What is the Efficacy of Existing Interventions for Reducing the Impact of Post-Traumatic Osteoarthritis Following Anterior Cruciate Ligament Injury? A Systematic Review

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A dissertation submitted to Auckland University of Technology in partial fulfilment of the requirements for the degree of Master of Health Practice

2022

Health and Environmental Sciences

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Attestation of Authorship

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.

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Candidate Contributions to Co-Authored Papers

Chapter 2 McIntosh, C., O'Brien, D.W., and Reid, D. (2023). What is the efficacy of existing interventions for reducing the impact of post-traumatic osteoarthritis following anterior cruciate ligament injury? A systematic review. *[To be submitted to New Zealand Journal of Physiotherapy]*.	McIntosh 80% O'Brien 10% Reid 10%

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Acknowledgments

I would like to extend a sincere thank you to both of my supervisors Dr. Daniel O'Brien and Prof. Duncan Reid. The support, encouragement, wisdom, and humour they shared added to my learning over and above the expertise and coaching provided to enable me to complete this practice project. Their passion for the topic and for continued learning has been shared generously and has been invaluable.

Thank you also to my colleagues, Joanne (Jo) Smith and Brian Doherty who critically reviewed all of the studies included in the systematic review while working full-time as clinical physiotherapists and Team Leaders and participating in their own ACL injury rehabilitation.

Finally thank you to my dear friend, Sharyn Hunt BA (Hons), DipTchg, Deputy Principal Lynfield College*,* a proponent of our high school motto, "Doctrina Vitam Illuminet" (Let learning enlighten life / He Akonga te Oranga), who kindly proofread the dissertation.

Abstract

Introduction. Anterior Cruciate Ligament (ACL) injury has been identified as a risk factor for developing post-traumatic osteoarthritis (PTOA). The individual and societal burden of ACL injuries and PTOA are considerable in Aotearoa New Zealand (AoNZ). This burden is predicted to increase if there is no change in how these injuries are managed. A variety of ACL injury management options exist in AoNZ. Rehabilitation is a recognized component of ACL injury management. The efficacy of different ACL rehabilitation interventions on reducing the impact of PTOA is unknown.

Objective. This systematic review aimed to identify, synthesise and critique the findings of research that has evaluated the effectiveness of ACL injury management on the development of PTOA. This review will appraise the quality of the identified literature, to answer the research question, what is the efficacy of existing interventions for reducing the impact of PTOA following ACL injury?

Methods. A systematic search of electronic databases CINAHL, SPORTDiscus MEDLINE (via EBSCO) and Scopus was completed and studies relevant to the objective were identified. A quality critique of the selected studies was undertaken using a modified Downs and Black appraisal tool. Data central to the study objective were extracted and analysed.

Results. Six articles were retained for final review, quantified as good quality. Five studies compared the effect of surgical anterior cruciate ligament repair (ACLR) with non-surgical management of ACL injuries on the development of PTOA. Only one study investigated the effect of different ACL rehabilitation protocols on the development of PTOA. The incidence of PTOA following ACL injury was comparable regardless of the management interventions compared in each of the studies.

Conclusion. Current research shows the risk of PTOA after ACL injury is not changed by ACL injury management. Further research is required to inform ACL injury management to reduce the long-term impact of ACL injury and optimise the wellbeing of the growing ACL-injured population. In the meantime, the evidence supports physiotherapists to implement programmes for ACL injury prevention and promoting knee joint health following ACL injury.

Overview of this Dissertation

This dissertation is structured in three chapters. Chapter 1 introduces the research topic and research question. Chapter 2 is the systematic review undertaken to answer the research question. This chapter is written in a format ready for publication in a peer reviewed journal. Chapter 3 discusses the clinical implications based on the research findings and contemporary literature.

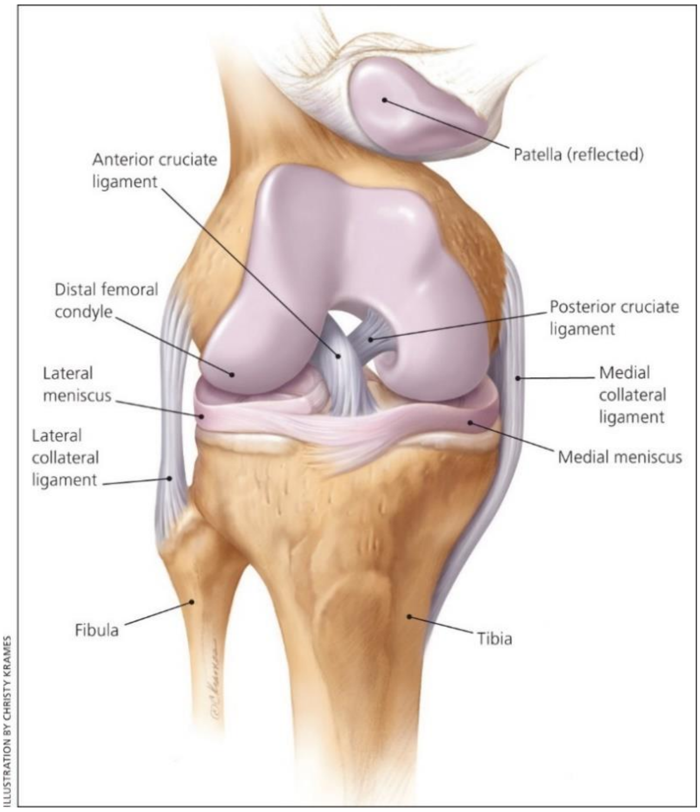
Chapter 1: Introduction

1.1 ACL Position and Function

The knee is a complex joint with stability and motion primarily governed by ligaments. The anterior cruciate ligament (ACL) is one of the four main ligaments, along with the posterior cruciate ligament (PCL) and the medial and lateral collateral ligaments, providing stability to the knee joint. As shown in Figure 1, the ACL originates from the posteromedial aspect of the lateral femoral condyle and inserts into the intercondylar area on the tibial plateau, crossing over the PCL as it traverses diagonally from the posterior to the anterior of the central knee (Duncan et al., 2016). In addition to collagen fibres, mechanoreceptors and nerves incorporated into the ACL contribute to the proprioception of the knee joint (Domnick et al., 2016). The ACL's primary function is stabilising the knee by resisting anterior displacement of the tibia on the femur, knee joint rotation, and hyperextension. When the knee is flexed, the ACL also helps resist varus and valgus forces (Duncan et al., 2016).

Figure 1

Anatomy of the knee



Adapted from Calmbach WL, Hutchens M. Evaluation of patients presenting with knee pain: part I. History, physical examination, radiographs, and laboratory tests. *American Family Physician*. 2003;68(5):907

1.2 Mechanism of ACL Injury and Injury Rates in Aotearoa New Zealand

ACL injury occurs directly or indirectly when stresses exceed ACL tissue tolerance (Woo et al., 1991). ACL strain increases with tibiofemoral compression, anterior tibial forces, and combined knee abduction and internal rotation. There are two main mechanisms of injury, direct and indirect. Direct injuries caused by impact to the knee or thigh creating valgus strain are infrequent and often also cause medial meniscus and medial collateral ligament injuries (Schultz et al., 2015). Indirect injuries are more common and are typically caused by suddenly slowing down or stopping, changing direction or pivoting with the foot planted on the ground, or landing awkwardly (Domnick et al., 2016). These are responsible for nearly three-quarters of ACL injuries (Boden at al., 2010). These non-contact incidents involve pivoting or landing with huge forces from momentum combined with knee internal rotation and abduction, which can increase ACL stress beyond tissue tolerance to the point of partial tear or rupture (Shin et al., 2011). A non-contact combined valgus- and internal-rotation trauma of the knee is described as one of the most frequent mechanisms for an ACL rupture and frequently occurs in sports such as rugby, football, and netball in Aotearoa New Zealand (AoNZ) (New Zealand ACL Registry, 2021). Rates of ACL injury are high and increasing in AoNZ, with an annual incidence of ACLR between 2009 and 2016 of 58.2 per 100 000 person-years and an increase of 11% annually over that period (Sutherland et al., 2019). The vast majority of ACL injuries occur in young athletes while participating in sport, with only 13% of ACL injuries having a non-sporting mechanism of injury (New Zealand ACL Registry, 2021).

1.3 ACL Injury and Post-Traumatic Osteoarthritis (PTOA)

ACL injury commonly leads to the devolvement of early knee osteoarthritis (OA), typically referred to as post-traumatic OA (PTOA). An increasing body of research shows that ACL injury predisposes to PTOA (Li-Juan et al., 2020). Approximately one-third of people will show radiographic PTOA within the first decade following ACL injury (Pietrosimone et al., 2017), and about 50% of people with ACL injuries subsequently develop PTOA within 10 to 15 years regardless of whether they have had surgical repair or conservative ACL management (Everhart et al., 2021; Frobell et al., 2007; Risberg et al., 2016). Because ACL injuries are more likely to occur in young athletes, PTOA following ACL injury also occurs in a disproportionately young population and progresses to end-stage disease more rapidly compared to other forms of OA (Ajuied et al., 2014).

In their acute stage, ACL injuries usually limit a person’s knee range of motion and physical activity and cause pain, muscle weakness, knee instability and altered biomechanics (Azus et al., 2019). These factors partially explain the increased risk of PTOA and total knee joint replacement (TKJR) after ACL injury; however, PTOA is a complex multifactorial condition with no consensus explanation (Lie et al., 2019). To date, no ACL injury management has been shown to reduce the rate of PTOA, and an inevitable chain of events appears to exist between ACL injury and PTOA (Webster & Hewett, 2022). This chain of events is among the non-modifiable risk factors for PTOA after ACL injury. Other non-modifiable risk factors include increased age, female gender and genetic factors (Silverwood et al., 2015).

The exact cause of primary OA is still unclear; however, the link between ACL injury and PTOA is clear. The pathophysiology of OA is complex and affected by modifiable (i.e., body weight, physical activity levels, and injury) and non-modifiable risk factors (increasing age, gender, and genetics) (Wang et al., 2020). Previous joint injury is a strong predictor of future PTOA, but the specific mechanisms of how the injury leads to the early onset of the disease are still unknown (Whittaker et al., 2021). Structural, mechanical, neuromuscular, and biological factors are thought to contribute to the causal link between ACL injuries and PTOA (Li-Juan et al., 2020). Further research is required to clarify the mechanism(s) of ACL injury that predispose a person to PTOA (Wang et al., 2020). However, some theories have been proposed from the synthesis of current research. The ACL injury event and subsequent knee instability may damage other knee structures and the ACL itself. In particular, concurrent injury to the meniscus, articular cartilage, joint capsule, and subchondral bone are hypothesised to contribute to the development of PTOA (Thomas et al., 2017).

Altered neuromuscular feedback occurs after ACL injury (Wellsandt et al., 2017). This is caused by ligament laxity, reduced muscle function, and damage to joint mechanoreceptors within the ACL itself (Wang et al., 2020). It is hypothesised that both the altered feedback mechanisms and quadriceps and hamstring strength deficits increase articular loading of the knee joint via decreased muscular control, contributing to cartilage degeneration (Tayfur et al., 2021). Knee structures work synergistically to maintain stability. After ACL injury, the ACL may fail to maintain knee stability and distribute load to other knee structures to compensate for ACL deficiency (Henriksen et al., 2014; Wang et al., 2020). Altered mechanical loading of the knee after ACL injury may also arise from concurrent damage to static stabilising structures (for example, other ligaments and the joint capsule), residual muscle weakness, disuse atrophy, altered proprioception, reduced quadriceps and hamstrings strength as dynamic stabilisers, and psychological factors, for example, fear of pain and reinjury (Ageberg & Roos, 2016).

Adaptive gait changes secondary to a lack of normal knee functionality may alter forces on knee cartilage and other knee structures contributing to PTOA (Friel & Chu, 2013). Post-traumatic inflammation disrupting metabolic pathways is hypothesised to trigger progressive PTOA (Wang et al., 2015). The ACL injury represents an initial trauma to the ACL, triggering biological factors deleterious to joint health. There is some evidence to also suggest surgical repair of ACL injuries may exacerbate or even replicate the acute injury response. The likelihood of experiencing PTOA may be increased by having a second knee insult via anterior cruciate ligament repair (ACLR) soon after an ACL injury (Thomas et al., 2017). Consequences of ACLR, including further (surgical) trauma to joint structures, prolonged joint inflammation plus altered weight bearing, may complicate healing, compared with initial non-operative management with a structured rehabilitation programme allowing the initial injury to settle (Filbay et al., 2021; Lie et al., 2019). All of these factors triggered by the initial ACL injury may alter the homeostasis of the knee joint, triggering a change in the mechanical properties of the knee cartilage (Kramer et al., 2011), leading to radiographic OA and ultimately to symptomatic clinical OA.

In addition to the ACL injury, Whittaker and Roos (2019) have suggested modifiable risk factors that can arise secondary to ACL injury and increase the risk profile for PTOA. Modifiable factors which may contribute to the causal link between ACL injury and PTOA include obesity, physical inactivity, muscle weakness, altered neuromuscular control and reduced functional performance, and fear of reinjury/pain (Whittaker et al., 2022b). Additionally, insufficient or incomplete rehabilitation before return to sport (RTS), poor nutrition, and unrealistic expectations may contribute to an elevated risk of PTOA (Whittaker & Roos, 2019). Modifiable risk factors are important as they offer an opportunity to intervene to halt or slow the inevitable chain of events leading from ACL injury to PTOA.

1.4 Individual and Social Cost of PTOA After ACL Injury is Considerable

ACL injury is associated with an increased risk of osteoarthritis within as few as 10 years after injury, frequently occurring during prime work and family-life years between ages 30 and 50 (Filbay et al., 2022; Friel & Chu, 2013). ACL injury can result in knee pain, reduced knee function, fear of reinjury, activity cessation, and poor knee-related quality of life (Filbay et al., 2022; Lie et al., 2019). These can give rise to direct and indirect costs, including prolonged work absenteeism and loss of productivity, as well as high healthcare and economic costs for the individual and society (Eggerding et al., 2022; Kiadaliri et al., 2016). Given the typically young age of people when they suffer an ACL injury, not only does the burden arise early, but it persists for extended durations compared to the non-ACL injured population. Up to 50% of ACL-injured young athletes never return to their pre-injury level of sport (Ardern et al., 2014). This reduced activity may exacerbate PTOA via the potential for increased body weight and the absence of the protective mechanism of activity. Kaur et al. (2019) identified two patient-reported outcome measure (PROM) themes following ACLR: continuum of fear of reinjury versus confidence, and ongoing knee-health related problems and need of health professional advice. The researchers described patients reporting good knee function continuing to be concerned about reinjury and PTOA in addition to experiencing ongoing knee health problems, including varying levels of pain and stiffness (Kaur et al., 2019). Due to the development of PTOA in younger people, it is also associated with more years lived with disability and socioeconomic burden than other forms of OA. A history of previous ACLR is related to undergoing TKJR as end-stage OA treatment (Khan et al., 2019), approximately nine years younger than the non-ACL injured population (Whittaker & Roos, 2019).

The precise incidence of ACL injury in AoNZ is unknown as not all ACL injuries are diagnosed until an orthopaedic surgeon is consulted (Janssen et al., 2012) and may be recorded as a knee strain or sprain instead until this time. The incidence of ACLR is often used to approximate the rate of ACL injury (Fausett et al., 2019). The total cost for direct healthcare and loss of earnings for injuries involving ACLR between 2016 and 2021 in AoNZ was $360 million (ACC, 2021). The largest contributors to this total cost are surgery, $189 million, and reimbursement for loss of earnings, $112 million. Given the rate of ACLR is increasing, the predicted burden is also anticipated to increase. The net cost of ACL injuries roughly equates to adding the indirect societal costs (productivity and disability) to the direct healthcare costs associated with ACL management implemented (Mather et al., 2013). The direct and indirect costs associated with ACL injuries relate to living with a symptomatic unstable knee and developing PTOA. Recent research has found that early ACLR may be less cost-effective compared with rehabilitation and optional delayed ACLR (Filbay et al., 2022). In contrast, Mather et al. (2014) reported that ACLR might be more cost-effective than non-operative management of ACL injuries considering reduced indirect societal costs (such as work status and earnings) relative to direct rehabilitation costs. These conflicting findings are complicated by the lifetime burden of ACL injuries and the duration of study required for reliable findings and reinjury rates, particularly following ACLR (Webster & Feller, 2016; Whittaker et al., 2022c).

In 2021, the NZ ACL registry recorded 2418 ACLRs, but estimated the actual number to be nearer 3000, and notes annual numbers are continuing to increase (New Zealand ACL Registry, 2021). This is consistent with Australian data that shows a 10% yearly increase in ACL injuries (Maniar et al., 2022). Persistent knee problems are common, and the risk of PTOA increases after ACL injury. The social and financial cost of knee OA in AoNZ is even more considerable (Arthritis New Zealand, 2018; Chua et al., 2019; Kigozi et al., 2018; Lan et al., 2020; Wilson & Abbott, 2019). In addition to pain and disability, evidence shows an association between PTOA and other poor health outcomes, particularly those related to inactivity and obesity, such as diabetes and cardiorespiratory health (Whittaker et al., 2015). ACL injury can have a long-term and widespread detrimental influence on health outcomes. While findings vary regarding the impact of initial injury management on the predicted burden of ACL injuries and PTOA, there is consensus that the cost of an ACL injury over a patient's lifetime is substantial; given the increasing rate of these injuries, the considerable societal burden is expected to increase.

Data suggest that Māori are disproportionately affected by ACL injuries and PTOA in AoNZ. Māori have higher participation rates than non-Māori in sports identified with an increased risk of acute ACL injuries, such as rugby and netball (*Māori participation in community sport report* | Sport New Zealand – Ihi Aotearoa, 2017). The NZ ACL Registry records rugby as the most common mechanism of ACL injury in AoNZ. Māori are highly represented in all levels of rugby participation, with almost 27% of all registered players and 27% of elite players identifying as Māori in 2017 (New Zealand Rugby Board, Annual Report, 2017) compared with representing 15% of the total AoNZ population (Māori population estimates: At 30 June 2017 | Stats NZ, n.d.). Lived experience means Māori are also highly visible in media examples of high-profile rugby heroes undergoing early ACLR due to the rate of high-performance representation (Hapeta et al., 2019).

TKJR is the definitive end-stage treatment for patients who have exhausted non-operative management for knee OA (Singleton et al., 2013). In 2017, Pasifika and Māori had the highest rates of TKJR for OA in AoNZ (Lao et al., 2019), yet it has been reported that there is no difference in rates of OA for these populations (Annual Update of Key Results 2017/18: New Zealand Health Survey, 2022). Singleton et al. (2013) found Māori tend to be younger at the time of TKJR and have worse outcomes and smaller functional gains post-operatively than non-Māori. These findings suggest that the risk of ACL injury and PTOA plus the disease burden of OA are disproportionately greater for Māori than non-Māori before and after definitive end-stage surgical management via TKJR.

1.5 Current ACL Injury Management in Aotearoa New Zealand

There are multiple options for ACL injury management in AoNZ, including surgical and non-surgical injury management. Data suggest that approximately 60% of people who rupture an ACL in AoNZ choose to have surgical repair (New Zealand ACL Registry, 2021). Reasons for people choosing surgical repair are varied and primarily influenced by the individual's existing beliefs and their treatment provider. For example, many young athletes believe that

ACLR is not only the best option for them to RTS in a timely, reliable manner but that the surgery will 'fix' their knee restoring it to its pre-injured state (Zadro & Pappas, 2018). Unrealistic expectations and prior beliefs in AoNZ are fuelled by media and increasingly social media, with sporting heroes frequently seen returning to sport after ACLR, similar to the misinformation reported in Australia (Gamble et al., 2019). In light of these beliefs, fear of further instability events and reinjury can prompt the choice for early ACLR. However, Kaur et al. (2019) report high rates of ongoing fear of reinjury despite ACLR in AoNZ.

In AoNZ, the common management pathway following ACL injury includes consultation with an orthopaedic specialist. Orthopaedic specialists are likely to discuss surgical ACLR and less likely to discuss ACL rehabilitation or conservative management (Fauset et al., 2019). The objectives of ACLR are to restore stability to the knee, enabling a return to pre-injury function; however, despite often achieving these goals, PTOA occurs at comparable rates to ACL injuries managed non-operatively (Friel & Chu, 2013). Non-surgical management including rehabilitation techniques has evolved, and rehabilitation programs have become widely accepted as a component of ACL injury management (Friel & Chu, 2013). Various programmes exist that attempt to improve engagement with consensus or evidence-based ACL injury management; however, the long-term outcomes of these programmes remain unclear, and the lack of evidence has led to high variability of non-surgical management following ACL injury (Culvenor et al., 2022; Davies et al., 2020; Whittaker et al., 2019). Regardless of management intervention, evidence of radiographic PTOA is present for 30% within two years of ACL injury (Frobell, 2011). This rate increases with time from injury (and ACLR), increasing to 50% showing evidence of radiographic PTOA within 15 years (Filbay et al., 2022). This high rate of PTOA is not mitigated by ACLR. ACLR and non-operative ACL management have comparable outcomes for PTOA.

OA management lags behind the management of other chronic diseases such as diabetes and cardiovascular disease in AoNZ (New Zealand Health Strategy 2016, 2022, p.17), where risk factors have been screened and monitored, enabling preventative and early therapeutic intervention to be applied for years (Abbott et al., 2022). Globally, low-value care is prevalent for musculoskeletal conditions, including ACL injuries, wasting healthcare resources with little (to no) benefit for patients and exacerbating inequitable outcomes while obstructing the delivery of high-value care (Hartvigsen et al., 2022). ACL injury management ranges from non-operative to surgical ACLR (Friel & Chu, 2013). Research shows many ACL-injured patients are not undertaking the rehabilitation required to address strength and functional deficits and are returning to sport without appropriate clearance and education (Ebert et al., 2018). Despite ACLR being common, the current management for ACL injury is based on limited evidence (Davies et al., 2020). Non-operative management for ACL injuries in AoNZ includes interventions inconsistent with evidence-based clinical practice guidelines (Fausett et al., 2019). Replacing low-value care will require evidence-informed change at the individual patient, clinician, organisational and systemic levels of our healthcare equation.

1.6 Rationale of The Study

1.6.1 What We Know

ACL injury is a risk factor for the development of PTOA (Friel & Chu, 2013; Wang et al., 2020). Research has shown little ability to reverse the signs and symptoms of established OA (Silverwood et al., 2015; Skou & Roos, 2017), suggesting that early management of those with risk factors, such as ACL injury, is a wise investment. Efficacious management of acute ACL injury should include considerations for preventing the injury in the first place, plus delaying the onset and preventing the progression of PTOA. ACLR, while able to recreate knee stability, has not been shown to reduce PTOA. ACL injury typically occurs in young, active people with an increased risk of PTOA and disability at a significantly younger age than the non-ACL-injured population following their injury. There is evidence OA leads to further poor health outcomes, including poor cardio-respiratory and mental health, and potentially amplifies other negative health consequences (e.g., pain, reduced activity, and weight management). The New Zealand Health Systems goal of Pae Ora / Healthy Futures focuses on three outcomes: Living longer and healthier lives, Improving the quality of life and Improving health equity. Māori experience poorer health outcomes overall than non-Māori and are a priority group for Pae Ora. In light of what is known about the ACL injury population and predicted burden, improving ACL injury management and PTOA outcomes following ACL injury is consistent with each of these health system outcomes.

1.6.2 What We Need to Know

Whether ACL injuries are managed with ACLR or nonoperatively, rehabilitation is an integral part of their management. It is important to identify the quality and content of management approaches, improve understanding of what specific management approaches these interventions contain, the efficacy of these interventions, and the quality of the literature that describes these interventions to consider the applicability (or adaptability) to the AoNZ context. The evidence showing no economic benefit of early ACLR compared to ACL rehabilitation (+/- delayed optional ACLR) suggests an improved understanding of what constitutes high-value care might optimise resource consumption and value of ACL injury management. PTOA secondary to ACL injuries creates a significant financial, health and social burden for individuals and the community in AoNZ. This burden is predicted to increase if there is no change in how these injuries are managed. There is growing research comparing ACLR with non-operative management but little research comparing the efficacy of specific rehabilitation interventions. There is a need for high-quality evidence-based ACL injury rehabilitation in AoNZ. Improved management based on the implementation of current evidence is required to replace low-value healthcare to improve equitable long-term outcomes for patients after ACL injury and ACLR (Risberg et al., 2016). In light of these concerns, the purpose of the next chapter was to critically examine the literature investigating the impact of ACL injury management on PTOA. This process will then be used to inform clinical practice in AoNZ by answering the research question, what is the efficacy of existing interventions for reducing the impact of PTOA following anterior cruciate ligament injury? The second chapter is a systematic review of the literature and has been presented in the format for a peer review journal publication.

Chapter 2: Systematic Review

2.1 Abstract

Anterior Cruciate Ligament (ACL) injury is a risk factor for developing post-traumatic osteoarthritis (PTOA). The burden of ACL injuries and PTOA is considerable and predicted to increase if there is no change in their management. The efficacy of different ACL rehabilitation interventions on reducing the impact of PTOA is unknown. This systematic review aimed to identify, synthesise and critique research findings that evaluated the effectiveness of ACL injury management on the development of PTOA. A quality critique of the selected studies was undertaken using a modified Downs and Black appraisal tool. Data were extracted and analysed to answer the research question, what is the efficacy of existing interventions for reducing the impact of PTOA following ACL injury? Six good-quality articles were retained for final review. Five studies compared the effect of surgical with non-surgical management of ACL injuries on the development of PTOA. One study investigated the effect of different ACL rehabilitation protocols on the development of PTOA. The incidence of PTOA following ACL injury was comparable regardless of the management intervention compared in each study. Further high-quality studies are needed to inform ACL injury management to reduce the impact of PTOA following ACL injury.

2.1.1 Chapter Format

This chapter has been arranged to meet the format of New Zealand Journal of Physiotherapy submission guidelines for systematic reviews. To maintain consistency of style throughout the thesis, the manuscript is presented here in a format that differs slightly to the version to be submitted for consideration of publication.

2.2 Introduction

ACL injuries frequently occur in active young people involved in pivoting sports such as rugby, netball, and football in AoNZ (New Zealand ACL Registry, 2021). ACL injury and repair permanently escalate the risk of early onset and accelerated progression of knee OA at a comparatively young age (Whittaker et al., 2022a). Visnes et al. (2022) recently found a 1.1% increased risk of total knee joint replacement (TKJR) 15 years after ACL reconstruction. Due to the young mean age of those sustaining ACL injury, this 1% progression to TKJR under the age of 40, creates a considerable long-term financial, health, and social burden on the individual and society. PTOA results in a longer period of joint disease and reduced quality of life compared with non-traumatic OA, which develops primarily in the elderly (Lie et al., 2019). This burden is predicted to increase if there is no change in how these injuries are managed (Chua et al., 2019). Exercise and education programmes appear to reduce the impact of knee OA after ACL injuries (Whittaker et al., 2021).

In AoNZ, between 1 July 2000 and 30 June 2005, 238,488 knee ligament injury claims were accepted by the Accident Compensation Corporation (ACC). Of these claims, 7375 resulted in ACLR, equating to 80% of all knee ligament surgeries over this period (Gianotti et al., 2009). The New Zealand ACL Registry shows the annual number of ACLR is increasing and that 2575 people underwent surgical ACL repair in 2021. However, estimates place the actual number closer to 3,000 when accounting for non-registered operations (New Zealand ACL Registry, 2021). People who experience an ACL injury and ACLR are five times more likely to experience PTOA than the comparable non-injured population (Snoeker et al., 2019). Furthermore, these people are five times more likely to undergo total knee joint replacement (TKJR) surgery, and the surgery is more likely to occur at a younger age than the general population (McCammon et al., 2020).

The social and financial cost of knee OA and TKJR in AoNZ is considerable (Arthritis New Zealand, 2018; Chua et al., 2019; Kigozi et al., 2018; Lan et al., 2020; Wilson & Abbott, 2019). Healthcare costs of knee OA are estimated to rise by $171 million to $ 370 million over the 25 years from 2013 to 2038, and the number of TJKR procedures to grow by 3970 per annum to 9040 per annum over the same period (Wilson & Abbott, 2019). Amongst the social costs of knee OA, efficiency and productivity losses were estimated at $1.6 billion in 2018, and an estimated 12,401 New Zealanders of working age (15 to 64 years) were unemployed due to arthritis in 2018 (Arthritis New Zealand, 2018). The healthcare burden of knee OA is predicted to increase for the foreseeable future, as there is no cure and only modest symptom management. Effective management programmes to reduce the impact of ACL injury and support the growing ACLR population are required (Whittaker et al., 2022c).

ACLR is primarily undertaken to improve knee stability and return symptomatic patients to activity. Research suggests that ACLR decreases further injury by increasing knee stability and should therefore be protective against OA (McCammon et al., 2020). Despite ACLR improving knee stability, the rate of OA remains high in this population (Abram et al., 2019; Friel & Chu, 2013). Abram et al. (2019) suggest that while ACLR improves knee stability, the altered biomechanics following ACLR may contribute to PTOA and, subsequently, to the need for TKJR.

PTOA management approaches, including education, exercise, weight management, strengthening surrounding musculature, and modified activity, have been proposed to improve symptoms (Barrow et al., 2019; Chu, 2019; Easwaran et al., 2021; Mechlenburg et al., 2018; Whittaker et al., 2022b). New programmes and interventions are being developed worldwide in response to the risk and costs of PTOA following ACL injury and repair. Programmes include varying combinations of exercise and advice, with variable delivery methods and variable outcomes (Patterson et al., 2021; Whittaker et al., 2022c). These programmes promote self-determination, self-management, adherence to exercise, and healthy lifestyles with accompanying exercise that potentially offer additional long-term outcomes and reduction in PTOA after ACL injury (Whittaker et al., 2022b).

Filbay (2019) describes the aim of ACL management being to restore knee function, address psychological barriers to activity participation, prevent further knee injury, including PTOA, and optimise long-term quality of life supported by the best available evidence at the time regardless of the treatment option (surgical or non-surgical) chosen. This systematic review of all identified studies on the topic of management of ACL injuries and PTOA is being undertaken to critically appraise the quality of these studies and the potential bias within these studies, to synthesise the findings to provide an evidence-based answer to the question, what is the efficacy of existing interventions for reducing the impact of PTOA following anterior cruciate ligament injury?

2.3 Method

2.3.1 Design, Protocol and Registration

This systematic review used the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines for conducting and reporting systematic reviews (Moher et al., 2009). The review methods and research question were confirmed, and the review protocol was prospectively registered with PROSPERO (PROSPERO acknowledgement of receipt number: 313167) before the literature search, data extraction, and analysis commenced. Ethics committee approval was not required for this review.

2.3.2 Search Strategy and Information Sources

A systematic search of CINAHL, SPORTDiscus, MEDLINE (via EBSCO) and Scopus was undertaken in April 2022 to retrieve all relevant articles, using a modification of keywords and MeSH terms identified to answer the review question (Table 1). Reference lists from these articles were manually cross-checked to identify any additional literature.

Table 1

Search strategy for EBSCO health database

Search	Keyword/s
S1	(Acl or "anterior cruciate ligament") n4 (injur*)
S2	(OA or osteoarthritis or PTOA or "post-traumatic osteoarthritis") n4 (knee)
S3	S1 AND S2
S4	Interven* or manage* or treat* or prevent* or rehab*
S5	S3 AND S4
S6	rct or "random* control* trial*" or "clinical trial*"
S7	S5 AND S6

2.3.3 Screening and Article Selection

Next, publication titles and abstracts of all the identified articles were evaluated based on inclusion and exclusion criteria to screen for eligibility. All articles were imported into End Note X9, where duplicates were excluded (*End Note X9*, 2013). Full-text articles were obtained and reviewed where the title and abstract meet the inclusion criteria.

Inclusion and exclusion criteria.

The search focused on identifying clinical studies evaluating the efficacy of ACL injury management on the development of knee PTOA in adult humans. Articles were included if the study used a randomised controlled trial (RCT) or clinical trial (e.g., prospective/retrospective case studies and cohort trials) methodology and were available in full text in English. Measurement of incidence of OA using an imaging modality (radiologically or MRI) or via relevant biomarkers (e.g., inflammatory markers) was a required outcome measure for inclusion.

Articles were excluded if OA was implied via clinical measurement of signs and symptoms indicative of impaired knee function (e.g., knee laxity) or via subjective (e.g., Knee Injury and Osteoarthritis Outcomes Score [KOOS]) or objective assessment of knee stability and function. Trials comparing different surgical methods or graft material were excluded, as were studies of non-human subjects.

2.3.4 Study Quality Appraisal

The quality of articles was critically appraised using the Downs and Black checklist to assess the methodological quality of randomised and non-randomised studies (Downs & Black, 1998). The checklist was selected because it is appropriate for a variety of study designs. The checklist includes 27 items designed to assess methodological components of reporting, external and internal (bias and confounding) validity and power. The final item (27) was modified to record Yes = 1 or No = 0 in relation to whether a power calculation was performed or not rather than according to a range of study powers with scores up to a maximum of 5 (Zadro et al., 2019). This made the maximum score possible for the checklist 28 rather than 32 (Appendix A). A score of 0 indicates the lowest methodological quality and 28 the highest. Hooper et al. (2008) assigned methodological quality levels to a range of Downs and Black scores to enable categorisation; *Excellent* (26-28), *Good* (20-25); *Fair* (15-19); and *Poor* (≤14).

The student researcher and two additional peer reviewers independently appraised the quality of each study, with discrepancies in scoring resolved through discussion and consensus. Prior to the independent evaluation of included literature, the reviewers met to discuss the checklist and complete a trial evaluation of an article outside of the search criteria to ensure consistency in the application of each question.

2.3.5 Data Extraction and Synthesis

All identified articles were subjected to data extraction by the student researcher following the Patient, Intervention, Comparison, Outcome (PICO) framework (Eriksen & Frandsen, 2018). The data extracted included patient demographics, intervention details, comparison interventions, outcome measures for the interventions (radiologic or MRI imaging and inflammatory biomarkers), and the results of the intervention. Due to the small number of included studies, a short narrative summary of each of the six retained studies has been produced before the presentation of the extracted data and related narrative synthesis. The heterogeneity of the interventions and reported outcomes in the included studies precluded meta-analysis. Hence, a narrative synthesis was used to investigate and report similarities, differences and results between the included studies. Where studies explored multiple outcomes, data extraction was restricted to the inclusion criteria measurement of OA.

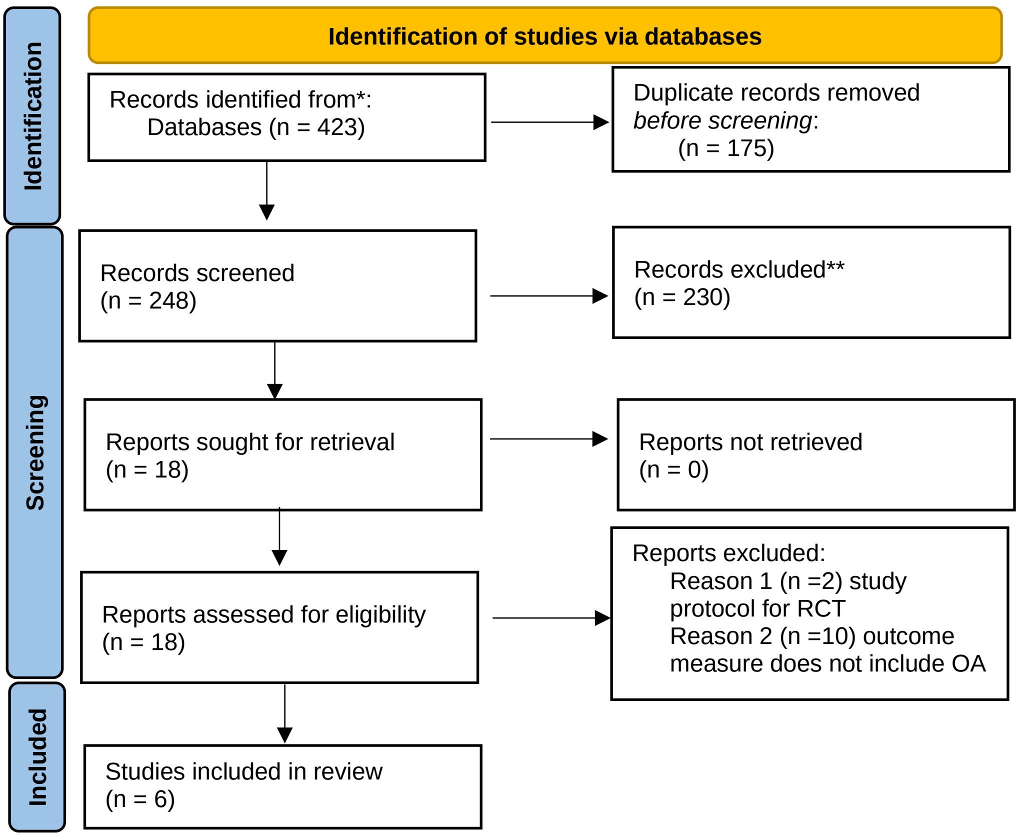
2.4 Results

2.4.1 Study Selection

Figure 2 illustrates the process undertaken to select the studies for quality appraisal and data extraction. The search of electronic databases identified 423 records. After removing duplicates (175), 248 studies were screened by reviewing the title and abstract. After reviewing abstracts, 230 studies were excluded. The three main reasons for exclusion at this stage were not including a radiological measure of OA disease (i.e., X-ray or MRI), animal-based studies or studies that solely focused on comparison of surgical techniques and did not describe rehabilitation. Of the 18 full-text studies retrieved and reviewed in full, two were excluded as they were not RCT but were study protocols for RCT and 10 were excluded as the outcome measures did not include an objective OA measure. Six studies were retained for the final analysis.

Figure 2

PRISMA diagram demonstrating study selection



From: Page MJ, et al. (2021) The PRISMA 2020 statement: An updated guideline for reporting systematic reviews. BMJ 2021;372:n71. doi:10.1136/bmj.n71

2.4.2 Study Quality Appraisal

Six studies, including a total of 488 participants who sustained a primary ACL injury to a previously un-injured knee, were included in this systematic review. Table 2 shows the individual Downs and Black scores of the studies included in the review. The methodological quality of all studies was categorised as *Good* (Hooper et al., 2008), with studies scoring between 20 and 24 out of 28 on the modified Downs and Black checklist. Bias tends to be greater in studies with low methodological quality (Hooper et al., 2008). However, as all articles were categorised as being of *Good* quality, all six studies were retained for data extraction.

Trends were noticed across the appraised studies. All studies scored 0 (No) for item 14 (*Was an attempt made to blind study subjects to the intervention they have received?).* This is a common finding as it is impossible to blind participants to the intervention they receive in this type of clinical trial. While participants could not be blind to intervention, they were blind to allocation up until the point of initial intervention. Conversely, all studies scored 1 (Yes) for item 15 (*Was an attempt made to blind those measuring the main outcomes of the intervention?) and* scored 1 (Yes) for item 23 (*Were study subjects randomised to intervention groups?).*

Of note, most studies also scored poorly for item 8, measuring study quality (*Have all adverse events that may be a consequence of the intervention been reported?),* and item 11, considering external validity (*Were the subjects asked to participate in the study representative of the entire population from which they were recruited?).*

Three studies (Frobell et al., 2013; Meunier et al., 2007; Nambi et al., 2020) scored highly (10/11) on the first ten items measuring study quality. Three studies (Meunier et al., 2007; Nambi et al., 2020; Wirth et al., 2021) also scored highly (2/3) on items 11 to 13, considering external validity. All studies scored well in items 14 to 20 considering internal validity/bias, with all studies scoring 5 (Frobell et al., 201; Nambi et al., 2020) or 6 out of 7. Frobell et al. (2013) and Nambi et al. (2020) scored full marks (6/6) from items 21 to 26, considering internal validity/confounding. The modified power question 27 scored 1 (Yes) in all studies.

Table 2

Downs and Black Checklist

Research title	**Lead author**	**Total**	**Quality**	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
Treatment for acute anterior cruciate ligament tear : five year outcome of randomised trial	Frobell et al., 2013	24	good	1	1	1	1	1	1	1	1	1	1	0	0	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1
Effects of isokinetic knee muscle training on bone morphogenetic proteins and inflammatory biomarkers in post-traumatic osteoarthritis after anterior cruciate ligament injury : a randomized trial	Nambi et al., 2020	24	good	1	1	1	1	2	1	1	0	1	1	0	1	1	0	1	1	1	1	0	1	1	1	1	1	1	1	1
Long-term results after primary repair or non-surgical treatment of anterior cruciate ligament rupture : a randomized study with a 15-year follow-up	Meunier et al., 2007	23	good	1	1	1	1	2	1	1	0	1	1	0	1	1	0	1	1	1	1	1	1	1	1	1	0	0	1	1
Early anterior cruciate ligament reconstruction does not affect 5 year change in knee cartilage thickness : secondary analysis of a randomized clinical trial	Wirth et al., 2021	21	good	1	1	1	1	1	1	1	0	0	1	0	1	1	0	1	1	1	1	1	1	1	1	1	0	1	0	1
No difference in osteoarthritis after surgical and non-surgical treatment of ACL-injured knees after 10 years	Tsoukas et al., 2016	20	good	1	1	1	1	0	1	1	1	1	1	0	0	0	0	1	1	1	1	1	1	1	0	1	1	1	0	1

Change in cartilage thickness, post traumatic bone marrow lesions, and joint fluid volumes after acute ACL disruptions	Frobell et al., 2011	20	good	1	1	1	1	1	1	1	0	1	1	1	0	1	0	1	1	1	1	0	1	0	0	1	0	1	1	1

2.4.3 Characteristics of Included Studies

A short narrative summary of each of the six studies retained for this review is provided to give an overview of the small body of literature. Of note, the first three studies are follow-up studies from the Knee Anterior Cruciate Ligament, Non-surgical versus Surgical Treatment (KANON) trial (Frobell et al., 2010).

Frobell (2011), completed a two-year prospective study of 61 patients from the KANON trial using MRI to investigate cartilage thickness following an ACL injury. Thirty-four patients were randomised to structured rehabilitation plus early ACLR, and 27 patients were randomised to structured rehabilitation plus optional ACLR (of note, 11 participants elected to have delayed ACLR). Data collected at baseline, three, six, twelve and twenty-four months after injury showed MRI changes in cartilage morphology at two years, indicating a significant reduction in tibiofemoral cartilage volume, thickness and surface area for most regions of the knee surface, with no significant differences in tibiofemoral cartilage reduction between groups. The exception was the central medial femur, where thickening was found for both surgical and non-surgical groups. This study shows that changes in cartilage thickness are unrelated to the initial ACL injury management at twenty-four months follow up.

Frobell et al. (2013) analysed the five-year follow-up data from the KANON trial. One patient from the original KANON trial was lost to five year follow up. Fifty-nine patients were allocated to structured rehabilitation plus optional delayed ACLR. Of this group, 30 people elected to have delayed ACLR for ongoing knee instability, and 29 underwent structured rehabilitation only. Fifty-nine patients allocated to structured rehabilitation plus early ACLR were available for the five-year follow-up. All participants followed a consensus-based structured rehabilitation programme (Risberg et al., 2004). The programme comprised early weight-bearing and 24-week physiotherapist-led, four-level progressive closed- and open-kinetic chain quadriceps strength and neuromuscular training (Frobell et al., 2010). Standardised frontal plane radiographs of the tibiofemoral compartment and patella axial radiographs of the patellofemoral compartment in weight-bearing were obtained at baseline and five years. There were no significant differences in radiographic evidence of OA between the two groups at five years follow-up. Additionally, there was no significant difference in radiographic OA between as treated knees undergoing early or late ACLR or those managed with structured rehabilitation only.

Wirth et al. (2021) reported the five-year follow-up data from the KANON trial but focused on ancillary comparison of the change in tibiofemoral cartilage thickness visualised by MRI. Baseline and five-year follow-up MRIs were available for 117 patients, 59 randomised to structured rehabilitation plus early ACLR and 58 randomised to structured rehabilitation plus delayed optional ACLR. Over five years, the full analysis set and the as-treated analysis showed an increase in tibiofemoral cartilage thickness was experienced by both treatment groups. No significant difference was seen in the change in overall tibiofemoral cartilage thickness between treatment groups over the five years from baseline.

Meunier et al. (2007) reported outcomes of radiographic OA comparing surgical with non-surgical management at 15 years since ACL injury. One hundred patients under 30 years with ACL rupture were randomised to surgical repair (n=44) or conservative management (n=56). Seven patients were lost to 15-year radiographic follow-up, 32 of the surgical group underwent augmented ACL repair, and 10 underwent ACL repair without augmentation. All surgical patients were non-weight bearing in a full-length cast for six weeks. Sixteen participants from the conservative management group later elected to undergo ACLR. Both groups followed an intensive strength and coordination rehabilitation programme. The surgical group began this once they had regained knee range of motion. No further detail is provided about the nature of this rehabilitation. There were no significant differences between groups in radiographic OA at 15 years follow-up, nor in activity level or KOOS score. Those who underwent late ACLR showed the most frequent occurrence of radiographic OA.

Tsoukas et al. (2016) evaluated radiographic evidence of OA, function, and physical activity 10 years after ACL injury. Thirty-two participants were randomly allocated to conservative management (n=15), or surgical repair via hamstring tendon graft (n=17). All patients participated in the same rehabilitation programme after either the ACL injury (conservative management), or after surgical repair. Passive knee movement and partial weight-bearing using a knee extension brace commenced immediately for the first six weeks. Stationary bike, proprioception exercises, short arc quadriceps sets, and hamstring curls were performed for the next six weeks. At three months, jogging, swimming, and cycling commenced, at six months, pivot sports resumed, and at eight months, contact sports resumed. The 10-year findings showed no significant differences in radiographic OA between groups. ACLR resulted in improved functional outcomes and stability than conservative management. While otherwise achieving a ‘good’ methodology review, this study's sample size and power are insufficient for the findings to be highly generalisable to a wider population.

Nambi et al. (2020) compared the effect of isokinetic and sensory-motor muscle training on two markers of OA severity and progression, bone morphogenetic proteins (BMP) and inflammatory biomarkers, in male footballers with PTOA following ACL injury. Sixty participants were randomly allocated to isokinetic training (n=20), sensory-motor training (n=20), or a standard home exercise programme (HEP) (n=20) for four weeks. Each group completed the prescribed exercise protocol five days per week following a five-minute warm-up. The isokinetic and sensory motor groups were supervised by an experienced physiotherapist. The isokinetic exercises were completed using a specified isokinetic dynamometer to target isokinetic hamstring and quadriceps strength at increasing angular speeds in three sets of 15 repetitions. Sensory motor exercises progressed from static (stationary standing exercises) to dynamic (30-second forward thrusts and t-band kicks) to functional (toe skipping, heel skipping, squats and wobble board exercises) training. The HEP included a range of unsupervised hamstring, quadriceps, gluteal and calf strengthening exercises. There were no significant changes from baseline PTOA (indicated by BMP or inflammatory markers) to completion of a four-week programme observed in any group. However, the isokinetic group reported a greater reduction in pain and improved function. At eight-week and six-month follow-up, the isokinetic group also showed a reduction (improvement) in inflammatory biomarkers compared to the sensory training or HEP groups. While all participants had experienced PTOA for more than three months following ACL injury, it is not apparent which participants had/had not undergone ACLR or the duration since their ACL injury.

2.4.4 Extracted PICO Data

The studies achieved a mean modified Downs and Black score of 22 out of 28. Table 3 demonstrates the key characteristics extracted from the retained studies using the PICO format and the corresponding Downs and Black score.

Table 3

PICO Framework of Study Criteria

Author	Title	D&B	Objective	Participants	Intervention	Control	Outcome measure/s	Results
Frobell et al., 2013	Treatment for acute anterior cruciate ligament tear: Five year outcome of randomised trial	24 Good	To compare the five-year radiographic outcomes of PTOA between those treated with rehabilitation plus early ACLR and those treated with rehabilitation and optional delayed ACLR	n=121 m&f Mean 26y BMI 24 No previous knee injury	Structured rehabilitation plus early ACLR at five-years FU n=59 (47m, 12f) Mean 27y BMI 24.4	Structured rehabilitation with optional delayed ACLR at five-years FU n=58 (28m, 20f) Mean 25.7y BMI 23.8	KOOS SF-36 Tegner activity scale Radiographic Osteoarthritis	No statistically significant differences between the two groups Increase in radiographic OA for all cohorts
Nambi et al., 2020	Effects of isokinetic knee muscle training on bone morphogenic proteins and inflammatory biomarkers in post-traumatic osteoarthritis after anterior cruciate ligament injury: A randomised trial	24 Good	To determine the effects of isokinetic training of knee muscles on bone morphogenic proteins and inflammatory biomarkers in PTOA after ACL injury	n=60 m 18-25 y With PTOA > three months post ACL injury 4-8/10 VAS BMI 22.6	Isokinetic training n=20 m mean 22.3 y BMI 22.5 Sensory motor training N=20 m Mean 22.4 y BMI 22.8	Conventional home exercise programme n=20 m Mean 22.9 y BMI 22.6	VAS pain Bone morphogenic proteins Inflammatory biomarker serum levels	At six months VAS mean improvement isokinetic 89%, sensory motor 62%, control 59%, Bone morphogenic proteins no significant difference, Inflammatory biomarkers significant improvement (decrease CRP, TNZ-a, IL-2 and IL-4) isokinetic compared with sensory motor and no significant difference with control
Meunier et al., 2006	Long-term results after primary repair or non-surgical treatment of anterior cruciate ligament rupture: A randomised study with a 15-year follow up	23 Good	To compare the prevalence of radiological PTOA changes at 15-years between those treated with surgical repair or non-surgical treatment following an acute ACL rupture	100 m&f <30 y With ACL rupture	Structured rehabilitation plus ACLR at 15 years FU n=54 (33m, 21f) Mean 22 y	Conservative management at 15 years FU n=56 (35m, 21f) Mean 21 y	KOOS Lysholm Radiographic osteoarthritis	No significant differences between the groups ACLR neither reduced risk of PTOA nor increased subjective outcome scores
Wirth et al., 2021	Early anterior cruciate ligament reconstruction does	21 Good	To compare the five-year change in femorotibial cartilage	n=117 m&f mean 26 y BMI 24	Structured rehabilitation	Structured rehabilitation plus optional	MRI Overall femorotibial	Increase in FTJ cartilage thickness in all groups with no significant difference in mean

	not affect 5 year change in knee cartilage thickness: Secondary analysis of a randomised clinical trial		thickness between those treated with structured rehabilitation and early ACLR and those treated with structured rehabilitation and optional delayed ACLR following acute ACL tear	ACL injury to previously uninjured knee	plus early ACLR at five-years FU n=59 (47m, 12f) Mean 27 y BMI 24.4	delayed ACLR at five-years FU n=58 (38m, 20f) Mean 25.7 y BMI 23.8	joint (FTJ) cartilage thickness	change in FTJ cartilage thickness between groups
Tsoukas et al., 2013	No difference in osteoarthritis after surgical and non-surgical treatment of ACL-injured knees after 10 years	20 Good	To compare the incidence of radiological PTOA after ACL rupture between patients treated conservatively and patients treated with ACLR with hamstring tendon graft at ten-years	n=37 m mean 32 y BMI <30 ACL rupture to previously uninjured knee	ACLR with hamstring autograft at ten-years FU n=17 Mean 31 y	Conservative ACL injury management at ten-years FU n=15 Mean 33 y	Tegner & Lysholm activity scales IKDC scores KT-1000 arthrometer laxity measurement Radiological PTOA	Each showed early signs of radiologic PTOA with no significant difference between groups. Laxity improved with ACLR with A/P tibial translation 1.5mm (SD 0.2) versus 4.5mm (SD 0.5) (p=0.03)
Frobell, 2011	Change in cartilage thickness, post traumatic bone marrow lesions, and joint fluid volumes after acute ACL disruptions	20 Good	To compare the two-year development of cartilage thickness between patients who received rehabilitation and early ACLR and patients who received rehabilitation and optional delayed ACLR and patients who received rehabilitation only, following acute ACL injury	n=58 (42m, 16f) mean 26.7 y Acute ACL injury (a cohort of the first patients of the KANON study completing all scheduled study MRI)	Early ACLR plus rehabilitation n=34 Delayed optional ACLR plus rehabilitation n=11	Rehabilitation only n=16	Cartilage thickness (mm) Joint fluid volumes (mm3) Bone marrow lesions via MRI Tegner scale of activity	No significant difference between groups for cartilage thickness All patients showed significant cartilage thinning in the trochlea of the femur mean, change 0.11mm (SD 0.12) p<0.001, plus posteromedial and posterolateral cartilage thinning, and cartilage thickening of the central medial aspect of the femur mean change 0.05mm (SD 0.13) p=0.001

Note: ACL = anterior cruciate ligament, ACLR = anterior cruciate ligament repair, BMI = body mass index, D&B = Downs & Black score, f = female, FU= follow up, FTJ = femorotibial joint, KOOS = Knee Injury and Osteoarthritis Outcome Score, m = male, MRI = magnetic resonance imaging, OA = osteoarthritis, PTOA = post-traumatic osteoarthritis, VAS = visual analogue scale, y = years

2.5 Narrative Synthesis of Extracted Data

2.5.1 Participants and Population

The participants in all six studies were described as previously physically active, aged between 18 and 35 years and had sustained a primary acute ACL knee injury. The mean duration since ACL injury ranged from two to 15 years after injury, except for Nambi et al. (2020), who failed to report this clearly. Four studies included male and female participants, and two studies (Nambi et al., 2020; Tsoukas et al., 2016) included males only. Five studies recorded body mass index (BMI), with all participants' mean scores being between 22 and 24 (Kgs/M^2), indicating they were within healthy ranges. Meunier et al. (2007) did not report BMI scores. Most studies reported no or very few losses to follow-up, with the exception of Wirth et al. (2021), who did not report on this. Participants were recruited from hospital attendance for ACL injuries in Sweden (Frobell, 2011; Frobell et al., 2013; Meunier et al., 2007; Wirth et al., 2021) and Saudi Arabia (Nambi et al., 2020). Mean Tegner scores >5 and <10 indicated participants were from moderately active to competitive sporting populations while excluding professional athletes (Lysholm & Tegner, 2007). Most ACL injuries occurred while participating in competitive sports (Frobel. 2011; Frobel et al., 2013; Nambi et al., 2020; Wirth et al., 2021), with mean Tegner scores >7.

2.5.2 Intervention

The impact of a variety of interventions was investigated across the included studies. Surgical ACLR via hamstring or bone-patellar tendon-bone autografts was described in the more recent surgical comparisons (Frobel, 2011; Frobel et al., 2013; Wirth et al., 2021). However, Meunier et al. (2007) considered earlier augmented and un-augmented ACLR occurring between 1980 and 1983. Delayed ACLR was an option for participants experiencing ongoing instability in four studies (Meunier et al., 2007; Frobel, 2011; Frobel et al., 2013; Wirth et al., 2021). Details of physiotherapy supervised, structured rehabilitation is described in four studies (Frobel, 2011; Frobel et al., 2013; Nambi et al., 2020; Wirth et al., 2021). In the follow-up to the KANON trial (Frobel. 2011; Frobel et al., 2013; Wirth et al., 2021), rehabilitation is based on a best-practice consensus-informed programme, commencing with early weight bearing, followed by goal-based progressions combining closed- and open-kinetic chain quadriceps strengthening and neuromuscular training (Frobell et al., 2010). Nambi et al. (2020) described participants receiving either isokinetic, sensory motor training or a standard HEP. Intervention durations were described in four studies and varied from four weeks (Nambi et al., 2020) to 24 weeks (Frobel. 2011; Frobel et al., 2013; Wirth et al., 2021) and eight months (Tsoukas et al., 2013). Participant compliance with study interventions was high in four of six studies but was unable to be determined in the remaining two studies (Frobell, 2011; Nambi et al., 2020).

2.5.3 Control or Comparison

Table 3 shows that five of the studies compared the impact of initial surgical ACLR with non-surgical management on the development of PTOA after ACL injuries. Three of these (Frobel. 2011; Frobel et al., 2013; Wirth et al., 2021) provided sufficient detail about the non-surgical management to compare surgical ACLR with a structured, supervised rehabilitation programme, while the other two (Meunier et al., 2006; Tsoukas et al., 2013) provided insufficient information about the non-surgical intervention for the same comparative analysis; instead, their comparison is limited to that of surgical ACLR with non-surgical management. Nambi et al. (2020) compared the impact of training regimes on existing PTOA after ACL injury and failed to record if participants had or had not undergone ACLR.

2.5.4 Outcomes

Table 3 shows all studies describe outcome measures with suitable sensitivity and specificity to be considered valid outcome measures of OA. Where findings included both objective measures of OA disease and symptomatic measures of OA illness (Filbay & Grindhem, 2019), for example, joint laxity (Tsoukas et al., 2016) or pain (Nambi et al., 2020), there was no correlation between radiological findings and pain or laxity scores in intervention groups. Follow-up durations ranged from two to fifteen years duration from the index injury.

2.5.5 Results

All six studies reported no significant differences between the intervention and the comparison/control groups for evidence of radiographic OA, MRI visualisation of cartilage thickness or bone morphologic proteins. Nambi et al. (2020) report a reduction in inflammatory biomarkers at six weeks and eight months after a four-week isokinetic training programme.

PTOA was recorded within 2 to 15 years of ACL injury in five of the six included studies and at an unspecified but short duration by Nambi et al. (2020). PTOA was recorded at an early age considering the population age range of participants in all studies.

2.6 Discussion

This systematic review identified six good-quality clinical trials that explored the impact of ACL injury management approaches on the development of PTOA. Five of the six studies compared surgical with non-surgical approaches, and the synthesis of these studies suggests the likelihood of developing PTOA is not affected by receiving surgical or conservative management after an ACL injury. In contrast, only one study (Nambi et al., 2020) compared post-operative rehabilitation approaches, meaning limited recommendations can be made about this research and suggests that more work needs to be done in this area. These main findings are discussed below in the context of currently available research.

Synthesis of the reviewed studies shows that surgical management is not superior to conservative management in the prevention of PTOA following ACLR. This summation is supported by Filbay (2019) and Friel and Chu (2013), who showed early ACLR is not superior to evidence-based rehabilitation in reducing subsequent PTOA after ACL injury. Some researchers argue that the onset of PTOA is caused by the ACL injury itself (Frobell et al., 2011) and is not influenced by the management interventions post-injury. Cuzzolin et al. (2021) propose that the mechanism of ACL injury has a traumatic impact on all knee structures, predisposing the knee to PTOA, and is not just a ligament injury. Potter et al. (2012) found that all ACL injuries are associated with chondral damage at the time of injury and propose that this will deteriorate over time. Moreover, Frobell et al. (2011) hypothesise that events at the time of ACL injury may cause a cascade of biologic sequalae contributing to early PTOA, with the later progression of PTOA linked to altered biomechanics following ACL injury and repair.

Limited recommendations can be made from this systematic review about rehabilitation protocols following ACLR because only one identified study compared different ACL injury rehabilitation protocols (Nambi et al., 2020). This study showed the inclusion of isokinetic muscular training within structured rehabilitation after ACL injury (plus or minus ACLR) might reduce inflammatory biomarkers; however, the impact of this on PTOA is unclear. This finding is supported by Wang et al. (2020), who report the involvement of ACL injury in the development of PTOA is complex and multifactorial, proposing structural, mechanical and neuromuscular factors in addition to biological (inflammatory) factors; however, they conclude that the precise mechanism remains unclear. The extracted studies do not otherwise show that any management intervention is more or less effective in reducing the impact of PTOA after ACL injury than others. Whittaker and Roos (2019) have highlighted there is not a lot of knowledge about evidence-based rehabilitation to prevent or delay the onset of PTOA after an ACL injury and are trialling an approach combining exercise and education based on the current evidence-based understanding of causal factors of OA.

The findings of this review have identified a significant gap in the current literature exploring the rehabilitation of people following ACLR to reduce the likelihood and impact of developing PTOA following ACL injury. Increased understanding of the causes of PTOA will improve management of the onset and progression after ACL injury and lead to future studies comparing specific intervention protocols targeting the causal mechanisms. However, in the meantime, future studies should consider comparing modes of ACL injury rehabilitation delivery to optimise adherence to a healthy lifestyle, including education and exercise boosted with periodic face-to-face supervision (Cinthuja et al., 2022), group rehabilitation (da Silva et al., 2015) or app-based rehabilitation (Clark et al., 2019; Clausen et al., 2020) to enhance engagement, monitored over an extended duration. Moreover, a recent consensus statement by Whittaker et al. (2022a) to support clinical practice in the absence of empirical research, supports these recommendations.

2.7 Strengths and Limitations

Strengths of this systematic review include the use of the Downs and Black checklist by multiple reviewers following a structured search of available literature leading to a robust, reproducible, structured synthesis of current research. Additionally, the six studies included were of ‘good’ methodological quality. Several limitations should be considered when interpreting the findings of this review. Rigorous application of search strategy excluded non-English publications and studies lacking an objective measure of OA. This limited data extraction to only six studies that assessed the efficacy of ACL injury management on outcome measures of OA included in this systematic review. Heterogeneity is noted in these studies, and quantitative analysis by pooling outcome data (meta-analysis) was not possible. In the existing literature, only one study investigated the impact of particular rehabilitation protocols on OA outcomes following ACL injury.

2.8 Future Research

This review shows that ACL injury increases the likelihood of PTOA regardless of injury management. Moreover, long-term engagement in healthy lifestyle behaviours (i.e., weight management and physical activity) may be needed to reduce the potential sequelae of the injury (Frobell et al., 2011). However, more clinical trials comparing the impact of different rehabilitation approaches over time on the incidence, progression and burden of PTOA are required before clinical recommendations are made for one rehabilitation strategy over another in relation to ACL injury management. Furthermore, the use of a consensus definition of symptomatic PTOA (Lie et al., 2019), and standardised clinical criteria for radiographic OA (Oiestad et al., 2009), will enable meta-analysis of future study findings.

2.9 Clinical implications

This review provides evidence from a small collection of well designed studies that undergoing surgical repair or not, does not change the likelihood of developing PTOA after ACL injury. Therefore, clinicians should provide patients with advice regarding all options for ACL injury management to inform treatment decision-making and commence rehabilitation early as either the sole form of intervention or as pre-habilitation if ACLR is completed. Limited evidence is provided that ACL rehabilitation should include education and progressive criteria-based strengthening exercises (Frobel. 2011; Frobel et al., 2013; Wirth et al., 2021). Therefore, clinicians should include these as components of individualised rehabilitation programmes while encouraging engagement in long-term healthy activity to help manage body weight (Filbay et al., 2021; Whittaker et al., 2021) and to enhance the protective factors of weight-bearing exercise (Ardern et al., 2014). Isokinetic training may reduce inflammatory biomarkers more than other rehabilitation programmes (Nambi et al., 2020); however, this finding should be treated with caution as the mechanism and association with PTOA remains unclear. An ACL injury can have a life-long impact, so ACL injury prevention is an important consideration for clinicians working with young athletes participating in pivoting sports. Primary ACL injury prevention mirrors re-injury prevention and further injury (PTOA) management (Thorborg et al., 2017), providing a double layer of protection against initial ACL injury as well as the sequelae of PTOA.

2.10 Conclusion

This review shows that the ACL injury population is at increased risk of PTOA and at an earlier age than the non-ACL injured population, regardless of their initial injury management. Good quality evidence shows surgical and non-surgical management have comparable outcomes for most people following ACL Injury. However, few clinical trials exist that assess the impact of different rehabilitation programs on the onset and progression of PTOA after ACL injury. Therefore, more high-quality future studies are needed to determine the best intervention to reduce the impact of PTOA following ACL injury.

Chapter 3: Dissertation Discussion

3.1 Introduction

The primary aim of this systematic review was to identify, appraise, and synthesise research that describes management approaches to reduce the impact of PTOA knee following ACL injury. Furthermore, the review aimed to answer the following research question, what is the efficacy of existing interventions for reducing the impact of PTOA following ACL injury? This dissertation has achieved these objectives. Only a small body of research considers the efficacy of management approaches on developing PTOA after ACL injury. Six good-quality RCTs were identified that investigated the impact of ACL injury management approaches on PTOA. Strong evidence from five RCTs shows no significant difference in rates of PTOA with surgical or non-surgical management of ACL injury. A single RCT compared the efficacy of different ACL injury rehabilitation approaches on PTOA and concluded no significant change in baseline PTOA with these approaches. Limited evidence from this review supports the suggestion that ACL injury rehabilitation should include education and progressive criteria-based strengthening exercises to limit the onset and progression of PTOA.

This review has identified several issues that have considerable practice implications and are discussed in the context of current literature in this chapter. These issues include the benefit of surgical ACLR following ACL injury, the value of ACL injury prevention programmes, and the optimisation of rehabilitation following ACL to reduce long-term disability. Next are recommendations for future research, practice implications for AoNZ drawn from this study and the final concluding statement. Table 4 summarises the introduction of what was known before this review (column 1 = Chapter 1), the review findings (column 2 = Chapter 2), and the clinical implications arising from this review (column 3 = Chapter 3).

Table 4

What was known/What this review adds/Clinical implications for practice

What was known	What this review adds	Clinical implications for practice
ACL injury pre-disposes to PTOA	Increased rates of PTOA in ACL injury population	Prevention of ACL injury is important
ACLR does not prevent PTOA	Strong evidence there is no significant difference in rates of PTOA with surgical or non-surgical management of ACL injury	ACL rehabilitation is beneficial as a component of ACL management regardless of surgical intervention or not
ACLR primary management choice in AoNZ	Small volume of research considering the efficacy of management approaches on the development of PTOA following ACL injury/further research required	Education regarding ACL injury management options is important for all involved in support of young athletes to make informed decisions
Low-value care is prevalent for musculoskeletal conditions	Limited evidence that ACL rehabilitation should include education and progressive criteria-based strengthening exercises	ACL rehabilitation should: • Start early after ACL injury • Include physiotherapy supervision • Progress on achievement of criteria • Continue for an extended duration • Lead into re-injury prevention • Lead into a lifetime of healthy activity
There is inconsistency between radiographic OA and clinical OA	Objective signs of PTOA may appear before patients experience clinical signs of OA	Collection of non-surgical ACL injury management data is important to gather to inform future research and clinical practice
Individual and social cost of PTOA after ACL injury is considerable given the early age of onset	Early age of PTOA equates to a long duration of impact of PTOA in ACL injury population	Engagement in extended duration of rehabilitation/healthy lifestyles important
Māori and Pasifika are disproportionately affected		Need to implement current evidence in ACL injury rehabilitation to improve PTOA outcomes

Note: ACL = anterior cruciate ligament, ACLR = anterior cruciate ligament repair, AoNZ = Aotearoa New Zealand, OA = osteoarthritis, PTOA = post-traumatic osteoarthritis

3.2 ACL Repair : To Operate or Not?

Restoring function and preventing instability via ACLR does not appear to reduce the risk of PTOA after ACL injury (Wang et al., 2020). While advances in surgical technique mean a range of options exist for ACLR, no evidence shows any of the current surgical options are superior to non-operative management of ACL injury for the prevention of PTOA (Friel & Chu, 2013). There are comparable outcomes for PTOA after ACL injury with surgical or non-surgical management, and ACLR does not prevent PTOA. Yet, surgical ACLR remains a popular choice following an ACL injury in AoNZ (New Zealand ACL Registry, 2021). The studies in this review refute the historical misconceptions that the best management for ACL injury is surgical ACLR and that ACLR reduces the rate of PTOA compared to rehabilitation alone. Surgical advances continue to be explored to improve the efficacy of outcomes (Jenkins et al., 2022), but despite these advances, this systematic review provides strong evidence there is currently no significant difference in rates of PTOA with surgical or non-surgical management of ACL injury. This finding is congruent with Filbay and Grindem (2019), who concluded that early reconstruction is not superior to evidence-based rehabilitation in reducing subsequent PTOA rates. Moreover, they found that ACLR restored a degree of knee stability but that there was no difference in rates of radiographic PTOA between those undergoing ACLR and non-surgical management after an ACL injury (Filbay & Grindem, 2019).

Rates of radiographic PTOA did not significantly differ for review participants who underwent ACLR and those who did not, indicating that ACLR does not prevent PTOA. This finding is consistent with Barenius et al. (2014), where PTOA was found at three times the rate after an ACL injury treated with ACLR compared with the contralateral healthy knee. Improved surgical techniques, including pre and post-operative rehabilitation, have improved outcomes (Friel & Chu, 2013); however, despite these changes, the risk of PTOA remains after ACLR. Despite this, most ACL injured in AoNZ undergo ACLR to restore joint stability (New Zealand ACL Registry, 2021).

The trauma associated with ACL injury is among the hypothetical causes of PTOA after ACL injury (Friel & Chu, 2013; Wang et al., 2020). Some researchers argue that sustaining a second ‘knee trauma’ in the form of an ACLR shortly after the injury may contribute to suboptimal healing compared with initial management with a goal-oriented exercise programme (Filbay et al., 2021; Larsson et al., 2017). Furthermore, Culvenor et al. (2019) conclude that early ACLR was associated with greater cartilage thickness loss over five years compared with optional delayed ACLR, suggesting that early ACLR may be related to short-term structural cartilage deterioration.

While this review indicates that non-surgical management may have comparable outcomes as surgical ACLR for the acutely ACL-injured population, different management options may meet the needs of different individuals. Meunier et al. (2006) found their initial non-surgical group who progressed to later ACLR indicated by symptomatic knee instability had the highest rates of radiographic OA at 15 years and had the highest levels of activity at the time of injury. A possible implication being patients with the highest level of pre-injury activity may have an increased risk of instability with non-surgical management and, therefore, may warrant the increased stability offered by surgical repair. The decision to operate or not should therefore be a fully informed and shared decision involving consideration of the risks and benefits alongside the individual’s circumstances and goals.

3.3 ACL Injury Prevention

This review highlights that an ACL injury increases a person’s risk of developing PTOA regardless of post-injury management. This finding suggests that ACL injury starts the biological trajectory to PTOA (Wang et al., 2020). Therefore, prioritising ACL injury prevention to try and stop these injuries from occurring, should be a priority to reduce the impact of this burden. This finding is supported by previous studies showing that ACL injury predisposes to PTOA (Barenius et al., 2014; Bodkin et al., 2020; Filbay, 2019; Lie et al., 2019). Since ACLR does not reduce PTOA, ACL injury prevention is the best medicine.

Most ACL injuries are non-contact injuries arising from movements taking the ACL beyond its tensile properties (Woo et al., 1991). ACL injury prevention should address movements, particularly jumping and landing, sudden stopping and changing direction that predispose athletes to increased force on the ACL (Hewett et al., 2016). ACL injury prevention comprising consistent neuromuscular training of proper cutting and jumping technique prepares athletes physiologically for sport (Culvenor et al., 2022). This training is shown to positively impact injury rates and athletic performance (Noyes and Westin, 2012). Prevention via improved function is suitable for primary ACL injury prevention, re-injury prevention and further injury (PTOA) management following ACL injury (Thorborg et al., 2017).

Education providing knowledge about PTOA after ACL injury can improve adherence to prevention and rehabilitation programmes, with athletes motivated to participate by understanding their performance and injury risk will be better than before (Van Ginckel et al., 2015). ACL injury prevention is an important component of education provided by rehabilitation professionals (Emery et al., 2015) and could be seen as the first step in a

PTOA mitigation or ACL injury management cycle. The consensus rehabilitation described in the review focuses on the resumption of pre-injury function and closes the ACL injury management cycle doubling as re-injury prevention and PTOA management (Whittaker & Roos, 2019).

3.4 ACL Injury Rehabilitation Programmes: Can Post-ACL Injury Management Reduce the Impact of PTOA?

This review aimed to explore the efficacy of management interventions on PTOA after ACL injury. However, our search findings demonstrated a notable shortage of studies investigating the effectiveness of different rehabilitation programmes in this population. Rehabilitation aims to restore knee stability, recover as near pre-injury function as possible and limit further injury (Ezzat et al., 2019). This means in the short term, restoring the ability to perform at an appropriate functional level and, in the long term, delaying the onset and progression of PTOA. Focus on restoring optimal function will likely also improve the efficacy of the management of PTOA (Whittaker et al., 2022a).

While it appears ACL injury starts a chain of events leading to potential PTOA, which cannot be stopped, post-ACL injury management may help reduce the impact of PTOA (Filbay & Grindem, 2019). Restoring knee stability, strength, and function are key goals of early ACL injury management, whether surgical or not. The review findings highlight the importance of managing ACL injury early to preserve joint health in light of the early onset of PTOA identified following ACL injury, as seen in all included studies and the predicted burden of PTOA (Filbay, 2019; Mather et al., 2013). Early commencement of structured rehabilitation enabling the acute signs of injury to subside before considering ACLR may benefit long-term outcomes by providing the opportunity for both continued conservative management and pre-habilitation prior to ACLR.

Additionally, there is evidence that pre-operative rehabilitation improves post-operative outcomes, including the risk of further injury and PTOA. Potts et al. (2021) highlight that quadriceps weakness is a frequent symptom after ACL injury and that poor pre-operative strength equates to poor post-operative strength. Persisting quadriceps weakness after ACLR may be related to the onset of PTOA (Øiestad et al., 2022; Piussi et al., 2020; Wang et al., 2020). It is suggested that pre-habilitation, including quadriceps strengthening, may improve quadriceps strength after ACLR and, in turn, improve PTOA outcomes (Potts et al., 2021). Early intervention may improve long-term joint health, including delaying the onset and progression of PTOA by positively impacting modifiable risk factors for PTOA (e.g., physical inactivity and weight gain) and slowing the chain of events.

There appears to be insufficient evidence to inform the use of a specific type or progression of rehabilitation intervention after ACL injury or ACLR to mitigate PTOA. However, some recommendations about rehabilitation can be gleaned from the limited evidence that ACL rehabilitation is beneficial as a component of ACL injury management regardless of surgical intervention or not. Some of the studies within the review described a consensus-based comprehensive ACL rehabilitation programme with criteria-based progressions rather than timeframe-based progressions (Frobel, 2011; Frobel et al., 2013; Nambi et al., 2020; Wirth et al., 2021). This programme details four goal-based rehabilitation exercise progressions for range of movement (ROM), muscle function, and functional performance (Frobel et al., 2010). Progressions commence after an initial period of early weight-bearing and isokinetic exercises allowing injury/surgery pain and swelling to settle. Closed chain exercises progress to open chain to improve ROM and strength. Static exercises progress to dynamic to improve balance, power, and function. The primary goal of these programmes is often the achievement of limb strength symmetry (Nicholls et al., 2021). Higher limb symmetry indexes have demonstrated protection against re-injury *(*Palmieri-Smith & Lepley, 2015), and quadriceps symmetry of 90% is often recommended before resuming training for sports and finally progressing to sports competitions (Lynch et al., 2015). Progressions are based on achieving the goals of the previous programme level. See Appendix B. Including similar criteria-based progressions is likely to be a beneficial component of ACL injury management programmes.

Since OA is a disease that progresses over years, a long duration of ACL injury rehabilitation leading to a healthy lifestyle approach is recommended to limit the insidious onset and progression of chronic PTOA (Filbay et al., 2019; Whittaker et al., 2021). The young age of review participants is indicative of their early age of PTOA onset. This is consistent with earlier findings (Lie et al., 2019; Whittaker & Roos, 2019), reporting the index ACL injury often occurs at a young age and subsequent PTOA also develops at a young age, becoming a considerable burden for the individual and their community (Wilson & Abbott, 2019). Engagement in extended-duration structured rehabilitation progressing into a lifetime of healthy activity is important to mitigate this burden (Culvenor et al., 2022). Adherence to the prescribed rehabilitation over an extended duration may be enhanced by a biopsychosocial approach (Scott et al., 2018), identifying client-centred goals and encompassing patient education and physical rehabilitation progressing into supported self-management (Filbay & Grindem, 2019). Identifying the resources (time, other commitments and access to gyms/pools/equipment) patients have for rehabilitation is important to develop realistic individualised programs. Various physical rehabilitation modalities should be considered to optimise engagement in a lifetime approach to match the rehabilitation method to the patient's needs (Filbay & Grindem, 2019). Including periods of supervision (Frobell et al., 2011 & 2013; Nambi et al., 2020; Wirth et al., 2021), as well as self-management supported through digital technologies, including the use of telehealth and gaming technology, relevant to the young age of many sustaining ACL injuries (Cinthuja et al.,2022), are likely to be beneficial to encourage the necessary extended duration engagement.

Supervision by a physiotherapist appears necessary in teaching rehabilitation exercises and progressing rehabilitation programmes (Frobell et al., 2010; Nambi et al., 2020). Intermittent supervision provides an important opportunity for physiotherapists to continue delivering education, support criteria-based progressions and compliance with the extended duration of rehabilitation after an ACL injury. Supervision may be even more important for the general population, who may lack the motivation and support of others (e.g., coaches, managers, teachers) to adhere to extended duration rehabilitation than the predominantly competitive athlete population of this review (Jenkins et al., 2022).

3.5 Recommendations for Future Research

This review highlights opportunities for further research on the efficacy of ACL injury management programmes to delay the onset and slow the progression of PTOA. There is a lack of high-quality clinical trials comparing the impact of ACL rehabilitation programmes on PTOA. Future research needs to shed more light on five current knowledge gaps.

Firstly, we know exercise and increased leisure time physical activity (LTPA) are important in ACL injury management and are widely promoted to manage PTOA symptoms (Bamman et al., 2016). Further research to consider the frequency, dose and intensity of exercise, as well as modes of exercise (e.g., resistance versus aerobic, continuous versus interval training, isokinetic versus isometric exercise), are required to support exercise prescription as an effective form of management following ACL injury (Logerstedt et al., 2013). Secondly, it is known there is inconsistency between radiographic OA and clinical (symptomatic) OA. Further research investigating the efficacy of ACL rehabilitation programmes on PTOA is indicated, including patient-reported outcome measures (PROMS) and objective measures to identify programmes that may help halt the progression of radiographic signs of OA becoming symptomatic. Thirdly, we know ACL injury is a precursor to PTOA; however, we lack clarity on the causal mechanisms. Further research clarifying the causal link between ACL injury and PTOA may help identify modifiable factors that clinicians can intervene to halt or delay the progression from ACL injury to PTOA. Fourthly, Māori are overrepresented in rates of ACL injury and OA. Further research to consider culturally acceptable programmes for ACL injury prevention and management is indicated to ensure equitable application in

AoNZ. Finally, research opportunities exist for rigorous large-scale, long-duration trials to provide an evidence base to inform treatment via optimal dosing of prescribed exercise, and quality of life via increased LTPA, after ACL injury. Such trials may motivate clinicians and ACL-injured patients to adhere to prescribed exercise programmes and engage in healthy, active lifestyles.

3.6 Practice Implications for AoNZ

The Ministry of Health Strategic Intentions 2021-2025 outlines the AoNZ health system goal of Pae Ora/Healthy Futures. The application of evidence-based management of ACL injuries for improved PTOA outcomes is consistent with Pae Ora by increasing the quality of life, time spent in good health and health equity. Barriers to evidence based practice (EBP) include factors limiting access to rehabilitation, such as the cost/co-payment and locations for existing rehabilitation options. Evidence-based pilot programmes are being trialled (Filbay & Grindem, 2019). In AoNZ, these aim to improve the efficacy of ACL rehabilitation and address inequities in access and outcomes for Māori, and people living in high-deprivation areas of AoNZ. They include strategies such as removing payments, removing limits on treatment numbers or durations from injury, and linkages to other comprehensive rehabilitation such as vocational and community rehabilitation programmes (Reid, 2022; Reid et al., 2022).

Other strategies being trialled internationally, include the virtual delivery of physiotherapy guided exercise-programmes encompassing group education, individualised goal setting and consensus-based home exercise programmes, all virtually supported by a suitably trained physiotherapist (Whittaker et al., 2022c). Initial results of such programmes show a positive impact, with people reporting engagement as a result of being involved in decisions about their treatment, and improved outcome measures relating to a reduced rate of hospital admission for PTOA via improved community management of ACL injuries. A pragmatic approach suggests physiotherapists apply mixed modes of delivery to EBP, including app-based, telehealth, group (da Silva et al., 2015) and in-person booster sessions alongside patient-centred goal setting and self-management (Cinthuja et al., 2022).

ACL injured people will likely experience diverse functional, psychological, and social challenges. Physiotherapists acting as health coaches are in a strong position to promote biopsychosocially informed healthy lifestyles to support long-term outcomes for the ACL-injured population, including discussion of psychology and nutrition, for example, within scope (Josefin et al., 2022). Offering EBP through various modes is most likely to meet the variety of needs of the ACL injured population and bring AoNZ nearer to equitable outcomes.

Table five summarises the challenges and opportunities for clinical practice in AoNZ collated from analyses of the review findings and contemporary literature.

Table 5

Challenges and Opportunities for Clinical Practice in AoNZ

Challenge	Opportunity
ACL injury is a pre-cursor to PTOA	Evidence-based prevention programmes
	Advocacy for system change and funding to support EBP
Inconsistency between radiographic and clinical OA	Early intervention to optimise knee health to halt progression of radiographic OA to clinically symptomatic OA
Inequitable access to, and engagement in rehabilitation	Collaborative rehabilitation including removal of barriers (location/cost/resources/communication/whanau involvement)
Media/social media reports	Education for the public
Patient expectations	Education for patients and their supports (e.g. parents/coaches/teachers)
Adherence to extended duration rehabilitation	Mixed mode EBP including self-management, group rehab and app-based rehab Physiotherapists as ‘coaches’/able to discuss e.g. nutrition within scope Patient-centered goal setting
Coding of ACL injuries to support reporting e.g. coded as ‘knee strain/sprain’ until reassessed by orthopaedic surgeons – then already on surgical pathway	Physiotherapists engaged in ACL registry reporting particularly of conservatively managed ACL injury
Gaps in rehabilitation data Rehabilitation protocols Dose/rate/frequency responses	Application of current evidence in ACL injury rehabilitation while awaiting further evidence

Note: ACL = anterior cruciate ligament, EBP = evidence based practice, OA = osteoarthritis, PTOA = post-traumatic osteoarthritis

The findings of this review have led to six practice recommendations:

Opportunities for physiotherapists to lead ACL rehabilitation in AoNZ. Physiotherapists have the knowledge and skills to lead ACL rehabilitation (van Melick et al., 2016). Collaborating via transdisciplinary work (e.g., with GPs and orthopaedic surgeons) may help remove provider and health system barriers, particularly regarding location, cost, and suitability and awareness of services by having all providers agree regarding early effective ACL rehabilitation (New Zealand health strategy 2016, 2022).

Patient and population health messaging. Providing evidence-based patient and population education is also a role for physiotherapists (Van Ginckel et al., 2015). Helping to overcome a wealth of online misinformation via improved communication and collaboration, including education for all involved with young, injured athletes and patients themselves, is important to inform decision-making. Shared decision-making is important for engagement in rehabilitation and should be integral to ACL rehabilitation to optimise adherence to an extended duration rehabilitation leading to a healthy lifestyle approach (Hoffmann et al., 2020).

Advocacy. This review presents opportunities for physiotherapists to use the evidence to inform advocacy for system change, including data collection and application of EBP. The comparable benefits of non-operative management of ACL injury highlighted in this systematic review may be reflected by records in the non-operative arm of the NZ ACL Registry. To date, non-operative records have been poorly reported by sports physicians and surgeons (New Zealand ACL Registry, 2021). Additionally, it appears ACL injured people in AoNZ are receiving very little rehabilitation, as evidenced by Fausett et al. (2019) and that OA management lags behind the management of other chronic diseases, as noted in the NZ 10-Year Strategic Health Plan, despite the predicted burden (New Zealand health strategy 2016, 2022, p.17). Including reporting of ACL injuries in the NZ ACL Registry by physiotherapists, who are often the first line of diagnosis and management of ACL injury in AoNZ, may improve non-operative data collection to better inform the selection of initial ACL injury management, future research, and evidence-based clinical practice.

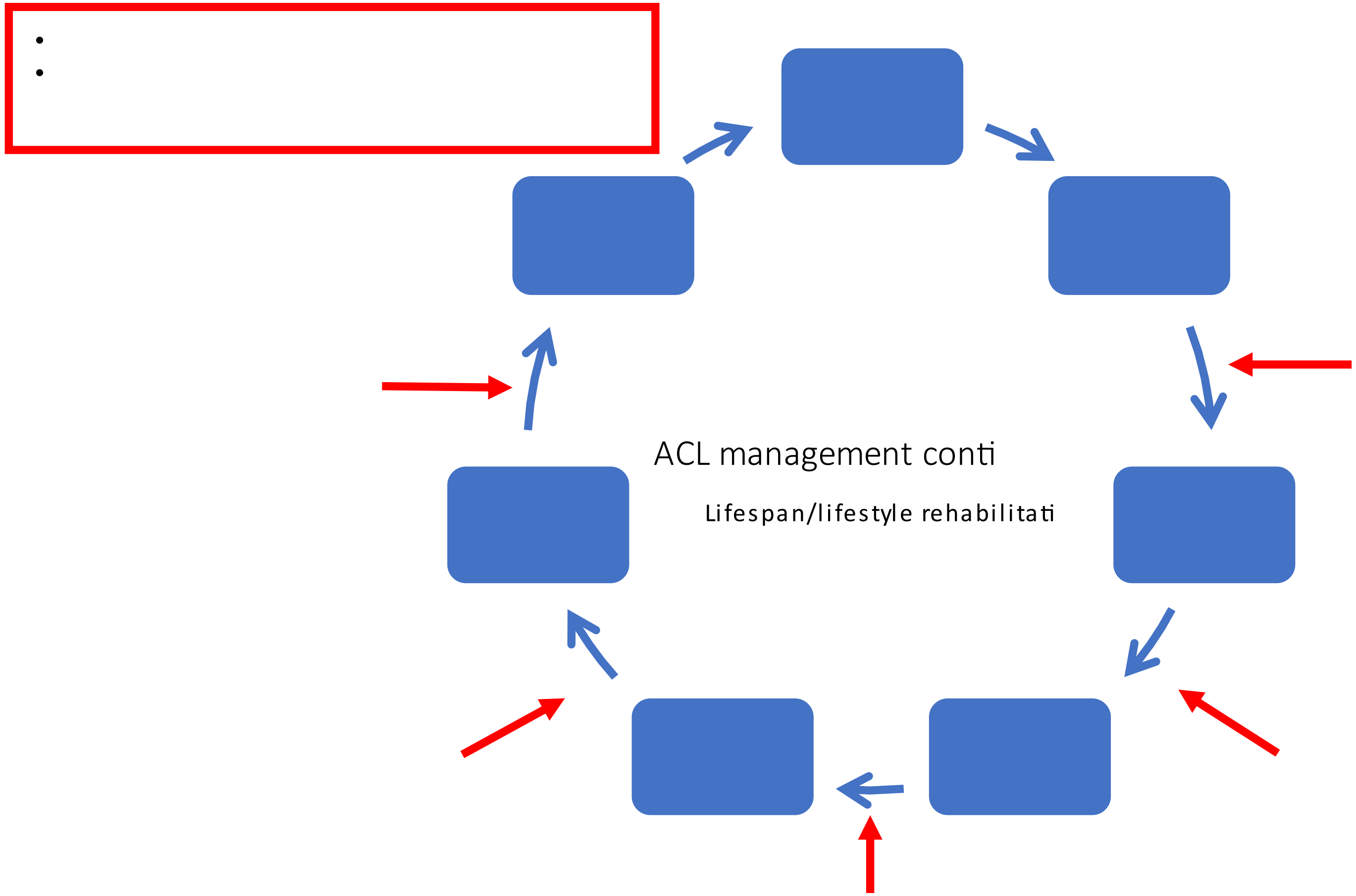
Prevention. Understanding that ACL injury pre-disposes to PTOA, primary prevention is described as prevention of the initial ACL injury, particularly amongst those most at risk from participating in cutting and pivoting sports. Secondary prevention describes strategies to slow or halt the progression of PTOA following the initial ACL injury. Tertiary prevention describes strategies to improve the function of those experiencing symptomatic PTOA (Whittaker & Roos, 2019). As previously described, a range of evidence-based initiatives exist where physiotherapists can engage in primary prevention. Secondary and tertiary prevention, including management of modifiable risk factors for PTOA, should form part of ACL injury management programmes. Both should include weight management to avoid obesity, resumption of physical activity, and restoration of neuromuscular strength and limb symmetry. Secondary prevention should also minimise the risk of another ACL injury. Symptomatic knee OA is clinically important, and is why people seek healthcare (Lie et al., 2019). Radiographic OA often appears earlier, and physiotherapists may have a unique opportunity to intervene early to prevent progression from radiologic to clinical OA, and the onset of pain or disability by including primary, secondary and tertiary prevention within an ACL injury management continuum.

Education. Physiotherapists are well placed to provide evidence-based education regarding ACL injuries and their management for all involved in supporting young athletes to make informed decisions. Increased public and patient understanding of RTS rates and that conservative management is comparable to surgical ACLR will improve perceptions, minimise poorly informed choices, and help this population make better decisions for their future (Zadro & Pappas, 2019). Despite the evidence, there is a persistent misconception that surgical ACLR is required for RTS. In contrast to high expectations (Zadro & Pappas, 2019), evidence shows approximately 50% of ACL-injured athletes will RTS (Ardern et al., 2014), and of those, one in four will reinjure their ACL (Kyritsis et al., 2016). Gamble et al. (2022) summarise that orthopaedic surgeons consulted about management options following ACL injury provide little education about non-surgical options or the comparable risk of PTOA after ACLR. Many myths exist regarding ACL injury management and PTOA, with strong beliefs held despite these beliefs not being supported by the current evidence base (Webster & Feller, 2019). These beliefs confuse rehabilitation, challenge EBP and exacerbate inequitable access to and engagement in ACL rehabilitation in AoNZ. High-profile media coverage of NZ sporting superstars and heroes reinforces the belief that surgical reconstruction is required for good results following ACL injury. This is an unrealistic comparison for the majority of the ACL-injured population. Outdated and incorrect online information can compound poor ACL rehabilitation decision-making. Often patients' and surgeons' expectations are mismatched, which can contribute to unrealistic rehabilitation expectations (Gamble et al., 2022), and 70% of the ACL-injured population are undertreated with current rehabilitation (Ebert et al., 2017). Providing evidence-based education could address concerns or misguided beliefs to better align patients with rehabilitation suited to their needs.

Application of EBP to ACL rehabilitation. The focus of efficacious ACL injury management may fall along a continuum of primary injury prevention and treatment of established OA. The continuum may commence with an ACL injury, repair or revision. Components of the continuum should not be discrete but rather include overlap, e.g., education and engagement should commence while the initial injury or ACLR is allowed to settle (resolution of swelling and pain sufficient to allow commencement of movement and exercises), along with isokinetic exercises and early weight-bearing (Cinthuja et al., 2022) as illustrated in Figure 3. Shared decision-making should repeatedly occur during ACL rehabilitation to consider criteria-based progressions based on client-centred goals and instability.

Figure 3

ACL Injury Management Continuum



3.7 Conclusion

This review provides strong evidence there is no significant difference in rates of PTOA with surgical or non-surgical management of ACL injury and limited evidence that ACL rehabilitation should include education and progressive criteria-based strengthening exercises. It highlights gaps in the current research and recommends future research to better answer the question, what is the efficacy of existing interventions for reducing the impact of knee PTOA following ACL injury?

Knowing that ACL injury permanently increases the risk of PTOA, including education and shared decision-making in rehabilitation programmes are indicated to support engagement in healthy lifestyles for ongoing self-management of the increased lifetime risk. This review and related literature support efficacious ACL injury management on a continuum of structured ACL rehabilitation progressing from ACL injury prevention to a healthy lifestyle approach to preserve knee health. Physiotherapists can use their knowledge and connections to advocate for system change and funding to support high-quality EBP awaiting further research findings.

While evidence-based rehabilitation dosage is as yet unknown, it is known that PTOA after ACL injury is an anticipated sequence of events and that exercise is medicine in the management of PTOA. We also know that low-value care is prevalent for musculoskeletal conditions and that ACL injured receive less rehabilitation than recommended. The objective signs of PTOA may appear before patients experience clinical signs of PTOA and the early age of onset of PTOA after ACL injury equates to a long duration of the burden of PTOA for the ACL-injured population. Rehabilitation following ACL injury can effect both short- and long-term outcomes. We continue to have the propensity to deliver low-value ACL injury rehabilitation which appears unlikely to halt PTOA in AoNZ. ACL injuries and their long-term trajectory are shown to create an increasingly significant and inequitable individual and societal burden. Current research indicates it is unlikely injury management will stop PTOA, therefore it is important to prevent ACL injuries in the first instance, and improve how people live with the increased risk of PTOA after ACL injury.

This review provides evidence for physiotherapists to provide a strong public health message regarding ACL injuries and their management to the AoNZ public and patients, and to advocate for system change to reflect EBP. While we wait for further research to inform aspects of ACL injury management, we need to implement the current evidence into rehabilitation programmes, to LEAPP (Lead evidence-informed Education and Advocacy, while implementing programmes for ACL injury Prevention and Promotion of knee health) ACL injury management forward for Pae Ora.

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Appendix A

Downs and Black Items: extracted from Downs & Black (1998)

Checklist for measuring study quality

Reporting

1. *Is the hypothesis/aim/objective of the study clearly described?*

yes	1
no	0

2. *Are the main outcomes to be measured clearly described in the Introduction or Methods section?*

If the main outcomes are first mentioned in the Results section, the question should be answered no.

yes	1
no	0

3. *Are the characteristics of the patients included in the study clearly described ?*

In cohort studies and trials, inclusion and/or exclusion criteria should be given. In case-control studies, a case-definition and the source for controls should be given.

yes	1
no	0

4. *Are the interventions of interest clearly described?*

Treatments and placebo (where relevant) that are to be compared should be clearly described.

yes	1
no	0

5. *Are the distributions of principal confounders in each group of subjects to be compared clearly described?*

A list of principal confounders is provided.

yes	2
partially	1
no	0

6. *Are the main findings of the study clearly described?*

Simple outcome data (including denominators and numerators) should be reported for all major findings so that the reader can check the major analyses and conclusions. (This question does not cover statistical tests which are considered below).

yes	1
no	0

7. *Does the study provide estimates of the random variability in the data for the main outcomes?* In non normally distributed data the inter-quartile range of results should be reported. In normally distributed data the standard error, standard deviation or confidence intervals should be reported. If the distribution of the data is not described, it must be assumed that the estimates used were appropriate and the question should be answered yes.

yes	1
no	0

8. *Have all important adverse events that may be a consequence of the intervention been reported?* This should be answered yes if the study demonstrates that there was a comprehensive attempt to measure adverse events. (A list of possible adverse events is provided).

yes	1
no	0

9. *Have the characteristics of patients lost to follow-up been described?*

This should be answered yes where there were no losses to follow-up or where losses to follow-up were so small that findings would be unaVected by their inclusion. This should be answered no where a study does not report the number of patients lost to follow-up.

yes	1
no	0

10. *Have actual probability values been reported(e.g.0.035 rather than <0.05) for the main outcomes except where the probability value is less than 0.001?*

yes	1
no	0

External validity

All the following criteria attempt to address the representativeness of the findings of the study and whether they may be generalised to the population from which the study subjects were derived.

11. *Were the subjects asked to participate in the study representative of the entire population from which they were recruited?*
The study must identify the source population for patients and describe how the patients were selected. Patients would be representative if they comprised the entire source population, an unselected sample of consecutive patients, or a random sample. Random sampling is only feasible where a list of all members of the relevant population exists. Where a study does not report the proportion of the source population from which the patients are derived, the question should be answered as unable to determine.

yes	1
no	0
unable to determine	0

12. *Were those subjects who were prepared to participate representative of the entire population from which they were recruited?*
The proportion of those asked who agreed should be stated. Validation that the sample was representative would include demonstrating that the distribution of the main confounding factors was the same in the study sample and the source population.

yes	1
no	0

unable to determine	0

13. *Were the staV, places, and facilities where the patients were treated, representative of the treatment the majority of patients receive?* For the question to be answered yes the study should demonstrate that the intervention was representative of that in use in the source population. The question should be answered no if, for example, the intervention was undertaken in a specialist centre unrepresentative of the hospitals most of the source population would attend.

yes	1
no	0
unable to determine	0

Internal validity - bias

14. *Was an attempt made to blind study subjects to the intervention they have received ?*
For studies where the patients would have no way of knowing which intervention they received, this should be answered yes.

yes	1
no	0
unable to determine	0

15. *Was an attempt made to blind those measuring the main outcomes of the intervention?*

yes	1
no	0
unable to determine	0

16. *If any of the results of the study were based on "data dredging", was this made clear?* Any analyses that had not been planned at the outset of the study should be clearly indicated. If no retrospective unplanned subgroup analyses were reported, then answer yes.

yes	1
no	0
unable to determine	0

17. *In trials and cohort studies, do the analyses adjust for diVerent lengths of follow-up of patients, or in case-control studies, is the time period between the intervention and outcome the same for cases and controls ?* Where follow-up was the same for all study patients the answer should yes. If diVerent lengths of follow-up were adjusted for by, for example, survival analysis the answer should be yes. Studies where diVerences in follow-up are ignored should be answered no.

yes	1
no	0
unable to determine	0

18. *Were the statistical tests used to assess the main outcomes appropriate?*
The statistical techniques used must be appropriate to the data. For example nonparametric methods should be used for small sample sizes. Where little statistical analysis has been undertaken but where there is no evidence of bias, the question should be answered yes. If the

distribution of the data (normal or not) is not described it must be assumed that the estimates used were appropriate and the question should be answered yes.

yes	1
no	0
unable to determine	0

19. *Was compliance with the intervention/s reliable?*
Where there was non compliance with the allocated treatment or where there was contamination of one group, the question should be answered no. For studies where the eVect of any misclassification was likely to bias any association to the null, the question should be answered yes.

yes	1
no	0
unable to determine	0

20. *Were the main outcome measures used accurate (valid and reliable)?*
Downs, Black For studies where the outcome measures are clearly described, the question should be answered yes. For studies which refer to other work or that demonstrates the outcome measures are accurate, the question should be answered as yes.

yes	1
no	0
unable to determine	0

Internal validity - confounding (selection bias)

21. *Were the patients in diVerent intervention groups (trials and cohort studies) or were the cases and controls (case-control studies) recruited from the same population?* For example, patients for all comparison groups should be selected from the same hospital. The question should be answered unable to determine for cohort and casecontrol studies where there is no information concerning the source of patients included in the study.

yes	1
no	0
unable to determine	0

22. *Were study subjects in diVerent intervention groups (trials and cohort studies) or were the cases and controls (case-control studies) recruited over the same period of time?* For a study which does not specify the time period over which patients were recruited, the question should be answered as unable to determine.

yes	1
no	0
unable to determine	0

23. *Were study subjects randomised to intervention groups?*

Studies which state that subjects wererandomised should be answered yes except where method of randomisation would not ensure random allocation. For example alternate allocation would score no because it is predictable.

yes	1
no	0
unable to determine	0

24. *Was the randomised intervention assignment concealed from both patients and health care staV until recruitment was complete and irrevocable?*
All non-randomised studies should be answered no. If assignment was concealed from patients but not from staV, it should be answered no.

yes	1
no	0
unable to determine	0

25. *Was there adequate adjustment for confounding in the analyses from which the main findings were drawn?*
This question should be answered no for trials if: the main conclusions of the study were based on analyses of treatment rather than intention to treat; the distribution of known confounders in the diVerent treatment groups was not described; or the distribution of known confounders diVered between the treatment groups but was not taken into account in the analyses. In nonrandomised studies if the eVect of the main confounders was not investigated or confounding was demonstrated but no adjustment was made in the final analyses the question should be answered as no.

yes	1
no	0
unable to determine	0

26. *Were losses of patients to follow-up taken into account?*
If the numbers of patients lost to follow-up are not reported, the question should be answered as unable to determine. If the proportion lost to follow-up was too small to aVect the main findings, the question should be answered yes.

yes	1
no	0
unable to determine	0

Power

27. *Did the study have suYcient power to detect a clinically important eVect where the probability value for a diVerence being due to chance is less than 5%?*
Sample sizes have been calculated to detect a diVerence of x% and y%.

	Size of *smallest* intervention group	
A	$<n_1$	0

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B	n_1–n_2	1
C	n_3–n_4	2
D	n_5–n_6	3
E	n_7–n_8	4
F	n_8+	5

Appendix B

Rehabilitation Protocol of the Kanon Study extracted from Frobell (2010)

The protocol included four levels described by exercise examples and goals for range of motion, muscle function, and functional performance for the first 24 weeks of rehabilitation. Goals for each level should be met prior to progression to the next level. Time intervals for each level were suggested but not superior to the goals. A slower progression was expected in those assigned to rehabilitation plus ACL reconstruction. Pain, swelling and discomfort slowed the progression, and if persistent a visit to the treating clinician was scheduled. Use of anti- inflammatory drugs (NSAID) was allowed if needed.

Examples of exercises appropriate for each phase are presented. These exercises are examples and the Physical Therapist also used complementary exercises complying with the guidelines for each phase.

	0-4 weeks	5-8 weeks	9-12 weeks	13-16 weeks	17-24 weeks
Unloaded range of motion (ROM) ***Goals***	As tolerated *Full extension Flexion > 120 deg*	As tolerated *Full extension Flexion comparable to other side*	Normal *Comparable to other side*	Normal *Comparable to other side*	Normal *Comparable to other side*
Muscle function ***Goals***	Quadriceps: unloaded full control Hamstrings: loaded exercises Exercises for other lower limb muscles and trunk are initiated *Full quadriceps control in sitting and standing*	Quadriceps: loaded non-weight bearing in 40-120 deg and closed-chain (weight bearing) exercises in 0-80 Hamstrings: full ROM Exercises for other lower limb muscles and trunk	Quadriceps: closedchain exercises without limitations Hamstrings: exercises without limitations Exercises for other lower limb muscles and trunk	Quadriceps: openchain exercises without limitations Hamstrings: exercises without limitations Exercises for other lower limb muscles and trunk *Non-surgical: Less than 10% difference in quadriceps and hamstrings strength between legs*	Quadriceps: openchain exercises without limitations Hamstrings: exercises without limitations Exercises for other lower limb muscles and trunk *Surgical: Less than 10% difference in quadriceps and hamstrings strength between legs*

	0-4 weeks	5-8 weeks	9-12 weeks	13-16 weeks	17-24 weeks

Symptoms ***Goals***	Pain: tolerated, treated if necessary Swelling: tolerated, treated if necessary *No morning swelling*	Pain: tolerated, treated if necessary Swelling: tolerated, treated if necessary *No pain* *Occasional activityrelated swelling*	No pain Occasional activityrelated swelling tolerated *No activity-related pain* *Occasional activityrelated swelling*	No pain Occasional activityrelated swelling tolerated *No activity-related pain* *Occasional activityrelated swelling*	No pain Occasional activityrelated swelling tolerated *No activity-related pain* *Occasional activityrelated swelling*
Walking ***Goals***	As tolerated forward and backwards without pain* and limping (initially with crutches) *Full weight-bearing without pain or limping* *Crutches may be discharged when patient is able to walk backwards without limping*	Full weight-bearing Daily walking without restrictions *Full weight-bearing* *Walking without pain or limping*	Full weight-bearing Slow and fast walking on treadmill *Full weight-bearing* *Walking without pain, swelling or limping*	Full weight-bearing Running on treadmill/even surface Non-surgical: Unrestricted running *Full weight-bearing* *Non-surgical: Running without pain, swelling or limping*	Full weight-bearing Surgical: Unrestricted running *Full weight-bearing* *Surgical: Running without pain, swelling or limping*

	0-4 weeks	**5-8 weeks**	**9-12 weeks**	**13-16 weeks**	**17-24 weeks**
Balance/ Coordination	One-leg standing in functional positions	One-leg standing in functional positions on soft ground and Babs-board	One-leg standing in functional positions on more demanding surfaces and Babs-board	One-leg standing in functional positions on more demanding surfaces Two legged bounces Easy sport-specific movements Easy agility exercises	One-leg standing in functional positions on more demanding surfaces One legged bounces Provoked sportspecific movements Provoked agility exercises
Goals	*One-leg standing without difficulties*	*Comparable to other side*	*Comparable to other side*	*Non-surgical: Onelegged hop and square-hop[1] less than 10% difference between legs*	*Surgical: Onelegged hop and square-hop[1] less than 10% difference between legs*

	0-4 weeks	**5-8 weeks**	**9-12 weeks**	**13-16 weeks**	**17-24 weeks**

Activities ***Goals***	Unloaded and loaded biking on stationary bike backwards and forwards with clips *Unloaded biking forward with clips*	Biking on stationary bike without restrictions Wet-vest exercises and running in deep water Non-surgical: Outdoor biking without restrictions	Biking on stationary bike without restrictions Wet-vest exercises and running in deep water Slide-board training	Non-surgical: Introduction of sport-specific exercises Surgical: Outdoor biking without restrictions *Non-surgical: Back to pre-injury activity level*	Surgical: Introduction of sport-specific exercises *Surgical:* *Back to pre-injury activity level*
Action if goal is not reached		If ROM, Symptoms, Weightbearing goals are not reached: Doctors Visit			

*As tolerated = acceptable pain according to Pain Monitoring System Visual Analog Scale 5 (0-10) (Thomee, R. A comprehensive treatment approach for patellofemoral pain syndrome in young women. Phys Ther 1977(12): 1690-703.

[1] Ostenberg A, Roos E, Ekdahl C, Roos H. Isokinetic knee extensor strength and functional performance in healthy female soccer players. Scand J Med Sci Sports. 1998 (5):257-64.

Phase 1 and 2, 0-8 weeks.

Home program; 2-7 days after injury/operation.

Knee flexion:

Lay on your stomach, bend your injured knee to about 90 degrees and lift your foot and lower leg towards the ceiling.

Knee extension:

Sit in front of a wall with your injured leg slightly bent and a ball under the knee.
Put the foot against the wall and press the knee towards the floor.
Keep the tension in the knee extensors.

Muscle function:

Sit on a chair/stool. Stand up slowly with full muscle control, equally distributed load on both feet.

Phase 1 and 2. 2-8 weeks after injury/reconstructive surgery

Lay on your back with hips and knees in 90 degrees with your feet against the wall. Slide your injured leg up and down along the wall by extending and flexing your knee.

Stand with your back against the wall and a soft ball behind your injured knee. Squeeze the ball against the wall by extending your knee.

"Norwegian push-ups".
Press a soft ball between your knees, flex and extend your hips and knees. Keep back straight.

Stand on a step board, step down by flexing foot, knee and hip...
Important! Neutral alignment of foot, knee and hip. Do not lean trunk forward.

...forward

... to the side

Leg press, start at 90 degrees and extend your legs.

Kneebendings with a stick. Important! Neutral alignment of foot, knee and hip. Do not lean trunk forward.

Lay on your back with the injured leg on a hard pillow, keep your hands around your other knee. Lift your pelvis.

Lay on your back with both legs on the hard pillow. Lift your pelvis using one leg, move your other leg sideways.
Alternate between legs.

A. Stand with your injured leg slightly bent on the step board.

B. Take one step up with your injured leg and extend your knee. Continue the rise until on your toes, keep the knee extended.

Lean against the board on your injured side. Lift your hip up from the board. Simultaneously, extend and lift the other leg in abduction.

Stand on your injured leg on a balance board with your knee semi flexed.

Stand on your injured leg on a trampoline, flex and extend your knee slightly and slowly with full control.

Stand on your injured leg and slide sideways and back again with your other leg. Use a small towel under the other shoe for sliding.

<u>Phase 4 and 5. 13-24 weeks after injury/reconstruction</u>

Lunges while moving medicine ball from side to side.

Stepping down to the side from stepboard with deep kneebendings.

Leg extentions with resistance.

Stand on your injured leg with your other lower leg resting on a pillow. Flex your injured knee with dumbbells in your hands.
Important! Neutral alignment of foot, knee and hip.

Squeeze a soft ball between your knees. Jump forward on both legs over a series of step boards.