with insidious onset and implications of privately paying cost for specialist care.

Participant symptoms were wide ranging in duration, from 80 days to over three years, highlighting the chronicity of traumatic TFCC injuries. Normal timeframes for healing for TFCC injuries have not been established. They are potentially influenced by many factors such as age, general health, occupation, or recreational loads required and undertaken, or injury to dominant hand. In clinical practise, patients with ulnar-sided wrist pain often report high levels of pain intensity in acute phases, which may be attributed to an inflammatory response to injury, or could reflect a high level of neural innervation over the TFCC region. Pain intensity levels potentially may have settled with longer durations of injury, accordingly, impact the accuracy and reliability of the diagnostic tests that were conducted. This study excluded participants with acute injuries, less than four-weeks from date of injury. This was purposeful in order to utilise a criterion measure (e.g., MRI), which is not often performed at such an early stage in patients' injury and recovery. Early high-level imaging has both financial and service implications, and the evidence on early imaging was previously shown not to have any benefit on a better or earlier recovery (Carey, 2009; Chou et al., 2009; Wheeler et al., 2018). No known study has reported on the accuracy of diagnostic tests in acute versus chronic injuries. This was not aim of this study and not analysed due to the small sample size, but it is unknown if the duration of injury impacts the accuracy of diagnostic tests and predictability of TFCC injuries.

4.5.4 Imaging and Diagnosis

In this pilot study, 16 participants were confirmed to have a TFCC injury. Of the 16 participants with a confirmed TFCC injury, the majority were categorised as type 1B (39.1%) or 1A (21.7%). This supports the findings of previous research in which 1A or 1B TFCC injuries were reportedly the most common type of TFCC injuries (Nozaki et al., 2017; Schmauss et al., 2016). The findings of this study are relevant to patients with this degree of structural TFCC injury, but should only be generalised with caution to patients with more severe or extensive TFCC injuries.

The specialists' final diagnosis of TFCC injuries were congruent with MRI findings in all cases, that is, all participants that had structural damage of the TFCC observed on MRI, were diagnosed as having a TFCC injury by their specialist. All participants diagnosed with something other than a TFCC injury had evidence of these abnormalities on MRI. For those participants with both evidence of TFCC injury and additional structural changes on MRI, the specialists determined which injury was of primary concern, and if any were of insignificance or incidental findings. This highlights the value that specialists place upon MRI findings as a part of their diagnostic work up. Given the existing evidence suggests that diagnostic tests for the TFCC have limited value, it is not surprising that orthopaedic specialist place a large emphasis on MRI findings.

All participants MRI scans showed some type of structural change, including degenerative conditions such as osteoarthritis, injury to other ulnar-sided wrist structures and central/radial wrist structures. Some of these structural changes were deemed to be the cause of participants' symptoms, and thus listed as their diagnosis, other structural changes were considered to be incidental findings, such as the presence of ganglions. The determination of whether these structural changes were deemed to be primary cause of symptoms or incidental findings was at the discretion of the specialist, which is likely to be based on a combination of factors, including their history, symptoms and clinical examination. The implications of this are that in those patients whose symptoms fail to resolve, and have limitations in their clinical examination, and report functional limitations in daily activities, referral to specialists for higher level investigation is warranted.

4.5.5 Clinical implications

The process of diagnosing a musculoskeletal injury has traditionally placed a large emphasis on the results of diagnostic tests. Yet, diagnostic accuracy research into diagnostic tests does not support their clinical usefulness. The findings of this pilot study support those of previous reviews on diagnostic tests for TFCC injury diagnosis; that no singular test can conclusively confirm or exclude a TFCC injury (Andersson et al., 2015; Valdes & LaStayo, 2013). Despite the conclusive results that the use of a singular diagnostic test has no diagnostic utility, this study has shown that a specific combination of findings obtained from the clinical examination accurately predicted TFCC injuries in those confirmed with a TFCC injury. This finding highlights the

importance of the whole clinical examination, not just relying on the diagnostic tests in the physical assessment, in diagnosing TFCC injuries. The findings of this pilot study echo similar diagnostic accuracy studies of diagnostic tests of other joints, in particular those in the shoulder (Cadogan et al., 2016; Salamh & Lewis, 2020), in which diagnostic tests showed limited clinical utility and combination predictors from the entire clinical examination increased predictability of injuries.

4.5.6 Limitations

The study was designed as a pilot study to determine if a larger study was warranted. This was a purposeful decision due to the unknown data regarding true prevalence of TFCC injuries in the cohort that was studied, and the estimates of accuracy and level of precisions for this. The benefits of performing a pilot study with its smaller number of participants include that it has less intense requirements in terms of time, finances and equipment. It can help to assess the feasibility and practicability of any future studies and help to identify any weakness or logistical issues inherent in the study methods that should be addressed before committing to well-developed research. It can also help to inform sample size calculations for future studies. The limitations of a small sample size in a defined cohort include its generalisability to larger or different populations than the cohort used in the study. The small sample size also produces a poor precision of point estimate, in which results are unlikely to produce statistically significant estimates.

The statistical analysis undertaken in this pilot, including the use of the lasso, maximised results from a small data set. The lasso is a shrinkage tool which has been cross-validated, which improves prediction performance by quelling overfitting. It is a modification of the logistical regression likelihood to enable shrinkage, which automatically corrects overfitting and collinearity while directly optimising a predictive criterion, in comparison with significance-based selection methods. In the absence of full study, the results of this pilot study provide best evidence possible on diagnosis of a TFCC injury. The small sample size limits generalisability because we do not know if similar results would be observed in a larger sample that would include a broader range of participant characteristics. This study has strong internal validation, but requires external validation. The participants included in the study appear to be

representative of those commonly seen in hand therapy practices in Aotearoa New Zealand but may not truly represent a larger sample.

In the present study the reference standard was specialist diagnosis informed by MRI findings. The gold-standard of TFCC diagnosis is through arthroscopic investigation, but the evidence and use of MRI as a primary diagnostic tool is increasing. Our method of participant recruitment potentially created a selection bias. This study utilised a specific participant cohort, in that it included participants under the care of orthopaedic hand surgeons. This was in part due to the requirement for the participant to undergo an MRI as the reference standard. This is an expensive form of investigation, and is not typically available or undertaken in the majority of musculoskeletal injuries in the first few months of injury. Referral to hand surgeons, traditionally is reserved for those with either significant injury, or failure of progression with conservative management strategies (such as physiotherapy or hand therapy). This therefore could include participants with injuries of longer duration, higher levels of pain, and potentially higher levels of damage. Therefore, accuracy of diagnostic tests and other variables to predict TFCC injuries is likely be different in a more acute, or less severe population. Recruiting consecutive patients was not intended from the methods used, which included multiple recruitment sources. Therefore, it was impossible to guarantee that all the specialists and their reception teams would be able to identify and recruit all appropriate patients using a consecutive patient approach.

4.5.7 Future research

The purpose of this pilot study was to investigate if a larger study that could provide definitive data regarding the diagnostic accuracy of the clinical examination of the wrist for TFCC injuries is warranted. Conducting a repeat study with a larger sample size could help to provide more statistical significance and power to the subsequent results and recommendations, specifically around the diagnostic accuracy of individual tests and combinations of clinical examination variables. Based on our findings, we can provide an indication of the sample size required for a study to build a reliable, definitive predictive model of TFCC tear diagnosis. As described in 4.3.4, we limited the predictors under consideration to the lasso-selected predictors (gender, mode of injury, indicator of constant symptoms, indicator of crepitus, pain intensity with

pronation-based ADLs, indicator of pain with supination-based ADLs, passive radial deviation ROM, passive pronation ROM, grip strength in neutral) to which we added the lasso-excluded predictors with a p-value smaller than 0.3, as obtained from the bias-reduced simple logistic regression fits (indicators of pain with twisting wrist and with palm facing down, pain scale with palm facing upwards, ulnar deviation active ROM, GRIT ratio). Applying the formula from 4.3.4, we obtained a minimum required sample size of 246. A sample size of this magnitude would potentially be able to determine if specific diagnostic tests were more accurate with certain types or categories of TFCC injuries. However, performing such a large study would require a multi-centred approach. Despite the importance of a correct diagnosis for correct patient management, the feasibility of undertaking this in terms of financial costs, radiological and specialist services, as well as time for recruitment would likely be improbable.

Given the chronicity of TFCC injuries observed in this study's cohort, it raises the question of accuracy of diagnostic tests in acute versus chronic timeframes, and if clinical examination variables alter over the course of injury. Examining participants at initial presentation, six weeks, three- and six-month timeframes may help to allude to changes in clinical presentations during the course of patients' injuries. It may also assist in determine predictors shown at initial presentation those who fail conservative management strategies and require specialist input and high-level investigations such as MRI. The preliminary findings from this study (the model of nine variables) could potentially be applied to different patient cohorts, such as those within the first four weeks of injury, to test its external validity.

4.6 Summary

This study aimed to determine the reliability and diagnostic accuracy of elements of the clinical examination used to identify TFCC injuries, in comparison to a reference standard of specialist diagnosis, with MRI confirmation. TFCC diagnostic tests used to determine TFCC injury were reliable when performed by different assessors. However, used as a stand-alone test, they have limited ability to accurately diagnose or exclude TFCC injuries. The results of this pilot study demonstrated a model of nine predictors was 100% accurate in predicting TFCC injuries in its cohort who had a diagnosed TFCC

injury. It is predicted to be wrong in only 17% if applied to another group of patients similar to this study's cohort.

Chapter 5: Summary, key findings and recommendations

The purpose of this chapter is to summarise and integrate the findings from the systematic reviews and the pilot study. It will discuss implications of these findings upon clinical practise. The key findings from my research are as follows, and will be discussed in the following paragraphs

1. TFCC diagnostic tests are reliable between therapists.
2. Individual TFCC diagnostic tests, including the ulnar fovea sign, shear, grind and GRIT tests have limited clinical utility in predicting TFCC injuries.
3. A combination of TFCC diagnostic tests does not increase the accuracy of predicting TFCC injuries.
4. A combination of factors from the clinical examination increases the accuracy of predicting symptomatic TFCC injuries.
5. MRI scans have high levels of accuracy to detect TFCC injuries
6. There may be a higher prevalence of TFCC injuries in younger age ranges than previously reported.
7. The chronicity of TFCC injuries, may be greater than previously reported.

5.1 Key findings

In regards to the reliability of the TFCC diagnostic tests, both the systematic reviews and the pilot study showed that the majority of TFCC diagnostic tests had high levels of inter-rater reliability. This indicates that these diagnostic tests consistently provide the same results between different therapists. Additionally, the inter-rater reliability of clinical examination components such as ROM and grip strength were also observed to have high levels of agreement. This is an important finding because it suggests that clinicians perform and interpret tests in a similar manner. As such, clinicians can be confident in the reliability between therapists for most elements of the clinical examination for patients with suspected TFCC injuries. Intra-rater reliability was not assessed in this pilot study as the tests were only performed on one occasion. The literature review highlighted that this aspect has only been investigated in a small number of studies. High levels of intra-rater reliability have been reported in the push-off test (Vincent et al., 2014) and the peak torque rotational test (Andersson et al.,

2016). Further recommendations on intra-rater reliability in other diagnostic tests are limited. However, a reliable test is not useful clinically unless it is accurate in its desired testing aim, and an accurate test is not useful unless the result is repeatable, so the reliability and accuracy of diagnostic tests should be considered together when implementing clinically.

The results of both of the systematic review and the pilot study suggests that there is limited clinical utility with individual TFCC diagnostic tests. Based on the literature review, no single TFCC diagnostic test was conclusively useful for making a TFCC injury diagnosis. There was some clinical utility in the ulnar fovea sign, grind test, and DRUJ ballotment. The shear test had low diagnostic accuracy and the push off test was not recommended. However, there was conflicting results between the studies. The pilot study showed that there was low-moderate clinical utility in diagnosing TFCC injuries using the ulnar fovea sign, shear, grind and GRIT tests, but the results were not of statistical significance. No singular TFCC diagnostic test had the ability to both conclusively confirm or exclude TFCC injures. The lack of a singular test to both confirm and exclude pathology is not uncommon in the context of musculoskeletal medicine diagnostic tests. Few tests possess both high specificity and sensitivity values (Fritz & Wainner, 2001). Caliş et al. (2000) examined the diagnostic accuracy of diagnostic tests for subacromial impingement syndrome, of the six tests they investigated, no test was shown to have both high levels of sensitivity and specificity. The results from this pilot study also followed this notion, with no TFCC diagnostic test exhibiting both high statistical metrics confirming (specificity or LR+) or excluding (sensitivity or LR-) TFCC injuries.

The multitude of TFCC diagnostic tests reflect the complex anatomical and functional ability of the TFCC. TFCC injury could be to any of the structures within the complex, and due to their individual anatomical and functional structures, individual tests and specific forces are purported to stress these structures. Based on the tests and mechanical actions, the piano key theoretically tests the dorsal DRUJ ligaments, the grind test, assesses the TFC disc, the shear test assesses the ulnocarpal ligament, and ulnar fovea palpation the insertion of the ulnocarpal and radioulnar ligaments at the ulnar styloid. The GRIT test aims to induce ulnar carpal impaction and impinge the TFC articular disc in its pronated forearm position and when applying finger squeezing. This

study suggests that individual tests do not test isolated structures in the way we think they do, and brings into question the notion that individual tests stress and diagnosis injury to isolated structures within the TFCC. However, as this was not an aim of the current thesis, this cannot be confirmed by the current study. Nonetheless, it may potentially have an impact on the accuracy of the TFCC diagnostic tests, as each test has specific mechanics which aims to stress different components of the TFCC. The lack of studies investigating the accuracy of diagnostic tests of specific TFCC structures injuries reflects the shortage of large participant studies investigating this concept. Only two papers (Schmauss et al., 2016; Tay et al., 2007) were located that used sub-group analysis, including specific TFCC sub-structures, which looked at estimates of sensitivity and specificity in the ulnar fovea sign and grind test. Tay et al. (2007) reported a decline in both estimates of sensitivity and specificity with specific TFCC structure injuries for both foveal disruptions and ulnotriquetral ligament injuries. Schmauss et al. (2016) reported a slight increase in sensitivity values but decline in specificity values for both the ulnar fovea test and the grind test in central TFC perforations. But this was no better than other clinical factors such as pain location, and pain location with a history of trauma. Despite the complex anatomical makeup and varied functional roles of the TFCC, the lack of current evidence in regards to the accuracy of diagnostic tests with specific TFCC structures is insufficient to support claims that suggest that they can. Therefore, clinicians should be wary in taking this approach.

Reliance on a single test to make a diagnosis is not always recommended due to a lack of sufficient clinical accuracy of individual tests (Alqarni et al., 2011). In clinical practice diagnostic tests are sometimes performed in isolation but more commonly in combination, in order to increase therapists' confidence in confirming or excluding a specific condition. In order for clusters to be effective, each included test or factor must have acceptable reliability and accuracy. Second, they must be sufficiently diverse, i.e., they must execute testing diversely, either as it relates to structure or force or variable. The effect of using multiple TFCC diagnostic tests to accurately predict TFCC injuries has not previously been investigated. The results of the pilot study indicated that utilising multiple TFCC diagnostic tests does not increase

predictability of determining TCCC injuries. In fact, there were better predictors of TFCC injury than combinations of different diagnostic tests can provide.

The pilot study conducted in this thesis, is the first known study to have examined predictive variables for TFCC injuries. It highlighted the value that combinations of components in the clinical examination have on diagnosing TFCC injuries. This study showed that a combination of nine variables increased predictability of TFCC injuries. These factors included being of male gender, sustaining a strain-type mechanism of injury, the presence of constant symptoms, the presence of crepitus, pain intensity with pronation-based activities, the presence of pain with supination-based activities, the higher the amount of grip strength in a neutral position, the lesser the degree of passive radial deviation and pronation movements. This model of nine predictors is designed to be used in combination, meaning that all factors included in the model need to be asked and assessed, and the corresponding co-efficient applied in order to obtain a score. This score will then provide clinicians with a predicted probability of a TFCC injury. An example of the use of the model is shown in Table 28 on page 100. A score over 50% is the threshold to indicate those predicted with a TFCC injury, and less than 50% indicates those predicted not to have a TFCC injury. The implementation of this model in a clinical setting would not unfeasible, but would add to clinicians workload. Clinical implementation could be achieved through a computer based or online spreadsheet and corresponding calculator, or worked out manually with a printout of the model and the associated calculations required. These findings challenge traditional diagnosis principles, in that the use of special diagnostic tests has a large emphasis placed upon their value, over and above other aspects of the clinical examination such as patient history. This should encourage clinicians to trust their ability to recognise TFCC injuries based off a range of factors from the entire patient examination, not just rely on the outcome of a few physical tests. The findings of this pilot study corresponds well with recent findings of subacromial shoulder pathology, where special diagnostic tests lack clinical utility, and other factors (such as pain location, mechanism of injury, pain associated with movement) were identified that increased sensitivity values (Cadogan et al., 2016).

Despite the lack of conclusive research supporting their use for diagnostic accuracy, there may be other benefits related to performing TFCC diagnostic tests. These tests

can be provocative in nature, and can provide clinicians a starting point for diagnosis. Furthermore, these tests can provide information on the progression of symptoms and injury in a case where a test has a quantifiable outcome, e.g., the weight-bearing or grip strength tests, or with pain provocation tests when they no longer reproduce patients' familiar pain.

The use of MRI scans in clinical practice in Aotearoa New Zealand is considered a standard approach for diagnosing wrist injuries. The literature review on MRI scan efficacy for detecting TFCC injuries indicated high levels of accuracy. It is noted that using MRI protocols, including a higher scan resolution, such as 3.0 Tesla and a wrist coil, has been shown to yield higher levels of accuracy. The pilot study results showed no disparity between participants' MRI scans and specialist diagnoses for patients who have reported TFCC injuries, thereby highlighting the importance that MRI scans have on the diagnostic process. Although only 70% of participants had a confirmed TFCC injury, significant underlying pathologies were reported for the remaining 30%. These outcomes indicated the value and importance that is placed on MRI scans combined with a specialist diagnosis, with patients with ongoing symptoms. Previous research around the prevalence of abnormalities on MRI scans has shown that they do not necessarily equate to patients source of pain (Gill et al., 2014; Jensen et al., 1994). Using specialist diagnosis as the reference standard, rather than MRI results aims to mitigate this concern, because the surgeon is making a diagnosis based not only on the MRI but also on the patient's symptoms, history and clinical examination. Given the findings of MRI reports and link with specialist diagnosis there could be an argument to consider early MRI scans for all patients with ulnar-sided wrist pain. However, several factors would counter this notion including the cost implications, increased demand on specialist and radiological services and prolonged timeframes required to complete this. It could equally be argued that if patients have all nine confounding variables present and TFCC injury is highly suspected, then that combination of findings from the clinical exam could predict the presence of TFCC injury and referral for MRI may not be needed.

Reported epidemiological data on TFCC injuries are minimal worldwide. In Aotearoa New Zealand, statistical data is grouped as 'wrist sprains' which is inclusive of TFCC injuries. However, as this is not subcategorised by location or structure, true TFCC

injury numbers remain unknown. My research has added helpful data on rates of TFCC injuries in Aotearoa New Zealand. A review of a metro clinic indicated that ulnar wrist sprains represented approximately 10% (150/1,467) of the clinical caseload; 25% of these cases required further investigation, where 38 patients were referred for an MRI scan, and 28 (75%) participants subsequently received a confirmed TFCC injury diagnosis. The pilot study results indicated a similarly high prevalence, with nearly 70% of participants confirmed to have had a TFCC injury. There is limited known prevalence rates of TFCC injuries, beyond a few studies indicating a higher prevalence of TFCC tears in older age groups (Chan et al., 2014; Lordache et al., 2012), but failed to determine if this is purely degenerative in nature or reflects traumatic mechanisms of injury. This study found a higher prevalence rate (68.75%) of traumatic TFCC injuries in participants with PRT below the age of 50 years. This may be influenced by the inclusion criteria requiring a traumatic mechanism of injury and not degenerative or insidious onset of symptoms, and thus a higher rate of traumatic mechanisms is subsequently reported in younger patients.

The pilot study highlighted the chronic nature of TFCC injuries in its cohort, with the average mean duration lasting longer than nine months. This finding may be influenced by the methods of the pilot study because it only included participants who had injuries for over four weeks, thereby increasing the likelihood of longer duration symptoms. It is also likely to reflect that many of the study participants had to wait substantial periods of time before being assessed by a private hand specialist. The normal healing timeframes of TFCC injuries has not been established. The anatomical makeup of the TFCC, including the avascular nature of the TFC disc, and high neural innervation are likely to impact healing ability. Patients who have been referred to orthopaedic specialists due to ongoing symptoms also have correlating limitations in their functional ability. In more than half of the study population, patients were referred to specialists due to the failure of conservative treatment strategies implemented by either physiotherapists or hand therapists.

5.3 Clinical implications

The findings of this thesis challenges clinicians from using narrow diagnostic parameters and traditional hallmarks of TFCC injuries. This study showed that all elements of the clinical examination, including the patient interview and physical

assessments are vital components in establishing a diagnosis. The research indicated that patients with TFCC injuries are not isolated to older age brackets, with higher prevalence found in those under 50 years. Nor are they isolated to those with a fall mechanism with forearm in a pronated position, with a strain mechanism being sufficient to cause TFCC injury. Singular diagnostic tests were insufficient for conclusively confirming or excluding TFCC injuries. However, a specific combination of clinical examination factors could potentially provide higher levels of accuracy and certainty for clinicians. Given the chronicity of symptoms seen in this study, it may reflect the complex anatomical and functional role of the TFCC. If patients experienced ongoing symptoms, a pathological reason, beyond a TFCC injury could be the cause. All of the participants in the pilot study had some degree and type of underlying pathology, which was confirmed by an MRI scan. In these instances, referral for higher-level assessment and investigation by a hand specialist is appropriate.

5.4 Recommendations for further research

This thesis raised additional queries and highlighted gaps within the current body of literature related to diagnosing TFCC injuries, including the following.

1. A larger study investigating, inter-rater, intra-rater and the diagnostic accuracy of TFCC diagnostic tests and clinical examination predictors will be beneficial, by providing more certainty around the efficacy of TFCC diagnostic tests. A larger sample size will provide more information related to epidemiological factors. Doing so may also further highlight any key subjective information and whether there is any correlation between physical examination and MRI scan results.

2. A longitudinal observational study will provide a basis for determining the effectiveness of TFCC diagnostic tests. Assessing participants during an initial appointment, as well as at six-weeks, twelve-weeks and six months following the injury may help to determine patterns of behaviour, levels of pain intensity, the clinical examination of strength and range movement in order to help to indicate the predictability of TFCC injuries.

3. Establishing consensus among specialist diagnostic approaches, including key subjective queries, clinical assessment techniques/tests and indications for

investigations. A modified Delphi survey could help to highlight individual preferences and support determining a consensus about key factors.

4. A modified Delphi study of radiologists may also help to determine the protocols used by radiological companies and radiologists when conducting and reporting on MRI scans for TFCC injuries.

5.5 Conclusions

This thesis has outlined key anatomical and pathological factors of the TFCC and its surrounding structures. It discussed the epidemiological, biomechanical and technical considerations of TFCC injuries. The focus of the thesis was on the efficacy of diagnostic tests for determining TFCC injuries. It specifically considered the reliability and diagnostic accuracy metrics of these tests. By conducting systematic literature reviews, the study evaluated the current knowledge base of TFCC diagnostic tests in terms of their known reliability and diagnostic accuracy, and discussed their limitations. Individual TFCC diagnostic tests were indicated as being highly reliable but could not be used in isolation to provide sufficient accuracy for diagnosing TFCC injuries. There was no indication that combinations of diagnostic tests yielded improved predictability of TFCC injuries. Rather, nine variables from the whole clinical examination were shown to be an effective predictor of TFCC injuries.

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Appendices

Appendix A: TFCC diagnostic Tests

Test	Overview
Articular disc shear test	The articular disc shear test assesses the ulnocarpal joint. It was first described by LaStayo and Howell (1995). It is similar to the pisiform boost or ulnomeniscal triquetral dorsal glide test although has differing testing instructions. It is a pain provoking test, looking for the reproduction of familiar pain. It is performed by producing a dorsal glide of the pisotriquetral complex on the distal ulnar head.
DRUJ ballottement	As described in Lindau et al. (2000): The forearm is placed in neutral rotation with support under the elbow. The examiner stabilised the distal radius to the carpus with one hand encasing the radial side to eliminate rotational movement. With the other hand, the examiner grips the ulnar head and applies a translation force relative to the radius and the carpus. The presence or absence of a firm (or hard) end feel in both directions is noted. The presence of instability and pain relative to the contralateral side.
Grind test	The grind test is a pain provoking test first described by (Schmauss et al., 2016); axial load is applied to the UC joint whilst rotating the DRUJ from extension to ulna deviation into a flexed position.
Gripping rotatory impaction test (GRIT)	The GRIT test was first described as a provocative test for ulnocarpal impaction syndrome, where there is abutment between the articular surfaces of the distal aspect of the ulna and proximal articular surface of the lunate and triquetral carpal bones (LaStayo & Weiss, 2001). Its mechanical aim is to impinge the articular disc (Kirchberger et al., 2015; Skirven et al., 2011), which occurs with a forceful grip in neutral and end-range forearm rotation positions. A positive test is where the ratio between positions is greater than one
Peak Rotational torque strength	The patient stands upright with their elbow against the waist in 90° flexion. The patient performs peak supination contraction, followed by peak pronation, measured from a neutral position. The amount of torque (newton metre; Nm) is reported.
Piano key sign	The piano key sign, which assesses static instability of the DRU joint through visual observation of ulna head. The presence of dorsal protuberance of the ulna head represents a positive test
Piano key test	The piano key test assesses disorders of the DRUJ. It is a pain provoking test, but also may also induce laxity. It was first described by Sachar (2008). The piano key test is performed with the patient's forearm supported against a flat surface and pressure is applied from a dorsal to volar direction across the ulna 4 cm proximal to the DRUJ.
Pisiform boost test	The ulnocarpal joint is assessed by the pisiform boost test. It is a pain provoking test, but may also reproduce laxity of clicking. A volar force is applied to the ulnocarpal joint, with the index finger over the ulnar styloid and thumb over pisiform bone (Brogan et al., 2019).

Test	Overview
Push off test	The push-off test provides a quantitative measure of weightbearing tolerance, which can be directly compared with standardised normal values and between contralateral limbs. It differs to the wrist weightbearing test in the position and equipment used. In this test, patients weight-bear through their upper limb, by leaning backwards on a Jamar hand-held dynamometer that is placed on a table (Vincent et al., 2014). A dynamometer is placed on a stable, non-slip surface in the second position (3.8 cm) and reversed so that the convex side of the dynamometer handle faces upwards. The examiner providing additional stabilisation support to the dynamometer. The subject is positioned at a high table with their buttocks leaning against the table but not sitting on the table. The subject's weight bears through dynamometer handle until they have applied their maximum tolerable load. The amount of weight tolerated (kilograms) is measured. Weight tolerated on the affected is compared to the non-affected limb.
Press test	The press test evaluates weightbearing tolerance, through the patients ability to lift their body weight whilst sitting in a seated position on a chair (Lester et al., 1995). It is a pain provoking test that aims to reproduce familiar focal ulnar sided wrist pain.
Ulna fovea sign	The ulna fovea sign was described by Tay et al. (2007). It is a pain provoking test looking to reproduce at tenderness over the ulna fovea region. It is theorised that is specifically assesses foveal disruption of DRUJ and UT joint ligaments. To perform the test the examiners thumb tip is pressed distally and deep into the interval "soft spot" between the ulnar styloid process, flexor carpi ulnaris tendon, volar surface of the ulnar head, and the pisiform.
Ulnomeniscal dorsal glide test (UMDGT)	The UMTDGT applies translation force to the ulnocarpal joint, looking for laxity or pain. With the examinator performing a pinching action, with the pisiform and triquetral bones moved in a dorsal direction, whilst the ulna is stabilised (Evans et al., 2013)
Wrist weightbearing test	The wrist weightbearing test is an elaboration on the press test. It is designed to provide a quantitative value of weightbearing tolerance, in comparison to contralateral limb. Using analogue scales that is placed on the floor, whilst the patient is kneeling, they place their hand in the centre of the scale with elbow in full extension

Appendix B: Systematic search results

Reliability of TFCC diagnostic tests literature search strategy and results

Search number	Keyword	Database					
		Scopus	Medline	Cinahl	Sports DISCUSS	Web of Science	Amed
S1	TFCC OR triangular fibrocartilage* OR ulna* wrist	1300	3882	755	252	5815	16
S2	provocat* OR test OR sign OR diagnos* OR clinical OR exam*	22,021,198	11,317,551	2,913,145	409,686	13,475,289	101,247
S3	reliab*	1,626,491	473,912	166,189	27,773	1,124,827	10,642
S4	S1 AND S2 AND S3	53	145	30	12	258	0

* = truncation

The accuracy of TFCC diagnostic tests according to the literature search strategy and its results.

Search number	Keyword	Database					
		Scopus	Medline	Cinahl	Sports DISCUSS	Web of Science	Amed
S1	TFCC OR triangular fibrocartilage* OR 'ulna* wrist'	3,048	3,517	629	227	4,996	16
S2	provocat* OR test OR sign OR diagnos* OR clinical OR exam*	31,552,349	11,107,858	2,468,248	403,500	13,225775	99,469
S3	accura* OR sensitivity OR specificity OR validity	12,724,889	2,486,084	551,690	74,388	4,646,100	22,341
S4	S1 AND S2 AND S3	1,058	442	90	27	547	0

* = truncation/Boolean operator

The diagnostic accuracy of 3.0T MRI for TFCC diagnosis, based on the literature search strategy and its results.

Search number	Keyword	Database					
		Ebsco	Scopus	Medline	Cinahl	Sports DISCUSS	Amed
S1	TFCC OR triangular fibrocartilage complex	14,113	1,309	1,123	302	101	14
S2	MRI OR magnetic resonance OR magnetic resonance imaging	5,547,368	162,5402	883,748	184,520	14,360	3916
S3	3T OR 3 Tesla OR 3-Tesla	670,638	20,682	12,247	3,737	247	34
S4	accura* OR sensitivity OR specificity OR validity	26,423,768	5,395,610	1,279,742	423,482	93,763	24,507
S5	S1 AND S2 AND S3 AND S4	325	6	4	2	0	0

* = truncation

Appendix C. Ethics approval

Auckland University of Technology Ethics Committee (AUTEC)

Auckland University of Technology
D-88, Private Bag 92006, Auckland 1142, NZ
T: +64 9 921 9999 ext. 8316
E: ethics@aut.ac.nz
www.aut.ac.nz/researchethics

28 March 2019

Steve White
Faculty of Health and Environmental Sciences

Dear Steve

Ethics Application: 19/74 Examining the diagnostic accuracy of information obtained from the clinical examination in diagnosing Triangular Fibrocartilage Complex (TFCC) injuries

Thank you for submitting your application for ethical review. I am pleased to advise that the Auckland University of Technology Ethics Committee (AUTEC) approved your ethics application at their meeting on 25 March 2019, subject to the following conditions:

1. Clarify the Primary Researcher's qualification noting that they appear to be different in B.1.2 of the application form and the Information Sheet;
2. Please clarify the responses to managing potential conflict of interest (K.1) if a participant is known to both members of the research team;
3. Clarify why it appears that the PGR1 review was performed by the Applicant;
4. Amendment of the Information Sheet as follows:
    a. Advise that participants can access their own results with an appropriately expert explanation.

The committee observes that data collection over a period of 8 months seems long in relation to the qualification being undertaken

Please provide me with a response to the points raised in these conditions, indicating either how you have satisfied these points or proposing an alternative approach. AUTEC also requires copies of any altered documents, such as Information Sheets, surveys etc. You are not required to resubmit the application form again. Any changes to responses in the form required by the committee in their conditions may be included in a supporting memorandum.

Please note that the Committee is always willing to discuss with applicants the points that have been made. There may be information that has not been made available to the Committee, or aspects of the research may not have been fully understood.

Once your response is received and confirmed as satisfying the Committee's points, you will be notified of the full approval of your ethics application. Full approval is not effective until all the conditions have been met. Data collection may not commence until full approval has been confirmed. If these conditions are not met within six months, your application may be closed and a new application will be required if you wish to continue with this research.

To enable us to provide you with efficient service, we ask that you use the application number and study title in all correspondence with us. If you have any enquiries about this application, or anything else, please do contact us at ethics@aut.ac.nz.

I look forward to hearing from you,

Yours sincerely

Kate O'Connor
Executive Manager
Auckland University of Technology Ethics Committee

Cc: rebeccatuhi@outlook.com; juliecollis@gmail.com; Alain Vandal

Appendix D: Study Pamphlet

This study is being conducted by Rebecca Tuhi as a part of a Master of Philosophy qualification at Auckland University of Technology.

This study has received ethics approval from Auckland University of Technology ethics committee (AUTEC), reference 19/74.

Rebecca's Research supervisor is:
Dr Steve White.
steve.white@aut.ac.nz
+64 9 921 9999 ext 7073

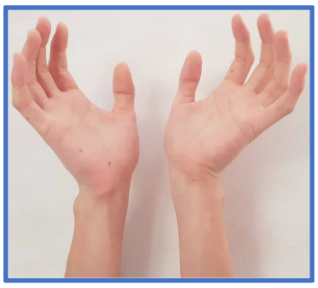
Want more information?

If you would like to know more about this study, please read the "study information sheet"

You can also contact Rebecca on
Telephone: 021 0300740
Email: rebeccatuhi@outlook.com

Thank you for your interest

A study on wrist injuries



If you are interested please contact
Rebecca Tuhi
Text/phone: 0210300740

Overview of the study

You are invited to participate in a study that is investigates the accuracy of tests designed to diagnose injuries to the cartilage & ligaments in the wrist.

Presently, there is insufficient evidence that demonstrates whether or not these tests can be relied on to prove or disprove an injury to these important structures.

The findings of this study may lead to changes in the way such injuries are diagnosed and consequently improved management of wrist

What does the study involve?

If you choose to participate in this study and give your written consent, your wrist will be examined by the researcher just prior to the MRI that your specialist has requested.

During this exam, you will fill out questionnaires about yourself, your injury and symptoms and an experienced hand therapist will perform commonly used diagnostic tests on your wrist. This includes measuring your wrist movement, strength and ligament integrity.

Can I take part in study?

You can take part, if you:

- Are over the age of 18
- Injured your wrist from an incident
- Have pain over the ulnar (little finger side) wrist
- have been referred for an MRI scan by your specialist

Your rights

Participation in this study is completely voluntary, i.e. your choice.
Your participation will not affect any current or further treatment.

Appendix E: Study information sheet

Participant Information Sheet

Date Information Sheet Produced: 1st February 2019

Project Title: Examining the accuracy of tests for wrist ligament injuries

An Invitation

Kia ora, my name is Rebecca Tuhi and I am a physiotherapist & hand therapist with ten years of clinical experience. My current role is in hand therapy at Handworks, which is a specialised hand therapy rehabilitation clinic. We work closely with local hospitals, A&E clinics, GPs and orthopaedic/plastic specialists to provide treatment for hand, wrist and upper limb conditions and injuries.

Since graduating as a physiotherapist in 2009, I became a registered hand therapist in 2016 and completed a Master of Health Practice through the Auckland University of Technology (AUT) in 2017. I also help teach on the post-graduate hand therapy course at AUT. Currently I am undertaking a Master of Philosophy at AUT, which is focused on wrist pain. My future hopes are to extend my studies to PhD level.

What is the purpose of this research?

This study aims to find information that would help in diagnosing injuries to the triangular fibrocartilage complex (TFCC) which is located on the little finger (ulnar) side of your wrist. We hope that finding out this information will help therapists and specialists, diagnose TFCC wrist injuries accurately.

The TFCC is a part of the wrist, made up of ligaments, a disc and a tendon that help to stabilise and support your wrist. It is usually injured by falling onto your hand, but can also be injured with lifting/twisting activities such as sports or work place actions. When the TFCC is injured people report pain over the little finger side of their wrist, which is worse with twisting movements, gripping actions and leaning on their hands. If people have ongoing pain that does not get better with therapy, they may be referred to a specialist and sent for an MRI scan. Due to wait-list demands on these services, there is often a delay for this to happen. Whilst MRI scans are very good at detecting TFCC injuries, only specialists can send patients for them and they are quite expensive. Although there are a number of tests used to diagnose injury to the TFCC the accuracy of these tests has not been demonstrated through well designed research. Without knowing how accurate these tests are, we cannot be confident in the test findings. This makes it difficult to establish an early, correct diagnosis and to decide on the most appropriate management.

Our intention is to publish the findings of this study in international research journals and to present them at hand therapy/physiotherapy conferences, as well as to undergraduate & post-graduate physiotherapy students.

How was I identified and why am I being invited to participate in this research?

You have been invited to participate because of your injury and the decision of your specialist to refer you for an MRI of your wrist. We would like you to consider participating in our study. There are a few criteria that are required to participate in this study, this includes being over 18 years of age and confident with the English language.

How do I agree to participate in this research?

Your participation in this research is voluntary (it is your choice) and whether or not you choose to participate will not change the treatment you receive. You are able to withdraw from the study at any time. If you choose to withdraw from the study, then you will be offered the choice between having any data that is identifiable as belonging to you removed or allowing it to continue to be used. However, once the findings have been produced, removal of your data may not be possible.

To express your interest in this study, you can complete the "expression of interest" form with your contact details at the receptionist or contact Rebecca directly on 0210300740 or rebeccatuhi@outlook.com.

What will happen in this research?

If you take part in the study, we will ask you to attend one appointment that will take approximately 45-60 minutes. This can be scheduled at a time convenient for you, including out of work hours such as the evening or on the weekend. We can arrange an assessment at multiple locations in the Auckland region, including at our physiotherapy clinics located in Greenlane, Howick, Botany or the AUT Integrated Health located in Northcote.

At this appointment you will be asked to complete questionnaires on your demographics (age/gender/type of work/hand dominance/injury). You will be asked about your pain levels and how well you can function with daily

tasks due to your injury. You will also have an assessment of your wrist, by a registered hand therapist, to assess your movement, strength and wrist ligaments. Some participants will be required to have two therapists complete the assessment, which would happen at the same appointment. This is because we need to assess the reliability of the test findings when done by different therapists.

What are the discomforts and risks?

Participating in this research is unlikely to cause you any damage or long-term pain. As part of the assessment, diagnostic tests will be performed. These tests will be the same (or very similar) to the tests that your specialist or therapist has already performed. These are tests that assess your ligaments, they may cause temporary discomfort. If in the unlikely event your symptoms are significantly aggravated, you would be entitled to apply for ACC coverage.

How will these discomforts and risks be alleviated?

The therapist conducting the tests is very experienced and as a part of your assessment will determine the appropriateness of performing the tests on you. If there is any reason why you should not undergo these tests they will advise you and stop the assessment. Also, at any time you will be able to stop the assessment by declining further tests.

What are the benefits?

Whilst there are no immediate benefits for the people actually participating in this research, we expect that the information gained from this study will have a beneficial impact for those who sustain similar injuries in the future. It is possible that this research will enable an accurate diagnosis to be made sooner than is currently possible and that the need for consultation with a specialist and an unnecessary MRI will be reduced.

How will my privacy be protected?

All information that is collected about the participants will be kept confidential. Participants will not be identifiable in any reports or publications. Once you are in the study, you will be given a unique identification code and all your data will be linked to that code. The only people who will have access to your information are the researchers (Rebecca Tuhi and Sarah Waldin) as well as the AUT research supervisors (Julie Collis, Steve White & Alain Vandal). All data collected will be stored electronically and will be password protected. This data will be held for 10 years and then destroyed. Anonymised data (data which does not allow identification) may be reused by the research team for future studies and publications.

What are the costs of participating in this research?

Apart from travelling to the appointment and time for the appointment, there is no further costs to the participants. A $20 petrol voucher will be given to all participants.

What opportunity do I have to consider this invitation?

It all depends on the timing of your MRI scan, which can take a few weeks to schedule. If you have not booked in for your MRI yet and are interested in participating, we would still love for you to contact us as soon as possible. We need to complete the assessment within two weeks of your MRI (either the week before or after). This is to make sure that both forms of investigation are undertaken during a time period in which the status of your injury doesn't change significantly (i.e. get better or worse).

Will I receive feedback on the results of this research?

If you wish, a summary of the study results can be sent to you at the completion of the research project. You are also able to access your own results with adjoining explanation from the physiotherapist researcher if you desire.

What do I do if I have concerns about this research?

Any concerns regarding the nature of this project should be notified in the first instance to the Project Supervisor, Dr Steve White (steve.white@aut.ac.nz, +64 9 921 9999 ext 7073).

Concerns regarding the conduct of the research should be notified to the Executive Secretary of AUTEC, Kate O'Connor, *ethics@aut.ac.nz*, 921 9999 ext 6038.

Whom do I contact for further information about this research?

Please keep this Information Sheet and a copy of the Consent Form for your future reference. You are also able to contact the research team as follows:

Researcher Contact Details: Rebecca Tuhi, rebeccatuhi@outlook.com, +64210300740

Project Supervisor Contact Details: Steve White, steve.white@aut.ac.nz, +64 9 921 9999 ext 7073

Approved by the Auckland University of Technology Ethics Committee on 2nd April 2019 AUTEC Reference number 19/74

Appendix F: Expression of interest form

Yes, I would like to be contact further about participating in the research project *"Examining the accuracy of tests for wrist ligament injuries"*

Name _____

Signature: _____

Contact Number: _____

Best contact time
- ☐ 8-12am
- ☐ 12-1pm
- ☐ 1-6pm
- ☐ 6-8pm

Once completed, please give this form to your specialist's receptionist.

Rebecca will contact you within a week to discuss this study further. You are also welcome to contact Rebecca directly on 0210300740

Appendix G: Phone screening questionnaire

Questions		Yes	No
Are you over 18 years of age			
Are you able to converse, read and write in English confidently			
Are you currently suffering from ulna sided wrist pain			
Pain rating (NPRS)	at rest		/10
	worst		……/10
How long does it take to settle your pain after being irritated		☐	>1 hour
		☐	>1 day
		☐	>2 days
Is your pain the result of a traumatic accident (i.e sports injury/fall)? How did your injury occur? _____			
Is this injury being covered by ACC?			
At the time of the injury did you fracture or dislocate any structures? _____			
Are you under the care of an orthopaedic or hand specialist?			
Have you been asked to go for an MRI?			
MRI Date: _____ Location: _____			
Have you previously injured this hand/wrist/forearm? _____			
Have you previously broken a bone in your hand or forearm? _____			
Have you previously had surgery on your hand or forearm? _____			
Have you been diagnosed with arthritis in your hand or wrist? _____			
Have you been diagnosed with any neurological conditions (i.e. Parkinson's disease, motor neuron disease or stroke)? List: _____			
Have you been diagnosed with any rheumatological diseases (i.e rheumatoid arthritis, lupus or polymyalgia)? List: _____			
Are there any other medical conditions you have been diagnosed with? List: _____			

Appendix H: Consent form

Consent Form

Project title: Examining the accuracy of tests for wrist ligament injuries.

Project Supervisor: *Dr Steve White & Julie Collis*

Researcher: *Rebecca Tuhi*

- ○ I have read and understood the information provided about this research project in the Information Sheet dated 1st February 2019.
- ○ I have had an opportunity to ask questions and to have them answered.
- ○ I understand that taking part in this study is voluntary (my choice) and that I may withdraw from the study at any time without being disadvantaged in any way.
- ○ I understand that if I withdraw from the study then I will be offered the choice between having any data belonging to me removed or allowing it to continue to be used. However, once the findings have been produced, removal of my data may not be possible.
- ○ I do not have a history of the following medical conditions
  - Neurological conditions such as stroke, Parkinson's Disease, Motor Neuron Disease.
  - Previous history of trauma, including fractures, joint dislocation or surgery to my hand or wrist
  - Diagnosed osteoarthritis of my wrist, hand or fingers.
  - Rheumatological disease (e.g. Rheumatoid arthritis)
  - Any illness or injury that affects my physical performance
- ○ I agree to take part in this research.
- ○ I understand that some of the assessment will be completed twice by two separate therapists with a portion of participants, and I agree to this.
- ○ I agree to allow the research team to have access to imaging results (including MRI) of my wrist
- ○ I agree to anonymised data (data which does not allow identification) being reused for future studies and publications.

- ○ I wish to receive a summary of the research findings (*please tick one*):
  No○ Yes○ (preferred method of correspondence; Post ○ Email ○)
- ○ I consent for possible future contact the research team (*please tick one*)
  No○ Yes○

Participants Name: _____

Date of Birth: _____

Participants signature : _____ Date: _____

Contact Details: Phone: _____

Address: _____

Email: _____

Approved by the Auckland University of Technology Ethics Committee on 2nd April 2019 AUTEC Reference number 19/74.

Note: The Participant should retain a copy of this form.

Appendix I: Patient Interview Questions

Background Details

1. Age: _____

2. Gender ☐ Male ☐ Female ☐ Gender Diverse

3. Nationality: (please state)_____

4. Hand dominance ☐ Right ☐ Left ☐ Ambidextrous
(you can use both hands the same)

Occupation & hobbies

5. Work status: ☐ Part-time ☐ Full-time
☐ Retired ☐ Student ☐ Not in paid employment

6. Occupation (including voluntary/unpaid work)_____

7. Is your normal work ☐ Sedentary ☐ Light ☐ Moderate
☐ Heavy ☐ Very heavy

8. Do you participate any regular hobbies or sports? (please list)
   - _____
   - _____
   - _____
   - _____
   - _____
   - _____

Injury Details

9. Side of Injury ☐ Right ☐ Left

10. What was the date of your injury?_____

11. How long have you had the pain/symptoms in the little finger (ulnar) side of your wrist?

Years_____months_____ days _____

12. How did your injury occur?

☐ Trauma (e.g. fall/impact/accident)
☐ Strain (e.g. strained my wrist while lifting)
☐ Overuse (e.g. repetitive action)
☐ Unknown
☐ Other (please state) _____

_____

13. Was a sport or recreational activity involved? (if yes, then describe the activity)_____

_____

14. Was it from a fall? ☐ No (continue to question 15) ☐ Yes (continue below)

a. Was the fall from a height? ☐ No ☐ Yes _____(metres off ground)
☐ Yes (from standing height)

b. Direction of the fall? ☐ Forward
☐ Backwards
☐ Sideways
☐ Unknown

c. What was the position of your arm when you fell? ☐ In front of body
☐ To the side of body
☐ Behind body
☐ Unknown

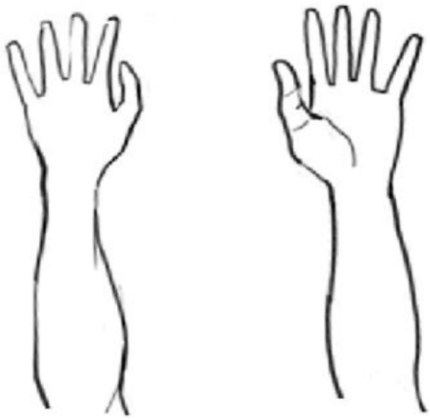
d. What was the position of your hand when you fell? ☐ Palm facing downwards
☐ Palm facing upwards
☐ Unknown

Pain and symptoms

15. Do you experience any of the following symptoms in your wrist or hand

Pain	No ☐	Yes ☐
Clicking	No ☐	Yes ☐
Catching or locking	No ☐	Yes ☐
Giving way or feeling unstable	No ☐	Yes ☐
Weakness with gripping or lifting	No ☐	Yes ☐
Pins & needles	No ☐	Yes ☐
Numbness	No ☐	Yes ☐

16. Location of your pain & symptoms (Please use diagram below to mark according the symbols of the key)



Palm down *Palm up*

KEY

X = main pain

/// = secondary pain

= clicking

○ = catching locking

:::: = numbness or pins and needles

17. Do you have any additional symptoms in your neck, shoulder, elbow?

No ☐

Yes ☐ (please describe where & what symptoms)_____

_____

_____

18. Can you describe your main pain (tick as many that apply)

Sharp pain ☐

Dull ache ☐

Other ☐ (please describe):_____

19. Pain/symptom frequency

Are the following symptoms present all the time (i.e. last the whole day/night)?

Pain	☐ No	☐ Yes
Locking	☐ No	☐ Yes
Clicking	☐ No	☐ Yes
Giving way	☐ No	☐ Yes

Do any of the following symptoms come and go (i.e. come just with certain activities or positions of hand/wrist)?

Pain	☐ No	☐ Yes
Locking	☐ No	☐ Yes
Clicking	☐ No	☐ Yes
Giving way	☐ No	☐ Yes

20. Do you have pain with the following tasks (if yes please rate on scale 0 = no pain. 10/10 worst pain)

Pain with gripping activities *(e.g. holding a mug)*	☐ No	☐ yes, rating _____/10
Pain with twisting wrist *(e.g. waving or checking watch)*	☐ No	☐ yes, rating _____/10
Pain with gripping whilst twisting wrist *(e.g. opening door handle)*	☐ No	☐ yes, rating _____/10
Pain with leaning on hands *(e.g. pushing off a chair/ground)*	☐ No	☐ yes, rating _____/10
Pain with activities with palm facing downwards *(e.g. riding bike)*	☐ No	☐ yes, rating _____/10
Pain with activities with palm facing side *(e.g. pouring jug)*	☐ No	☐ yes, rating _____/10
Pain with activities with palm facing upwards *(e.g. holding plate)*	☐ No	☐ yes, rating _____/10
Is there another activity that causes pain? (please state) _____		rating _____/10

21. Over the last week, please rate your pain level (please circle one number for each of the following)

	No pain										worst pain
In the morning	0	1	2	3	4	5	6	7	8	9	10
In the afternoon	0	1	2	3	4	5	6	7	8	9	10
In the evening	0	1	2	3	4	5	6	7	8	9	10
With activity	0	1	2	3	4	5	6	7	8	9	10

22. If you aggravate your wrist pain/symptoms, how long does it take to settle (tick only one)

☐ A few minutes ☐ A few hours ☐ The next day ☐ More than 2 days

23. Do any of the following help to settle your pain or symptoms

Rest or stopping/avoiding activity	☐ No	☐ Yes
Pain relief	☐ No	☐ Yes
Heat	☐ No	☐ Yes
Ice	☐ No	☐ Yes
Splinting	☐ No	☐ Yes
Compression	☐ No	☐ Yes
Massage	☐ No	☐ Yes

Other (please state)_____

24. In the last week, have you taken any medication to help with your pain? (please tick all that apply)

Non-steroidal anti-inflammatories (i.e. Ibprofen, diclofenac, naproxen, voltaren)
☐ Yes, medication_____
frequency (i.e daily or as needed _____ strength (if known)_____

Pain-relief (i.e paracetamol)
☐ Yes, medication_____
frequency (i.e daily or as needed _____ strength (if known)_____

Opioid-based pain-relief (i.e codeine, tramadol, morphine, oxycodone)
☐ Yes, medication_____
frequency (i.e daily or as needed _____ strength (if known)_____

Steroid-based (i.e. prednisone)
☐ Yes, medication_____
frequency (i.e daily or as needed _____ strength (if known)_____

Neuropathic pain-relief (i.e. amitriptyline, nortriptyline, gabapentin)
☐ Yes, medication_____
frequency (i.e daily or as needed _____ strength (if known)_____

Other (please state, including alternative medicine/homeopathic)
☐ Yes, medication_____
frequency (i.e daily or as needed _____ strength (if known)_____

25. Has there been any change in your pain or symptoms (increased or decreased) over the last week?

(if yes please rate on scale 0 = no pain. 10/10 worst pain)

☐ No ☐ Yes, Pain rating was _____/10. Now _____/10

Any reason for the change in pain? (please state, if known)_____

_____

26. With respect to your wrist injury, how would you describe yourself now, compared to immediately after your wrist injury? (circle number)

-5	-4	-3	-2	-1	0	1	2	3	4	5
very much worse					unchanged					completely recovered

Treatment and assessment history

27. Have you had any treatment for your wrist pain?

☐ No (please go to question 30) ☐ Yes, (tick that apply) ☐ Hand therapy ☐ Physiotherapy ☐ Chiropractor ☐ Other: _____

28. What treatments methods were used? (please tick all that apply)

☐ Splinting
☐ Advice / education
☐ Exercises
☐ Manual therapy (e.g. massage / manipulation)
☐ Acupuncture
☐ Other, please state _____

29. Are you still having treatment? ☐ Yes - how long have you had treatment for? _____
☐ No - how long did you have treatment for? _____

30. Who did you see first to assess your injury/wrist pain (please tick)

☐ GP ☐ Local A&E ☐ Hospital
☐ Physiotherapist ☐ Hand therapist ☐ Chiropractor
☐ Other _____

31. How soon after your injury did you seek medical consultation (i.e. Dr, physio), from when your wrist first started to hurt? (tick only one)

☐ Within 24 hours ☐ Within a fortnight ☐ Within 1 month
☐ Within 3 months ☐ Within 6 months ☐ Over 6 months

32. Have you had any investigations on your wrist? (tick all that apply & any details known)

☐ Xray: Date: _____ Radiology Company: _____
☐ Ultrasound: Date: _____ Radiology Company: _____
☐ MRI: Date: _____ Radiology Company: _____
☐ Other: Date: _____ Radiology Company: _____

33. Who is your orthopaedic or hand specialist/ surgeon? _____

34. Who referred you to your orthopaedic or hand specialist/surgeon? (tick only one)

☐ GP ☐ Local A&E ☐ Hospital
☐ Physiotherapist ☐ Hand therapist ☐ Chiropractor
☐ Self-referred ☐ Other _____

Appendix J: PRWHE questionnaire

*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 *L*	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 û 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

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Appendix K: QuickDASH questionnaire

QuickDASH

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. Do heavy household jobs (e.g. wash windows, clean floors)	1	2	3	4	5
3. Cary a shopping bag or briefcase	1	2	3	4	5
4. Wash your back	1	2	3	4	5
5. Use a knife to cut food	1	2	3	4	5
6. Recreational activities which require you to take some force or impact through your arm, shoulder or hand (e.g. golf, hammering, tennis etc)	1	2	3	4	5

	NOT AT ALL	SLIGHTLY	MODERATELY	QUITE A BIT	EXTREMELY
7. 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
8. 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
9. Arm, shoulder or hand pain	1	2	3	4	5
10. Tingling (pins and needles) 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
11. 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

QuickDASH DISABILITY/SYMPTOM SCORE = [(sum of n responses)–1] x 25 (where n is the number of completed responses)
n

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. Doing your work in your usual way?	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 an difficulty:	*NO DIFFICULTY*	*MILD DIFFICULTY*	*MODERATE DIFFICULTY*	*SEVERE DIFFICULTY*	*UNABLE*
1. Playing your instrument or sport in your usual way?	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 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 the assigned values for each response; divide by 4 (number of items); subtract 1; multiple by 25.

An optional module score may <u>not</u> be calculated if there are any missing items.

Appendix L: Physical Examination Form

Range of Movement

		Right	Left	Comment
Wrist extension	AROM			
	PROM			
Wrist flexion	AROM			
	PROM			
Radial deviation	AROM			
	PROM			
Ulna deviation	AROM			
	PROM			
Supination	AROM			
	PROM			
Pronation	AROM			
	PROM			

Provocative test

		Right	Left	Comment
Piano Key	Positive			
	Negative			
Ulna fovea	Positive			
	Negative			
Articular disc shear	Positive			
	Negative			
Ulna Grind	Positive			
	Negative			

GRIT	Neutral (kg)	Supination (kg)	Pronation (kg)
Left			
Right			
Ratio:			

Appendix M: Standardised protocol range of movement

Test	Description	
	Test position	Therapist measuring instructions
Wrist flexion (Norkin & White, 2009)	Place elbow on table with forearm in mid rotation Bend wrist forwards as far as comfortable	Goniometer placed over the dorsal aspect of the wrist, with the fulcrum over the dorsal wrist crease and stationery goniometer arm placed over the mid-forearm and moveable goniometer arm placed over the 3rd metacarpal
Wrist extension (Norkin & White, 2009)	Place elbow on table with forearm in mid-rotation Bend wrist backwards as far as comfortable	Goniometer placed over the volar aspect of the wrist, with the fulcrum over the volar wrist crease and stationery goniometer arm placed over the mid-forearm and moveable goniometer arm placed over the 3rd metacarpal
Wrist ulna deviation (Norkin & White, 2009)	Place elbow on table and forearm in mid-rotation With finger straight tilt fingers away from self, as far as comfortable	Goniometer placed dorsally, with the fulcrum over dorsal wrist crease and stationery goniometer arm placed over the mid-forearm and moveable goniometer arm placed over the 3rd metacarpal
Wrist radial deviation (Norkin & White, 2009)	Place elbow on table and forearm in mid-rotation With finger straight tilt fingers towards self, as far as comfortable	Goniometer placed dorsally, with the fulcrum over dorsal wrist crease and stationery goniometer arm placed over the mid-forearm and moveable goniometer arm placed over the 3rd metacarpal
Forearm supination (Norkin & White, 2009)	Elbow bent at 90 degrees and locked into side of body Turn palm to face ceiling	Goniometer placed over volar aspect of wrist crease, with goniometer fulcrum placed over the lateral aspect of the wrist at the ulna styloid. The moveable goniometry arm is in contact with the volar surface of the wrist and the moveable arm is perpendicular to the ground.
Forearm pronation (Norkin & White, 2009)	Elbow bent at 90 degrees and locked into side of body Turn palm downwards to face the ground	Goniometer placed over dorsal aspect of wrist crease, with goniometer fulcrum placed over the lateral aspect of the wrist at the ulna styloid. The moveable goniometry arm is in contact with the dorsal surface of the wrist and the moveable arm is perpendicular to the ground

Appendix N: Standardised protocol diagnostic tests

Test	Description		Positive test definition
	Testing position	Therapist instructions	
Ulna fovea sign. (Tay et al., 2007)	Participants elbow on the table, the examiner supports the patient's hand to keep the elbow in 90° to 110° of flexion, forearm in neutral rotation, and wrist in neutral position.	The examiners thumb tip is pressed distally and deep into the interval "soft spot" between the ulnar styloid process, flexor carpi ulnaris tendon, volar surface of the ulnar head, and the pisiform.	Reproduction of familiar pain
Piano key test. (Sachar, 2008)	Participants palm flat on the table	Applying a dorsal to volar load across the ulna 4 cm proximal to the DRUJ.	Reproduction of familiar pain at the DRUJ level.
Articular disc shear test (Kirchberger et al., 2015; LaStayo & Howell, 1995)	Participants be seated with the elbow resting on the tabletop with the forearm in a neutral vertical position.	The examiner's opposite thumb is positioned dorsally over the head of the distal ulna and the radial side of the index proximal interphalangeal joint is placed over the palmar surface of the Piso-triquetral complex. The examiner then squeezes the thumb and the index finger together to produce a dorsal glide of the pisotriquetral complex on the distal ulnar head.	Reproduction of familiar pain
Ulna Grind (Kirchberger et al., 2015; Schmauss et al., 2016)	Participants forearm is fixed with their elbow resting on the table and the forearm is brought in a vertical position, and the wrist in a maximum ulnar deviation.	Whilst applying axial load, the forearm is rotated from full supination to pronation.	Reproduction of familiar pain
Gripping rotatory impaction test (GRIT) (LaStayo & Weiss, 2001)	Participants elbow at 90 degrees flexion and held against their body.	Grip strength measured by handheld dynamometer is measured in forearm neutral (mid rotation), pronation and supination positions	If supinated grip is greater than neutral grip strength is greater than 1.0 (S/P: N>1)

Appendix O: Specialist Summary Form

Patient Name _____

Clinical diagnosis: _____

_____

_____

MRI Summary

☐ Yes; TFCC injury confirmed

- ☐ Disc tear ☐ Peripheral ☐ Central
- ☐ Radioulnar ligament ☐ Dorsal ☐ Palmar
- ☐ ECU subsheath
- ☐ Ulnocarpal ligament

☐ No; TFCC injury excluded

☐ Other pathology/injury: _____

Palmar Classification (if appropriate)

Type	Description
Type 1 Acute Traumatic tears	
☐ 1A	Central TFC perforation
☐ 1B	Peripheral ulna sided TFCC tear (+/- ulna styloid fracture)
☐ 1C	Distal TFCC disruption (disruption from distal UC ligaments
☐ 1D	Radial TFCC disruption (+/- sigmoid notch fracture)
Type 2 Degenerative	
☐ 2A	TFCC wear
☐ 2B	TFCC wear with lunate and/or ulna chondromalacia
☐ 2C	TFCC perforation with lunate and/or ulnar chondromalacia
☐ 2D	TFCC perforation with lunate and/or ulnar chondromalacia with Lunate triquetral ligament perforation
☐ 2E	TFCC perforation with lunate and/or ulnar chondromalacia with Lunate triquetral ligament perforation and ulnocarpal arthritis

Appendix P: Radiology summary

Patient Name _____

Patient Research ID _____

MRI date _____

MRI radiology company: _____

Radiologist: _____

MRI Summary

- ☐ TFCC injury confirmed
  - ☐ Disc tear
  - ☐ Radioulnar ligament
  - ☐ ECU subsheath
  - ☐ Ulnocarpal ligament
  - ☐ Peripheral
  - ☐ Dorsal
  - ☐ Central
  - ☐ Palmar
- ☐ TFCC injury excluded
- ☐ Other pathology/injury: _____

_____

Formal report: _____

_____

_____

_____

_____

_____

Appendix Q: Handworks Audit Data

Handworks Audit Data

Demographic	
Number of patients seen at Handworks	1467
Number of patients with ulnar wrist pain	150
Age	
- Mean	39 years
- Range	13-82 years
Gender	
- Females	78
- Males	72
Mechanism of injury	
- Trauma/Fall	80
- Strain	62
- Overuse	8
Hand dominance	
- Right	97
- Left	50
- Ambidextrous	3
Referral to specialists	38
Confirmed TFCC injury on MRI	28/38

Appendix R: Participant demographics

Participant characteristics.

Characteristic	All participants (n = 23)		PRT (n = 16)	NRT (n = 7)
	Mean (SD)	Number of participants (percentage)	Number of participants	Number of participants
Age mean	41.3 (13.07)		40.74 (14.44)	42.86 (SD 7.57)
Age range				
>30 years			4	1
31-40 years			3	1
41-50 years			4	3
51-60 years			4	2
61-70 years			1	0
<70 years			0	0
Gender				
Male		13 (56.5%)	9	4
Female		10 (43.5)	7	3
Hand Dominance				
Right		20 (87%)	13	7
Left		3 (12.9%)	3	0
Occupation				
Not working		1 (4.3%)	1	0
Physical		10 (43.5%)	7	3
Office-based		12 (52.2%)	8	4
Occupation workload				
N/A		1 4.3%)	1	
Light		10 (43.5%)	7	3
Moderate		4 (17.2%)	2	2
Heavy		1 4.3%)	0	1
Very heavy		7 30.1%)	6	1
Side of injury				
Right		13 (56.5%)	8	5
Left		10 43.5%)	8	2
Dominate hand injured				
Yes		14 (60.9%)	9	5
No		9 (39.1%)	7	2
Duration of symptoms				
>3 months		4 (17.2%)	3	1
3-6 months		6 (25.8%)	5	1
6-9 months		3 (12.9%)	3	0
9-12 months		3 (12.9%)	2	1
>12 months		7 (30.1%)	3	4

Characteristic	All participants (n = 23)		PRT (n = 16)	NRT (n = 7)
	Mean (SD)	Number of participants (percentage)	Number of participants	Number of participants
MOI force				
Trauma		16 69.9%)	12	4
Strain		6 (26.1%)	3	3
Overuse		1 (4.3%)	1	0
MOI category				
Recreation		12 (52.6%)	7	5
Work		6 (26.1%)	4	2
Other		5 (21.7%)	5	0
Fall				
Fall involved (yes)		11 (47.3%)	9	2
Fall from a height (yes)		11 (47.3%	9	2
Height of fall (m)	0.47 (0.93)		0.57m	0

N/A, not applicable. MOI, mechanism of injury. m: metres. NRT: negative reference test. PRT: positive reference test

Participants' reported symptoms and symptom behaviour.

	All participants (n = 23)	PRT (n = 16)	NRT (n = 7)
	Number of participants	Number of participants	Number of participants
Duration of symptoms			
>3 months	4 (17.2%)	3	1
3-6 months	6 (25.8%)	5	1
6-9 months	3 (12.9%)	3	0
9-12 months	3 (12.9%)	2	1
>12 months	7 (30.1%)	3	4
Pain			
Constant (yes)	13 (56.5%	10	3
Intermittent (yes)	22 (95.6%)	15	7
Sharp pain	21 (95.7%)	15	6
Dull aching pain	16 (69.6%)	11	5
Locking	2 (8.7%)	1	1
Clicking/crepitus	12 (51.6%)	9	3
Giving way	9 (39.1%)	4	5
Weakness	20 (86.9%)	15	5
Additional cervical, shoulder or elbow symptoms (yes)	5 (21.7%)	4	1
Time for symptoms to settle			
Within 30 minutes	8 (34.8%)	4	4
Within 2 hours	10 (43.5%)	8	2
Within 24 hours	3 (13.0%)	3	0
More than 48 hours	2 (8.7%)	1	1

NRT: negative reference test. N: number. PRT: positive reference test.

Appendix S: Diagnostic Accuracy metrics of clinical examination

Individual Predictors (not retained)

Test	TP	FP	FN	TN	Sn (95% CI)	Sp (95% CI)	PPV/NPV	LR+ (95% CI)	LR- (95% CI)	SFPLR (95% CI)	*p*-value
Age (range 18-62)										0.01 [-0.06, 0.08]	0.76
Pain location, medial ulnar	4	2	12	5	0.25 (0.07, 0.52)	0.71 (0.29, 0.96)	0.67 / 0.29	0.88 (0.21, 3.72)	1.05 (0.61, 1.82)	0.01 [-1.69, 1.77]	0.99
Pain location, dorsal DRUJ	4	4	12	3	0.25 (0.07, 0.52)	0.43 (0.10, 0.82)	0.50 / 0.20	0.44 (0.15, 1.27)	1.75 (0.71, 4.31)	0.31 [-1.44. 2.25]	0.73
Pain location, dorsal forearm	8	1	8	6	0.50 (0.25, 0.75)	0.86 (0.53, 0.23)	0.89 / 0.43	3.50 (0.53, 22.93)	0.58 (0.33, 1.04)	-0.23 [-1.95, 1.53]	0.79
Pain location, volar forearm	0	0	16	7	0.03 (0.0, 0.21)	1.0 (0.59, 1.0)	- / 0.30	0.45 (0.01, 21)	1.04 (0.84, 2.28)	-0.23 [-2.07, 1.74]	0.81
Presence of dull pain	2	5	5	11	0.28 (0.04, 0.70}	0.69 (0.41, 0.89)	0.29/0.69	0.91 (0.	1.04 (0.59, 1.84)	-0.05 [-2.00, 1.73]	0.96
Presence of giving way	4	3	10	6	0.29 (0.08, 0.58)	0.67 (0.30, 0.93)	0.57/0.38	0.86 (0.25, 2.96)	1.07 (0.61, 1.89)	-0.23 [-1.95, 1.53]	0.79
Presence of pain over pain during gripping ADLS	8	7	8	0	0.50 (0.24, 0.75)	0 (0.0, 0.41)	0.53 / -	0.50 (0.31, 0.82)	7.50 (0.49, 114)	0.49 [-1.29, 2.24]	0.47
Presence of pain with twisting ADLS	11	6	5	1	0.69 (0.41, 0.89)	0.14 (0.04, 0.58)	0.65 / 0.17	0.80 (0.51, 1.26)	2.19 (0.31, 15.45)	1.10 [-0.74, 2.99]	0.37
Pain intensity (NRPS) during twisting ADLS (range 0-10)										0.14 [-0.15, 0.51]	0.37
Pain intensity (NRPS) during gripping ADLS (range 0-8)										0.12 [-0.19, 0.47]	0.47
AROM radial deviation										-0.17 (-0.39, -0.12)	0.03
AROM ulnar deviation										-0.004 (-0.11, 0.10))	0.94
PROM ulnar deviation										-0.01 (-0.10, 0.08)	0.82
AROM supination										-0.04 (-0.16, 0.03)	0.31
PROM supination										-0.03 (-0.14, 0.05)	0.47
AROM pronation										-0.03 (-0.19, 0.08)	0.58

Test	TP	FP	FN	TN	Sn (95% CI)	Sp (95% CI)	PPV/NPV	LR+ (95% CI)	LR- (95% CI)	SFPLR (95% CI)	*p*-value
Grip strength supination										0.001 (-0.06, 0.07)	0.97
Grip strength pronation										0.001 (-0.07, 0.07)	0.97
GRIT Ratio										-0.20 (-0.79, 0.11)	0.21

- incalculable. * Statistically significant. TP: true positive. FP: False positive. FN: False negative. TN: True negative. Sn, sensitivity; Sp, specificity; PPV, positive predictive value; NPV, negative predictive value; LR+, positive likelihood ratio; LR–, negative likelihood ratio; CI, confidence interval;. SFPLR: Simple firth-penalised logistic regression

Appendix T: Investigation findings

Utilisation of medical imaging.

Investigations	Number of participants	Percentage
MRI	23	100%
X-ray	23	100%
Ultrasound	9	39.1%
CT scan	1	4.3%

CT: computer tomography. MRI: magnetic resonance imaging

Palmer classification of participants with PRT.

Palmer category	Number of participants	Percentage
1A	5	21.7%
1B	9	39.1%
1C	0	0%
1D	2	8.7%
2A	0	0%
2B	0	0%
2C	0	0%
2D	0	0%

PRT: positive reference test

Structural abnormalities observed via MRI among the participants.

Pathology	Number of participants	Percentage
TFCC		
- Tear	16	69.9%
- Ganglion	2	8.7%
Pisotriquetral joint		
- Effusion	1	4.3%
- Osteoarthritis	3	13.0%
ECU		
- Tenosynovitis	3	13.0%
- Strain	1	4.3%
Scapholunate Ligament		
- Tear	1	4.3%
- Ganglion	2	8.7%
Lunate bony impact/high signal	3	13.0%
Mid-carpal ligament strain	1	4.3%
Second dorsal compartment (EPL)	1	4.3%
- Tear	1	4.3%
- Tenosynovitis		
DRUJ arthrosis	1	4.3%
Distal radius fracture malunion	1	4.3%
Carpal tunnel syndrome	1	4.3%
Bicep tear	1	4.3%

ECU: Extensor carpi ulnaris. EPL, Extensor pollicus longus. DRUJ: distal radioulnar joint. TFCC: triangular fibrocartilage complex

Structural abnormalities observed via MRI among the participants with TFCC injuries

Patient	Dr reported diagnosis		MRI report
	Main diagnosis	Secondary diagnosis	
1	TFCC central disc tear and sprain ulna attachments		Small focal pin hole type tear articular disc of radial aspect of TFCC. Moderate sprain of ulnar foveal attachment TFCC and ulnar attachment of dorsal DRUJ ligament. Small intraosseous ganglion. Low grade subcortical bone oedema at ulna fovea. Small druj effusion & synovitis.
2	TFC tear. SLL partial tear	Ganglion over TFCC	Sprain injury of dorsal RU ligament. Possible low-grade interstitial injury at foveal insertion of TFC complex which is associated with small volar ganglion cyst. No high-grade of full thickness TFCC tear. No secondary features of ulnocarpal impaction. small druj effusion. diffuse sprain injury of dorsal extrinsic ligament complex of the wrist. intrasubstance partial tear localised to the membranous component of SL ligament, otherwise SL lig intact. mild thinning of articular cartilage within first CMCJ and PT joint
3	TFCC articular disc tear & DRUJ ligament tear DRUJ joint arthrosis.		High grade injury of TFCC with complete absence of articular disc and high-grade partial tears of foveal and styloid attachment. High-grade sprain/partial tear involving dorsal RU ligament. Mild ECU and 4th extensor compartment tenosynovitis. Background of DRUJ arthrosis with accompanying synovitis
4	TFCC partial tear. Cyst in lunate		TFCC dorsal ulnar styloid band mild-moderate partial tear. Lunate: proximal ulnar sided subcortical cysts with moderate diffuse bone marrow oedema
5	Peripheral partial tear to styloid and foveal attachments of TFCC.	Mild ECU tendinosis	TFCC styloid & foveal insertions partial tear, moderate grade. Mild ECU tendinosis & thickening of subsheath. Negative ulnar variance
6	TFCC tear with avulsion (cystic changes in ulna styloid, partial tearing of volar RU ligament with dorsal subluxation)	Moderate STT OA	Full thickness tear central discus, partial thickness tear of proximal and distal lamina. Cystic changes at ulnar styloid process. Partial thickness tear of DRUJ ligament. Dorsal subluxation of distal ulnar at DRUJ. Partial thickness tearing of SL ligament. moderated STT OA

Patient	Dr reported diagnosis		MRI report
	Main diagnosis	Secondary diagnosis	
7	Partial thickness tear TFCC. Right shoulder long head of biceps intrasubstance tear.		High grade partial thickness tear of ulnar attachments of RU ligaments. Volar and dorsal RUJ capsular sprain. Dorsal RC capsular sprain
8	TFC disc tear central.	OA and synovitis of PT joint	3mm tear in TFCC central articular disc & small volar ganglion. Dorsal SL ligament interstitial tear with ganglion. Mild thickening & scarring of volar SLL. Mild OA & synovitis in PT
9	TFCC tear adjacent to radial attachment. Left distal radius fracture with slight malunion & secondary DRUJ instability.	Mild SLL tear (insignificant)	TFCC "cleft" adjacent to radial attachment, consistent with previous partial tear or sulcus. SLL ligament volar aspect mild partial tear/delamination injury
10	Full thickness TFCC peripheral tear		Full thickness tear of proximal & distal laminae/foveal and styloid attachments of peripheral TFCC. Partial thickness tear extension into the peripheral aspects of the dorsal & volar RU ligaments
11	TFCC foveal attachment tear. Small perforation of TFC articular disc.		Sprain dorsal DRUJ ligament & ulnar foveal attachment TFCC. Small pinole focal perforation of TFCC articular disc radial aspect. Dorsal wrist ganglion over Sllig
12	TFCC peripheral disc tear at ulnar insertion. Synovitis & ECU tenosynovial thickening		Mild TFCC tear at ulnar insertion. Mild synovitis dorsal/ulnar wrist with ECU tenosynovial thickening and small DRUJ effusion. Ganglion cyst at dorsal SLL.
13	TFCC central full thickness perforation, with avulsion of bands to the ulnar styloid tip		TFCC full thickness central tear. Oblique intrasubstance tears with attached bands to the ulnar styloid tip avulsion fragment. SLL central band moderate partial tear. Ulnar styloid bone marrow oedema mild. Dorsal ecu subtendon sheath membrane mild oedema. partial tear and oedema of dorsal extrinsic intercarpal ligaments

Patient	Dr reported diagnosis		MRI report
	Main diagnosis	Secondary diagnosis	
14	TFC disc tear (radial & central aspect) Healed radial fracture with step in articular surface. Tenosynovitis of 2nd extensor compartment, EPL tear.		DR IA fracture healed with small residual step at distal articular surface. Fissuring at articular cartilage of lunate. Positive ulnar variance. TFC defect radial/central aspects. Splits in ECU tendon.
15	Partial tear of TFC disc and full thickness radial ulnar ligament tear ECU synovitis		TFCC articular disc and dorsal RU ligament partial interstitial tear with full thickness tear component. Mild synovitis at DRUJ. Minor chondral fissuring lunate.
16	TFC central disc tear		Central TFCC tear. Synovitis wrist (carpal joints and DRUJ)

Note: CMC: carpometacarpal. DR: distal radius. DRUJ: distal radioulnar joint. ECU: extensor carpi ulnaris. EPL: extensor pollicus longus. IA: intra articular. PT: pisotriquetral. OA: osteoarthritis. RU: radioulnar. SLL: scapholunate ligament. TFC: triangular fibrocartilage. TFCC: triangular fibrocartilage complex.

Appendix U: Participant Lasso coefficient and predictor probability results

Co-efficient factors		Participants																					
Factors	score	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Male Gender	0.173	0	0	0	0.173	0.173	0	0.173	0.173	0	0	0.173	0.173	0.173	0	0.173	0.173	0.173	0	0	0	0	0.173	0.173
MOI strain or overuse	0.097	0.097	0	0.097	0	0.097	0	0.097	0.097	0	0	0.097	0.097	0.097	0.097	0.097	0.097	0.097	0.097	0.097	0.097	0	0.097	0
Presence of constant symptoms	-0.462	0	-0.462	-0.462	0	0	-0.462	0	0	0	0	0	-0.462	-0.462	0	-0.462	-0.462	0	-0.462	-0.462	-0.462	-0.462	-0.462	-0.462
Presence of crepitus	-1.943	0	-1.943	-1.943	-1.943	0	0	-1.943	-1.943	0	-1.943	-1.943	-1.943	-1.943	0	0	-1.943	0	-1.943	-1.943	0	0	0	0
Pain intensity with pronation-based ADLs (0-10)	0.061	0.3064	0	0.306	0.061	0.184	0.368	0.061	0.613	0.245	0.123	0	0	0.490	0	0.184	0.306	0.368	0.184	0	0	0.368	0.429	0.490
Presence of pain with supination-based ADLs	0.495	0.495	0.495	0	0	0.495	0.495	0.495	0.495	0.495	0	0	0	0	0.495	0.495	0.495	0	0.495	0.495	0.495	0.495	0.495	0.495
Passive radial deviation ROM (degree)	-0.126	-2.518	-3.148	-4.785	-4.785	-2.267	-2.770	-2.518	-4.029	-3.400	-2.770	-4.407	-0.630	-2.896	-3.400	-3.526	-3.148	-4.029	-4.155	-4.281	-2.518	-3.148	-4.407	-2.141
Passive pronation ROM (degree)	0.0433	3.806	3.806	3.979	3.590	3.893	3.893	3.979	4.109	4.108	3.676	4.022	2.855	3.893	3.633	3.979	4.109	3.676	3.979	4.109	3.979	3.806	3.979	3.893
Grip strength in neutral (kilogram)	0.036	0.854	0.599	1.490	1.925	0.981	1.889	1.319	0.799	0.896	1.548	0.581	1.163	0.607	1.453	1.586	2.131	2.361	1.151	1.017	0.993	1.017	1.235	0.727
Sum of all predictors positive	-1.798	3.040	3.040	-1.318	-0.978	3.556	3.412	1.663	0.314	2.345	0.633	-1.476	1.253	-0.041	2.279	2.527	1.759	2.646	-0.655	-0.968	2.584	2.076	1.540	3.175
Predicted probability	0.954	0.343	0.241	0.273	0.967	0.973	0.827	0.535	0.92	0.691	0.172	0.761	0.423	0.913	0.919	0.841	0.928	0.321	0.256	0.93	0.889	0.823	0.96	0.954
TFCC injury?	Yes	no	No	No	yes	yes	yes	yes	yes	yes	no	yes	No	Yes	Yes	yes	yes	no	no	Yes	yes	yes	yes	yes