Effect of weight bearing on functional outcomes post non-surgically managed Achilles tendon rupture

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Abstract

Objective

In groups randomly allocated to immediate weight bearing or delayed weight bearing (standard care), to assess the difference in plantar flexor muscle endurance, strength, hop performance, perceived function, and Achilles tendon length at 12-18 months post injury.

Study Design

The first phase of this study was implemented by researchers from the Orthopaedic Department at Wellington Regional Hospital. It was a prospective randomised control trial (RCT) with the two treatment groups mentioned above. The second phase utilised the RCT cohort, but otherwise was independently conceived and implemented for this master's thesis research. It was a cross-sectional design assessing participants 12-18 months post conservatively managed Achilles tendon rupture in an immediate weight bearing (VACOped) group compared to a standard care group.

Background

Achilles tendon rupture is a traumatic injury event with increasing incidence and often long-term functional consequences. Ongoing deficits in plantar flexor endurance and strength are often seen 12 months post injury and return to sport rates post Achilles tendon rupture range from 50-70 percent. Hence, a significant amount of people who suffer this injury never return to normal function. There is poor consensus regarding the optimal conservative management strategy to date. Early mobilisation is a possible strategy, but results to date have been inconsistent and there is limited evidence of performance based testing post Achilles tendon rupture.

Method

Performance based functional outcomes were measured using the total heel raise work test, maximum voluntary contraction (MVC) of the plantar flexors, single leg hop for distance, single leg hop for height and a lateral movement 30 second continuous hop test. Achilles tendon length was measured using the resting angle method. Perceived function was measured using the Achilles Tendon Rupture Score (ATRS) and the Injury-Psychological Readiness to Return to Sport (I-PRRS).

Results

From the initial RCT, 34 participants were recruited (VACOped group: 20; Standard Care group: 14). There was a significant difference ($p < 0.05$) across limbs for the total heel raise work test, MVC test, hop for distance and height tests. There was no significant group or interaction effect ($p > 0.05$) observed across all performance based functional outcome measures.

There were no significant differences ($p > 0.05$) across groups in both the ATRS and the I-PRRS. The mean score for the ATRS in the VACOped group was 80 while the mean score in the standard care group was 72. The mean score for the I-PRRS in the VACOped group was 48 compared to 41 in the standard care group.

There was a significant difference ($p < 0.05$) across limbs, but no significant group or interaction effect ($p > 0.05$) was observed for Achilles tendon length measures. Regarding legs, a mean increase of 29 percent and 32 percent in Achilles resting angle was observed across legs in the VACOped and standard care groups, respectively.

Conclusion

Based upon the variables measured, immediate weight bearing did not lead to increased physical performance compared to the delayed weight bearing group at 12-18 months post injury. At this time point, findings highlighted notable and significant deficits in plantar flexor muscle endurance, plantar flexor muscle strength, maximum effort hop tests, and Achilles tendon length across limbs irrespective of group allocation. In line with previous research, secondary findings showed that there were also ongoing deficits in self-perceived function and self-confidence to return to sport post Achilles tendon rupture.

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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 used artificial intelligence tools or generative artificial intelligence tools (unless it is clearly stated, and referenced, along with the purpose of use), nor material which to a substantial extent has been submitted for the award of any other degree or diploma of a university or other institution of higher learning.

Signed:

Date: 08-05-24

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Chapter 1 - Introduction

1.1 Statement of the problem

The Achilles tendon is the largest and strongest tendon in the human body, capable of exerting forces up to 10 times body weight (Baxter et al., 2021). A primary function of the Achilles tendon is to transmit the force generated by the plantar flexor muscles to the heel and foot, allowing us to push off the ground and move the body forward and upwards. It is essential for activities like running and jumping. Achilles tendon rupture is a common musculoskeletal injury with an incidence rate of between 11-37 / 100,000 a year (Ganestam et al., 2016). Epidemiological studies over the last 20 years have shown an increase in the incidence of this injury (Ganestam et al., 2016), owing partly to the increasing demands of sports and an increasing number of older athletes participating in sporting activity. The average age of rupture is between 30-46, with males more likely to sustain a rupture than females (Lemme et al., 2018).

Debate exists about how to best manage Achilles tendon ruptures with surgical or non-surgical management. There is a clear downward trend in surgical procedures for Achilles tendon rupture (Ganestam et al., 2016). Evidence suggests that rupture rates and functional outcomes in the long term between surgical and non-surgical management are the same (Deng et al., 2017), however ongoing functional deficits in endurance, strength and hop performance are present post injury (Silbernagel et al., 2010; Olsson et al., 2011; Brorsson et al., 2018). At 12 months post injury, Silbernagel et al. (2010) showed a deficit of 26 percent in plantar flexor endurance. At two years post injury, in both surgical and non-surgical groups, Olsson et al. (2011) showed a mean difference of 20 percent in plantar flexor endurance, and 21 percent in plantar flexor strength between affected and unaffected sides. Brorsson et al. (2018) showed no significant difference in self-perceived functional outcomes at seven years post injury between surgical and non-surgical groups, but again performance deficits were still present between limbs. These authors showed that only 29 percent to 33 percent of the participants had a limb symmetry index higher than 85 percent in plantar flexor muscle endurance and strength. Such findings demonstrate that although there may not be a difference between surgical and non-surgical management of Achilles tendon rupture, significant muscle performance and functional deficits remain after this injury.

An Achilles tendon rupture requires intensive rehabilitation and a lengthy period away from sport. Return to sport rates are poor with up to 39 percent of National Basketball Association (NBA) athletes (Amin et al., 2013) and 26 percent of National Football League (NFL) athletes (Parekh & Shah, 2017) never returning to play following Achilles tendon rupture. Regarding professional soccer players,18 percent have not returned to the same level of competition two years after rupture (Grassi et al., 2020). A conservative estimate of 77 percent return to sport in the wider population of Achilles tendon rupture patients is reported, although return to play criteria is poorly described in the research (Zellers et al., 2016).

Early weight bearing post surgically repaired Achilles tendon ruptures is common practice and it has been shown to have no detrimental effects on tendon healing (McCormack et al., 2015). Current guidelines for non-surgical (conservatively) managed Achilles tendon rupture suggest cast immobilisation for two to four weeks followed by gradual weight bearing in a moon boot for a further four weeks. Long periods of non-weight bearing activity have been shown to have detrimental effects on muscle cross-sectional area, strength, and endurance (de Boer et al., 2008) and such muscle atrophy can be very difficult to reverse (Heikkinen et al., 2017; Peng et al., 2017). It has long been known that mechanical loading improves tendon health. Experimental studies show that dynamic rehabilitation post Achilles tendon repair promoted stronger callus formation, reduced calf muscle atrophy, and favourably influenced the development of collagen fibres within the tendon (Palmes et al., 2002). Such work would suggest that early weight bearing under controlled conditions may have beneficial effects on tendon healing as well as plantar flexor muscle preservation in a conservatively managed group. The role of early weight bearing in conservatively managed Achilles tendon ruptures has been sparsely investigated in the literature. The consensus is that early weight bearing is not detrimental to the healing tendon but ongoing deficits in self-perceived function are still present up to 12 months post injury (Barfod et al., 2014; Costa et al., 2006, 2020; Kastoft et al., 2019). Research has shown evidence of ongoing functional deficits up to 12 months post rupture (Kastoft et al., 2019) but there is a clear lack of evidence regarding the assessment of multiple, performance based tests to measure recovery more accurately.

Given the above findings, the rationale for the current study is based on the limited information assessing performance based outcomes, in conservatively managed groups performing immediate weight bearing following Achilles tendon rupture. Many patients often do not return to pre-injury level sporting activity, but the literature is lacking explanations of why this may be the case. In many instances, limited testing of muscle performance and function has been undertaken in those receiving early weight bearing during conservative management. Further research involving a more comprehensive set of performance variables might provide important information that may influence treatment options. It has been suggested that a battery of tests, which include muscle strength testing as well as functional hop tests, are superior to these tests in isolation (Gustavsson et al., 2006; Kyritsis et al., 2016; Thomeé et al., 2011). This is common practice in the rehabilitation of other major injuries such as anterior cruciate ligament injuries (Van Melick et al., 2016). This study aims to assess and compare a variety of functional outcomes at 12-18 months following an Achilles tendon rupture in immediate weight bearing versus non-weight bearing conservatively managed groups. The addition of a battery of performance tests including single leg hop testing is unique.

1.2 Purpose of the study

This study has three primary objectives:

1. To assess if there was a significant difference in strength, endurance, and power across uninvolved and involved limbs at 12 months post Achilles tendon rupture in groups who received immediate weight bearing vs conservative non-weight bearing management.
2. In the aforementioned groups, assess if there is a significant difference in tendon elongation across limbs.
3. In the aforementioned groups, assess if there is a significant difference in self-perceived functional outcomes.

1.3 Significance of the problem

The outcomes of this study may have significance for healthcare professionals involved in the rehabilitation and management of individuals who have experienced an Achilles tendon rupture. The findings may encourage healthcare providers to consider the role of immediate weight bearing versus standard care, non-weight bearing as a crucial aspect of the early rehabilitation program for those recovering from an Achilles tendon rupture. Additionally, this research may prompt further discussion on early rehabilitation exercises post Achilles tendon rupture. If significant differences are detected in functional performance between immediate and delayed weight bearing conditions, it may underscore the importance of healthcare professionals including weight bearing protocols in their treatment plans for individuals following an Achilles tendon rupture. Finally, having a battery of performance tests as part of a rehabilitation protocol post Achilles tendon rupture might encourage clinicians and patients to progress their rehabilitation in line with these tests and potentially improve the return to sport rates post injury.

Chapter 2 - Review of the literature

2.1 Introduction

This chapter begins with an explanation of the search strategy used for the literature review. We then look at Achilles tendon morphology followed by the incidence and prevalence of Achilles tendon rupture. Next, we examine risk factors related to Achilles tendon rupture and then focus on the current conservative treatment options post Achilles tendon rupture. This will lead us into the main section of the review focusing on early weight bearing, including immediate weight bearing, versus delayed weight bearing following conservative management of Achilles tendon rupture, which is the focus of this current piece of research. This will provide a basis for the research in this area and how it has evolved. Thereafter, we review how functional outcome measures are utilised post Achilles tendon rupture. Finally, self-reported outcomes following Achilles tendon rupture are described.

2.2 Search strategy

An initial review of the literature was performed, and an extensive list of keywords was obtained. These words were: Achilles, rupture, surgery, non-surgery, conservative, weight bearing, immediate weight bearing, delayed weight bearing strength, endurance, power, function, return to sport, hop test(ing), limb symmetry index, calf, gastrocnemius, soleus. Using these key words, six electronic databases were searched. This included PEDro, AMED, MEDLINE, Sports Direct, CINAHL and Sports Discus. The literature search was further improved by reviewing the reference lists of included articles and previously reviewed articles on Achilles tendon rupture.

2.3 Achilles tendon morphology and loading

The Achilles tendon is the largest tendon in the human body and is capable of exerting loads of up to 10 times our body weight while sprinting and jumping (Baxter et al., 2021). Thus, the Achilles tendon is made up of predominantly type I collagen fibres (Freedman et al., 2014). The Achilles tendon is an extension of the soleus muscle and the two heads of the gastrocnemius muscle. The muscles merge halfway down the lower leg and begin to spiral downwards towards the calcaneus, forming a single tendon approximately 5-6 cm away from the attachment to the calcaneus (Schepsis et al., 2002). This spiralling or winding of the fibres causes a near 90 degrees of rotation, with the lateral fibres rotating anteriorly and medial fibres rotating posteriorly (Schepsis et al., 2002). This spring-like design allows for greater recoil and elastic properties. During some jumping tasks, the plantar flexor muscles work in an almost isometric state during the landing phase, allowing for the tendon to stretch and subsequently recoil, resulting is maximum energy production (Lidstone et al., 2018; Fukashiro et al., 2005). Such recoil results in the tendon being responsible for between 47 and 75 percent of the work performed during jumping (Fukashiro et al., 2005). During lateral movements, such as cutting, ankle plantar flexion power was approximately twice that of the power observed at the knee and hip joints (Ono et al., 2023). The Achilles tendon may experience peak forces above 70MPa during maximum eccentric plantar flexion compared to most other tendons' peak forces of less than 30MPa (Komi et al., 1992; Kongsgaard et al., 2005). This ability to exert high amounts of force puts this complex at risk of injury.

2.4 Incidence and prevalence of Achilles tendon rupture

The incidence and prevalence of Achilles tendon rupture vary substantially based on factors such as age, sex, and activity level. It is becoming increasingly prevalent and incidence rates are rising. Huttunen et al (2001) showed a 17 percent increase in Achilles tendon rupture between 2001 to 2012 in the Swedish population. Lantto et al. (2015) showed an increase in incidence rate per 100,000 from 2.1 to 21.5 over 32 years (1979 and 2011). In New Zealand, over five years from 1998 to 2003, the incidence of Achilles tendon ruptures increased from 4.7 per 100,000 to 10.3 per 100,000, an increase of 119 percent (Tumilty, 2007). Males are much more likely to rupture their Achilles tendon when compared to females. Of the 27,000 participants involved in Huttunen et al's (2001) study, 79 percent were male. The injury is most commonly sports-related (Tumilty, 2007) and occurs between the ages of 35 to 45 (Lantto et al., 2015). Ganestam et al. (2016) also showed a rising incidence rate in people over 50 years old. This was thought to be due to the increasing activity levels seen in the ageing population.

2.5 Risk factors for Achilles rupture

Achilles tendon ruptures typically occur during rapid forced dorsiflexion at the ankle joint (Tarantino et al., 2020). The tendon most commonly ruptures 5-8 cm above the calcaneal insertion (Park et al., 2019). This is often the narrowest part of the tendon, and it is thought that high energy levels fail to be absorbed by the tissues in this region (Schepsis et al., 2002). Several risk factors for rupture have been suggested.

Achilles tendon ruptures occur most often between the age of 35-45 (Lantto et al., 2015). Some authors have suggested that the turnover of collagen fibres slows with ageing (Schulze-Tanzil et al., 2022). This will result in a reduction in stiffness, the ability to absorb energy, and mechanical strength (Lindemann et al., 2020). The rising level of participation of this age group in sporting activities, together with an ageing tendon, increases the risk of rupture (Ganestam et al., 2016). Age has also been shown to be a risk factor for contralateral Achilles tendon rupture. Adults in their 30's, who have sustained Achilles tendon ruptures, have a significantly increased risk for contralateral tendon rupture (Park et al., 2020).

Males are much more likely to rupture their Achilles tendon when compared to females (Huttunen et al., 2001). There is no known reason for this finding. It has been suggested that males have greater muscle mass and can exhibit greater forces thus putting the tendon more at risk of injury. However, if males have stronger muscle components it would be likely that the tendon would also be stronger given the in-series attachments between these elements.

Evidence suggests a positive association between Achilles tendinopathy and Achilles tendon rupture risk (Dakin et al., 2018; Xergia et al., 2023). Cook et al. (2016) describe the concept of a non-painful, degenerative tendon and this is often the presentation pre-rupture. Changes to the physical properties of the Achilles tendon have been observed in the ruptured tendon immediately post injury. For instance, an increase in type *III* collagen fibres has been seen at the site of rupture (Maffulli et al., 2011), indicating tendon degeneration pre-injury. Biopsies have also confirmed the presence of non-resolved chronic inflammation within the ruptured tendon (Dakin et al., 2019). It has also been shown that a smaller fibril diameter within the tendon is a risk factor for rupture (Claessen et al., 2014). When the ruptured tendon was analysed using digitised electron microscopy biopsy, a loss of larger fibrils in the core and periphery of the Achilles tendon was seen when compared to controls (Claessen et al., 2014). This would explain the scenario of an injury to an inactive person who decides to start running and jumping type activities. Relatedly, corticosteroids are utilised for many clinical conditions to reduce inflammation. The use of oral and injection administered corticosteroids has also been shown to increase the risk of Achilles tendon rupture (Van der Linden et al., 2003).

It is also suggested that race is a risk factor for Achilles tendon rupture. There is an increased incidence of Achilles tendon rupture in the African American race compared with the Caucasian race (Owens et al., 2007). It is not clear why, but genetics may play a part (Claessen et al., 2014).

2.6 Treatment options for conservatively managed Achilles tendon rupture

Following an Achilles tendon rupture, that tendon typically undergoes a period of immobilisation and unloading. Traditionally, standard practice for a conservatively managed Achilles tendon rupture includes 6-8 weeks of a hard cast with the foot in an equinus position followed by a further 4 weeks of gradual weight bearing in a below knee orthosis (Costa et al., 2006). Periods of non-weight bearing in a healthy population have been shown to result in reduced pennation angle, increased fascicle length, reduced muscle cross-sectional area (CSA) of plantar flexors (de Boer et al., 2008), and reduced Achilles tendon CSA and tendon stiffness (Zellers et al., 2017). Following an Achilles tendon rupture similar changes are seen in the plantar flexor muscles and Achilles tendon (Peng et al., 2017). These morpho-mechanical changes also correlate strongly with subjective functional outcomes including maximal heel raise heights (Peng et al., 2017). These negative effects can be very difficult to reverse (Brorsson et al., 2018). Heikkinen et al. (2016) showed a deficit in plantar flexor muscle strength up to 13 years post rupture leading us to think that these changes might be permanent.

In the last two decades, treatment approaches have evolved though, and researchers have started to examine the effects of early weight bearing post rupture. What follows is a review of the effects of early weight bearing, including immediate weight bearing, of the conservatively managed Achilles tendon. The focus of the review will be functional outcomes at or close to 12 months post injury, a time when it is typically expected that patients will have returned to pre injury levels of activity.

2.7 Early versus delayed weight bearing post Achilles tendon rupture

All tendons are dynamic structures and respond actively to loads (Bojsen-Møller et al., 2006). This mechanical trigger or catalyst causes a loading message to be communicated throughout the tissue. This message is received at a cellular level and the cells produce the appropriate materials and constituents necessary to adapt to this load. The communication at each phase occurs via cell signalling through messenger proteins, ion channels and lipids. This whole process is called mechanotransduction (Khan & Scott, 2009). Positive changes in CSA and tendon stiffness can be seen following acute bouts of exercise (Couppé et al., 2008). Given the positive effects of exercise and load on tendon health, it has been considered that early weight bearing following an Achilles tendon rupture could be seen as a beneficial approach to accelerate healing and return to activity.

The earliest published paper that embraced the concept of earlier weight bearing was Saleh et al. (1992). These authors performed a randomised control trial including 40 patients. All patients were managed conservatively with the control group immobilised for eight weeks in a hard cast followed by controlled mobilisation using heel wedges. The treatment group were treated for three weeks in a hard cast and then began early mobilisation in a below-the-knee orthosis. The orthosis was an ankle-foot orthosis which held the ankle in 15 degrees of plantar flexion but allowed some movement at the metatarsophalangeal joints. The authors measured the range of motion, isometric strength of plantar flexors and tendon length. Patients treated with the orthosis regained mobility significantly more quickly and patient preference was for the orthosis compared to the cast. Dorsiflexion range improved more rapidly after treatment in the orthosis, and patients returned to normal activities earlier. Recovery of strength of the plantar flexors was similar in the two treatment groups, and none of the patient had excessive lengthening of the tendon. This ability to prevent or reduce tendon lengthening post rupture is important. Increased tendon length post rupture has been shown to strongly correlate with reduced muscle performance, total heel raise work, altered biomechanics and patient outcomes (Aufwerber et al., 2020; Peng et al., 2017; Silbernagel et al., 2012). Relatedly, Heikkinen et al. (2017) showed that a shorter Achilles tendon correlated with greater strength, as measured by isokinetic testing, and less medial gastrocnemius and soleus atrophy.

Costa and colleagues (Costa et al., 2006) were the first to investigate the effects of immediate weight bearing in a conservatively managed Achilles tendon rupture sample. They conducted a randomised control trial which included 48 participants. A control group was placed in a below-the-knee gravity equinus cast for eight weeks. The cast was changed every two weeks and the equinus position was altered until the foot was in a plantigrade position at eight weeks. They were non-weight bearing for this time and then advised to begin weight bearing from week eight. The treatment group was placed in an over-the-counter hinge orthosis together with three heel raises to help achieve the equinus position. This orthosis allowed limited movement of the ankle to aid gait and participants were instructed to fully weight-bear. The equinus position was adjusted every two weeks like the control group and the boot was removed at eight weeks. The main outcome measures were related to return to normal sporting activity, walking, stair climbing and work activity. These were measured in weeks to return to these activities. Participants also completed a EuroQol health status questionnaire. Strength was assessed using isokinetic dynamometer testing of plantar flexion strength. At 12 months, their results showed no difference in isokinetic assessment of plantar flexor strength between groups. They did not comment on between limb differences. Patient-reported functional outcomes were all comparable between groups. The mean scores for the EuroQol health status questionnaire in the immediate weight bearing group were 85, with 100 being the normal level. Notably, up to 50 percent of patients in both groups did not return to sport by 12 months. Overall Costa et al. (2006) study demonstrated that immediate weight bearing had no detrimental effects on Achilles tendon recovery, however, they did not report on across limb deficits and did not perform any hop or endurance-based outcome measures. Self-perceived outcomes measures showed an 85 percent return to normal function at 12 months. The authors also showed the severity of this injury and the ongoing limitation it causes regarding return to sporting activities.

Metz et al. (2008) performed a randomised control trial with 83 participants and compared surgical versus non-surgical approaches with early weight bearing in both groups. The non-surgical group was placed in an equinus cast for one week and was non-weight bearing. They were then placed in a VACOped functional bracing orthosis. Full weight bearing was allowed as tolerated at this stage. The brace was fixed at 30 degrees plantar flexion for the first two weeks, 15 degrees for an additional two weeks, and then in a dynamic status of 0-30 degrees plantar flexion for the final two weeks. Metz and colleagues collected information on time to return to work, return to sport, patient satisfaction, and pain as well as range of motion of the ankle and isokinetic muscle strength of the plantar flexors. Their findings showed no statistical difference between the surgical and non-surgical groups on all outcome measures at 12 months. The authors reported that 81 percent of participants had returned to sport in the non-surgical group by 12 months. This return to sport rate is more favourable than Costa et al. (2006) study but still demonstrates that a large proportion of participants had not returned to sport. Again, these researchers did not include any performance based functional outcomes assessing variables such as plantar flexor muscle endurance and power.

Willits et al. (2010) conducted a randomised control trial assessing surgical versus nonsurgical approaches coupled with early, accelerated functional rehabilitation. The non-surgical group was placed in a functional bracing orthosis after the initial two weeks of a hard cast with the ankle in an equinus position. They were instructed to fully weight bear in the orthosis and began early rehabilitation at two weeks. These authors assessed the isokinetic strength of plantar flexors, ankle range of motion, and calf circumference. Outcomes at 12 months showed no statistically significant difference between groups across all parameters. At 12 months, participants in the non-surgical group exhibited an across limb deficit of 20 percent in plantar flexor strength. Across limb differences in calf circumference were 1.3 cm in the non-surgical group while range of motion was reduced in plantar flexion and dorsiflexion on the affected side. Once again, no endurance or hopping based outcomes were collected.

Barfod et al. (2014) conducted a randomised control trial assessing immediate weight bearing post Achilles tendon rupture. Their study included 60 participants randomly assigned to the control or treatment groups. Both groups were placed in an ankle orthosis with the ankle fixed in equinus using heel wedges. In the experimental group, weight bearing started day one and every two weeks over eight weeks the ankle was gradually brought to neutral by removing wedges. The control group was non-weight bearing for the first six weeks. At eight weeks both groups also went through a standardised rehabilitation programme with supervised physiotherapists from week nine to week 16. The authors utilised the Achilles tendon rupture score (ATRS) to assess perceived function. Heel raise height and total heel raise work (Silbernagel et al., 2010) were used to assess calf performance. Barford and colleagues (2014) showed no significant difference between groups in ATRS scores at 12 months. The immediate weight bearing group had a mean score of 73/100 on the ATRS indicative of some dissatisfaction with their perceived function. Of note, in a healthy non-injured population, means scores are 98/100 for this questionnaire (Nilsson-Helander et al., 2007). Across both groups, only 18 percent of patients had returned to pre-injury level sporting activity. The limb symmetry index (LSI) for the total heel raise work showed an average of 55 percent deficit at 12 months. Although it was aimed to be a superiority study in favour of immediate weight bearing, Barfod et al. (2014) concluded that there were no detrimental effects associated with this protocol.

Korkmaz et al. (2015) conducted a randomised control trial assessing early weight bearing in non-surgically managed Achilles tendon rupture patients. Both groups were placed in a below-the-knee cast with the ankle in approximately 20–40 degrees of plantar flexion for four weeks. The control group remained non-weight bearing for four weeks. The intervention group were permitted to walk with the assistance of a crutch and to partially weight bear on the affected limb. After the initial four weeks, all participants had the cast removed, and a moon boot with heel raises to maintain an equinus position was applied for 15 days. The authors utilised the ATRS to assess perceived function which at 12 months post injury showed no significant difference across groups. In both groups a score of 86 was reported for the ATRS. The authors did not assess any performance based functional outcomes of the plantar flexor muscles.

A study by Lantto et al. (2016) reported upon surgical versus non-surgical approaches and used a similar post injury protocol to Metz et al. (2007), whereby the non-surgical group were placed in plaster cast in an equinus position and then transitioned to a below the knee orthosis. The main difference was that the non-surgical group only spent one week in plaster cast compared to two weeks in Metz et al. (2007) study. The authors assessed strength using isokinetic testing and assessed perceived function with the RAND 36-Item Health Survey at 18 months. They assessed across group differences and between limb differences. Findings showed an across limb deficit of 25 percent in plantar flexor peak torque in the non-surgical group. The authors showed across group differences in favour of surgery in the RAND-36 in the domains of physical functioning, and bodily pain. Notably, the surgical group scored 97/100 and 87/100 in physical functioning, and bodily pain, respectively. In the non-surgical group, the scores were 88/100 and 74/100 respectively. Both groups scored poorly in general health, mental health, and vitality. Again, the authors demonstrated the ongoing deficit in perceived function and added new information concerning decreased emotional wellbeing post Achilles tendon rupture. No functional outcomes assessing plantar muscle performance were included.

Kastoft et al. (2019) performed a randomised control trial, assessing immediate weight bearing in conservatively managed Achilles tendon rupture patients. The control group and intervention group were treated similarly except for weight bearing status. Both groups were placed in fixed orthoses. The equinus position was adjusted every two weeks and at eight weeks the boot was removed. The control group was instructed to non-weight bear for the first six weeks, while the intervention group was instructed to weight bear immediately. The primary outcomes collected were the ATRS, total heel raise work and heel raise height. Return to work and sport was also assessed. The authors did not assess return to sport-based outcome measures. At 12 months, the findings showed no difference between groups on the ATRS, with the mean score being 74/100. Like Barfod et al. (2014), Kastoft et al. (2019) reported a between limb deficit in total heel raise work of 40 percent. No between group differences were seen for total heel raise work. Concerning heel raise height, the authors reported no between group difference but both groups had a between limb deficit of 30 percent. Such findings suggest that notable muscle performance and functional deficits remain up to 12 months post injury. Return to sport rates did not differ between groups. The authors reported that 96 percent of participants returned to some sport by 12 months, however only 13 percent had returned to pre-injury level.

Most recently, Costa et al. (2020) performed a large multicentred study assessing immediate weight bearing. They recruited 540 participants, the largest sample undertaken on this topic. The intervention groups were placed in fixed orthoses with heel wedges and instructed to weight bear immediately. The equinus position was adjusted every two weeks until the boot was removed at eight weeks. The control group was placed in an equinus cast for eight weeks. The equinus position was adjusted every two weeks and the control group were instructed to begin weight bearing at six weeks. The main outcome measure was the ATRS and a health-related quality of life questionnaire (EQ-5D-5L) together with re-rupture rate. This study did not include any performance based functional testing. At nine months the ATRS and the quality-of-life questionnaire did not differ between groups. The mean score of the ATRS was 73/100. Notably, at eight weeks post injury, findings showed a significant difference in favour of immediate weight bearing in the ATRS. The authors concluded that there was additional benefit in perceived function early post injury and that from a cost perspective there was a small advantage in utilising the functional brace rather than plaster.

Concerning self-perceived function, it is apparent that ongoing limitations persist long after an Achilles tendon rupture. At nine months after an Achilles tendon rupture, mean values on the ATRS are recorded as 73 (Costa et al., 2020) and at 12 months mean values are recorded at 73-80 (Barfod et al., 2014; Kastoft et al., 2019; Korkmaz et al., 2015). These results show that at the time points when most athletes are returning to sport, their perceived function is still significantly limited. More general well-being questionnaires such as the RAND-36 indicate ongoing issues in physical functioning, bodily pain, general health, mental health, and vitality. In a large multicentre study, Costa et al. (2020) highlighted economic factors showing a small advantage to utilising an immediate weight bearing functional brace. They also showed improved perceived function early post injury in favour of an immediate weight bearing orthosis. Psychological function as measured by psychological readiness and confidence questionnaires is lacking within Achilles tendon rupture research.

In summary, regarding performance based functional outcomes, there is limited data to assess plantar flexor performance following immediate weight bearing post Achilles tendon rupture. Of the outcomes that have been measured, no significant difference was seen between immediate weight bearing groups and delayed weight bearing groups. However, irrespective of loading, significant deficits in plantar flexor endurance (as measured by the heel raise work test) and strength remain up to 12 months post Achilles tendon rupture. Kastoft et al. (2019) and Barfod et al. (2014) reported a deficit in total calf raise work of 40 percent and 55 percent respectively at 12 months post injury. Willits et al. (2010) showed a deficit of 20 percent in plantar flexor strength through isokinetic testing. Immediate weight bearing has no detrimental effects on tendon lengthening, however, irrespective of limb loading protocols, deficits in heel raise height of 30 percent have been shown at 12 months (Kastoft et al., 2019). These functional deficits may result in poor return to sport rates post injury. Costa et al. (2006) showed a 50 percent return to sport rate at 12 months post injury, while Metz et al. (2008) showed an 81 percent return to sport rate. Barfod et al. (2014) reported that only 18 percent of participants had returned to the pre-injury level of sport 12 months post injury. At 12 months post injury, rehabilitation has been completed by patients and they are past the point for expected return to sport (Zellers et al., 2016). It would seem a safe time to do performance based tests without risk of re-rupture. No measurements of power, including hopping tests, have been reported in an immediate weight bearing cohort. These measurements are valuable in assessing return to sport readiness and are widely used in other common lower limb injuries.

2.8 Performance based functional outcomes post Achilles tendon rupture

Achilles tendon rupture rehabilitation typically occurs up to six to nine months post injury (Saxena et al., 2022). During this time, participants will undergo varied levels of rehabilitation (Christensen et al 2020; Zellers et al., 2019) and clear criteria and guidelines for return to play are lacking (Ardern et al., 2016). When assessing Achilles tendon rupture recovery, the significance of performance testing becomes paramount in evaluating the efficacy of rehabilitation and ensuring a successful return to full performance. Utilising a variety of tests to assess range of motion, strength and power offers a comprehensive understanding of a patient's function and readiness to return to sport. In recent years, there has been a broad consensus that utilizing a comprehensive array of outcome measures and tests to inform decision-making is preferable over depending on a single test in isolation (Gokeler et al., 2017; Grindem et al., 2016; Gustavsson et al., 2006; Kyritsis et al., 2016; Thomeé et al., 2011). A varied array of tests not only highlights a patient's progress but also reveals areas that require targeted attention. We will now review the testing methodologies used with Achilles tendon rupture research.

Heel raise height and resting Achilles tendon resting angle are moderately correlated with function (Olsson, Karlsson, et al., 2014; Zellers et al., 2018). There are several described methods of direct and indirect measures of Achilles tendon length within the literature. Direct measures include Radio Stereometric Analysis (RSA) at the time of open repair and radiological imaging such as ultrasound or MRI (Barfod et al., 2015; Schepull et al., 2010). These methods are expensive and time consuming. Indirect measures of tendon length are cheaper, faster, and easier to administer in the restraints of clinical practice. Indirect measures of tendon length were initially assessed using a tape to assess the maximum height of the heel during a heel raise (Silbernagel et al., 2012). This indirectly indicated tendon length. Attempts to accurately measure Achilles tendon length led to the development of the Copenhagen Achilles length measure (Hansen et al., 2020) and Achilles tendon resting angle (Carmont et al., 2013, 2015; Hansen et al., 2017). The Copenhagen Achilles tendon length measure is a measurement from the proximal landmark of the tendon, as defined as the distal point of the medial gastrocnemius muscle-tendon junction, and the distal landmark at the tendon insertion at the calcaneus. This is a reliable way of measuring Achilles tendon length (Hansen et al., 2020). The Achilles resting angle was developed by Carmont et al. (2013). They used a goniometer to measure the resting plantar flexion position of the ankle. This method was shown to be a reliable measuring method and has been used most widely in most recent literature to measure Achilles tendon length (Barfod et al., 2020; Carmont et al., 2015; Powell et al., 2018; Willits et al., 2010; Zellers et al., 2018).

Isokinetic testing of plantar flexor strength has been a common method of measuring concentric and eccentric strength of the calf muscle (Baumfeld et al., 2018; Chester et al., 2003; Lantto et al., 2016; Willits et al., 2010). This is an expensive method and not widely available to use within physiotherapy clinics, especially in New Zealand. Isokinetic testing is also a controlled and somewhat limited assessment of performance. Mullaney et al. (2006) found that Achilles tendon rupture patients who were treated surgically had isometric end range plantarflexion strength deficits of up to 34 percent and were unable to perform a decline heel rise, whereas on isokinetic testing no strength deficits were detected from neutral to 20 degrees dorsiflexion. This again shows the importance of having a selection of performance tests to assess function.

Maximum voluntary contraction (MVC) using a small handheld dynamometer is a much more cost-effective, easy-to-administer method of evaluating muscle strength (Riemann et al., 2010; Thorborg et al., 2010, 2013). Measurements of MVC using a dynamometer are a reliable method for evaluating plantar flexor muscle strength (Mattiussi et al., 2022; Rhodes et al., 2022). This method has not been used in an Achilles tendon rupture cohort to detect muscle strength deficits between limbs.

The ability to measure plantar flexor muscle endurance is a valuable tool to guide rehabilitation. Previous measures of plantar flexor endurance such as heel raise repetitions struggled to detect differences between limbs as they did not consider heel height during the test (Silbernagel et al., 2010). The total heel raise work test has been widely used to measure plantar flexor muscle endurance. This test was first described by Silbernagel et al. (2010) as a novel way to measure endurance. The test included the measure of heel raise height and heel raise repetitions. A calculation of the total distance covered was performed and multiplied by body weight, to give the total amount of work performed in joules. This test was validated and is a reliable way of detecting differences between limbs post-rupture (Silbernagel et al., 2010).

Hop testing is an important measure of power and the ability to produce force (Lombard et al., 2017). A battery of hop tests has become standard practice when assessing return to sport readiness in ACL rehabilitation and has been widely adopted by physiotherapists when assessing lower limb function post injury. It has been shown that hop testing can detect minimal changes in performance between limbs (Kotsifaki et al., 2022) and is the gold standard in return to play testing (Ardern et al., 2016; Thomee et al., 2011; Gustavsson et al., 2006). Kotsifaki et al. (2022) showed vertical hop testing to be the best predictor of difference between limbs when compared to hop for distance, showing the importance of having multiple methods of assessing performance before returning to sport. No research to date has assessed the use of these tests within a conservatively managed Achilles tendon rupture population. Silbernagel et al. (2006) used a test battery including a countermovement jump (CMJ), a drop CMJ, and hopping within an Achilles tendinopathy cohort and showed it to be a reliable and valid measure of performance. Nilsson-Helander et al. (2010) assessed power using hop testing when comparing surgical versus non-surgical management. The non-surgical group were non-weight bearing for 6 weeks. They used a single leg drop counter movement jump that involved landing from a 20 cm box and then jumping as high as possible. They demonstrated a 17 percent deficit between limbs on jump height. These researchers also tested hopping, examining the flight time to contact time ratio over 25 hops. They did not see any asymmetry between limbs on this test. Kiedrowski et al. (2022) used a hop for distance test to assess recovery post surgically managed Achilles tendon rupture. The authors reported that at 12 months post injury, a deficit of 21 percent was seen between limbs. Within the research reviewed regarding immediate weight bearing post Achilles tendon rupture, hop testing has not been used to assess function between the injured and non-injured limbs.

Limb symmetry index (LSI) is a commonly used criteria for guiding return to sport (Thomeé et al., 2011). LSI is a measure of how an affected limb performances in comparison to the unaffected limb and assesses if the performance is normal or abnormal. Recommendations from the European Board of Sports Rehabilitation (EBSR) state that athletes returning to non-pivoting, non-contact, and recreational sports should have an LSI of >90 percent in muscle strength and hop performance, while athletes returning to pivoting, contact sports, and competitive sports should have an LSI of 100 percent in muscle strength and >90 percent for hop performance (Thomeé et al., 2011). Within the research on immediate weight bearing post Achilles tendon rupture, plantar flexor muscle endurance and strength have been assessed individually. No hop tests have been used in the research to assess performance post immediate weight bearing following Achilles tendon rupture. When reviewing wider Achilles tendon rupture research, there is a clear lack of return to sport guidelines following Achilles tendon rupture (Ardern et al., 2016). Consideration of a battery of tests to fully assess performance and help guide return to sport is worthy of further attention, hence the addition of these tests within this study. Relatedly, research conducted in return to sport post Achilles tendon rupture showed poor return to sport rates. Trofa et al. (2017) looked at return to sport rates across basketball, football, hockey, and baseball in America and found that 31 percent of these professional players do not return to play. The players that do return participate in fewer games, spend less time on the field, and exhibit a lower level of performance compared to their pre-injury status. Similar figures continue in the NFL with 32 percent of players not returning to play (Parekh & Shah, 2017), NBA with 39 percent of players never returning to play (Amin et al., 2013) and in soccer with 18 percent of players not returning to competitive levels (Grassi et al., 2020).

2.9 Self-reported outcomes post Achilles tendon rupture

Questionnaires yield vital insights into participants' perception of their own experience such as pain, function, satisfaction, or fear of re-injury. This aids in the development of rehabilitation programmes. These findings can help enhance rehab programmes with forward-thinking approaches. Across Achilles tendon rupture research only four patient-reported outcomes measures have been utilised.

The Achilles tendon rupture score (ATRS) is the most widely used outcome measure in Achilles tendon rupture research. It was developed by Nilsson-Helander et al. (2007) and further validated by Ganestam et al. (2013). Its reliability has been shown to reach appropriate levels (Ganestam et al., 2013). This scale is designed specifically for use in assessing the function of patients following an Achilles tendon rupture. The ATRS is currently the only validated outcome measure specifically for use in Achilles tendon rupture research. This outcome measure has been used across all aspects of Achilles tendon rupture research and is the preferred measure of researchers. The ATRS has 10 items with a score out of 100 recorded. The lower the score, the higher the dysfunction. It includes questions specific to physical activity and symptoms. In health populations mean scores are reported at 96 (Ganestam et al., 2013).

The RAND 36-Item Health Survey (RAND-36) is a health-related quality-of-life measure developed by Ron Hays in 1993 (Hays, 1993; Hays & Morales, 2001). It is a profile measure that yields eight scale scores and two summary scores (physical and mental health). It has been used in Achilles tendon rupture research to assess the effects of early weight bearing post-surgically repaired Achilles tendon rupture (Aufwerber et al., 2020) and surgical versus non-surgical procedures (Lantto et al., 2016). It also lacks quality measures for returning to higher level activities such as sports and the ability to report on higher level performance. As the RAND-36 is made up of eight sub-scales it can make it challenging to conclude if a certain intervention is successful or not. Lantto et al. (2016) showed that early weight bearing post-surgically managed Achilles ruptures were no better at 12 months overall on the RAND-36 when compared to delayed weight bearing. The general health subscale did however favour the early weight bearing group.

The Musculoskeletal Functional Assessment Index (MFAI) is another outcome used to assess physical function (Swiontkowski et al., 1999). The questionnaire consists of a 34-item “dysfunction index”, assessing patient function, and a 12-item “bother index” assessing how much a patient is bothered by functional problems. The validity of the questionnaire has been assessed by Swiontkowski et al. (1999) who showed that its use in a clinical setting provides a valid assessment of the health status of an individual patient. Swiontkowski et al. (1999) also established the questionnaire's reliability. Twaddle and Poon (2007) used this measure to assess surgical versus non-surgical Achilles tendon rupture patients.

The EQ-5D-5L questionnaire is a self-reported outcome measure which evaluates generic quality of life and has been widely used within research. The EQ-5D-5L questionnaire was developed by Herdman et al. (2011). The validity of the questionnaire has been assessed by Herdman et al. (2011) and is a valid measure of quality of life across dimensions that include mobility, self-care, usual activities, pain/discomfort, and anxiety/depression. Costa et al. (2020) used this measure to assess the effects of immediate weight bearing following an Achilles tendon rupture.

Individual psychological status and readiness to return to sport have become more of a focus in recent times to help guide an athlete's back to sport following injury. Psychological readiness to return to sport post Achilles tendon rupture has not been assessed within the literature. Several psychological factors have been shown to correlate with a return to sport, including fear of re-injury, poor confidence, and kinesiophobia (D'Astous et al., 2020; Ardern et al., 2014). Kvist and Silbernagel (2022) reported that at the time point for returning to sport following an Achilles tendon rupture, a limiting factor for participants choosing not to return is fear of re-rupture. High levels of kinesiophobia in patients suffering from Achilles tendinopathy have been shown to affect their ability to perform physical exercise and rehabilitation and were associated with pain catastrophizing (Chimenti et al., 2021). Following surgical management of Achilles tendon rupture, Olsson et al. (2014) showed that at 12 weeks post injury, kinesiophobia had a significant negative correlation between patient-reported outcomes and physical activity level. An important psychological element associated with a successful return to sport is confidence (Hart et al., 2020). This factor has not been previously assessed in an Achilles tendon rupture cohort yet may be important. The Psychological Readiness to Return to Sport (P-PRRS) is a 6-item scale with a maximum score of 60 points, indicative of a high level of confidence in returning to sport. The validity and reliability of this questionnaire have been established by (Glazer, 2009) who tested it across various injuries, sporting levels and at different stages of the rehabilitation programme.

Chapter 3 - Methodology

3.1 Introduction

The principal aim of this research was to investigate the impact of immediate weight bearing post Achilles tendon rupture on physical performance of individuals undergoing non-surgical treatment for Achilles tendon rupture compared to non-weight bearing management, 12-18 months post injury. This study also investigated the difference in tendon elongation between groups. Finally, the difference in self-perceived functional outcomes post Achilles tendon rupture with immediate weight bearing versus conservative non-weight bearing management was investigated.

3.2 Study Design

The first phase of the study was implemented by researchers from the Orthopaedic Department at Wellington Regional Hospital. The trial was a randomised control trial (RCT) with two treatment groups. The study had a sample size of 172 participants. All participants presented to Wellington Hospital Orthopaedic Department with Achilles tendon rupture within 72 hours of injury and were screened for eligibility for the trial. The primary aim of the Hospital researcher's study was to examine self-perceived functional outcomes between the treatment groups at three, nine, and 12 months post Achilles tendon rupture.

For this master's thesis research project, we utilised the above mentioned RCT cohort to obtain participants, but otherwise the thesis research was independently conceived and implemented. The second phase of the study took place at Willis Street Physiotherapy, Wellington. Participants who had been recruited in phase one were contacted at 12 months and asked to participate in performance based testing in the clinic. The testing was carried out by one assessor. The assessor was not blinded to the group in which the participants were allocated. The research methodology and study protocol were reviewed and approved by the Auckland University of Technology Ethics Committee, Capital & Coast DHB ethics committee and Māori Partnership Board, Capital & Coast DHB Research Advisory Group – Māori (RAG-M) (see Appendix A, B, C). All participants read an information sheet (see Appendix D) containing details of the study before consenting to participate. All participants read and signed a consent form (see Appendix F) at the beginning of their testing session.

3.3 Selection of Participants

3.3.1 Participant Recruitment

Recruitment was limited to participants who participated in the above-mentioned phase 1 study at Wellington Hospital. Sample size was based upon the total heel raise work test which is one of the few physical performance tests previously investigated in Achilles tendon rupture cohorts. To detect a 20 percent difference across the immediate weight bearing group and the standard care group, based on means and standard deviations from Silbernagel et al. (2010) and pilot work in our lab, with an alpha level of 0.05 and power set at 80 percent the minimum sample size was 26 (Power and Precision Software, Biostat Corp New Jersey, USA).

The inclusion criteria was:

- Patients who were at 12-18 months post Achilles tendon rupture
- Aged 16 or older
- Had sustained an isolated unilateral, closed injury
- Had been recruited in phase one of the study

The exclusion criteria was:

- Previous ipsilateral injury
- Previous re-rupture of the initial injury or notable injury to this tendon in the preceding 12 months
- Other significant lower limb injuries that might confound tests being undertaken for the current study

3.3.2 VACOped group

The immediate weight bearing group was fitted with a VACOped boot day 0 post injury. This group were instructed and encouraged to begin immediate weight bearing (Costa et al., 2020). The boot was locked at a fixed 30 degrees of plantar flexion for four weeks. Thereafter 15-30 degrees dynamic movement was allowed for two weeks and finally 0-30 degrees dynamic movement for a further two weeks. Zero degrees of plantar flexion is the neutral ankle position. At eight weeks post injury, the VACOped was removed, and the patient commenced physiotherapy.

3.3.3 Standard Care Group

The standard care group were instructed to not bear weight on their injured limb for six weeks. During this time of immobilisation, they wore a fibreglass cast for four weeks and thereafter a moon boot with three heel wedges to maintain an equinus position of the ankle for a further two weeks. The ankle joint was maintained in a 30-degree plantar flexed position. At the six week mark, the patients began to weight bear and one heel raise was removed from the moon boot to position the ankle joint at 15 degrees of plantar flexion. At eight weeks post injury the patients transitioned to normal footwear with a 1.5 cm orthotic heel raise. At that stage they began physiotherapy.

3.4 Procedures

All testing was performed at Willis Street Physiotherapy in Wellington. All participants were tested by the lead researcher. Upon arrival, participants were given consent forms to complete before testing. The testing sessions lasted one hour. During that time, they completed questionnaires, Achilles tendon length was measured, anthropometric data was collected, and the participants completed a series of functional-based performance tests measuring plantar flexor muscle endurance, strength, and hop performance. Further detail concerning the assessment follows.

3.4.1 Self-reported Functional Questionnaires

The Achilles Tendon Rupture Score (ATRS) questionnaire (Appendix G), served as a reliable and validated tool for assessing functional outcomes following Achilles tendon injury (Nilsson-Helander et al., 2007). Participants rated their responses based on a scale that encompassed different aspects of daily activities and sports-related functions affected by the injury. Scores obtained assisted in gauging the extent of functional recovery and the impact of the injury on an individual's ability to perform various activities. Higher scores on the ATRS indicate better functional outcomes and enhanced capabilities in activities and sports-related function with a maximum score of 100.

The I-PRRS (Injury-Psychological Readiness to Return to Sport) (Appendix H), validated by Glazer (2009), served as a reliable and valid assessment tool for gauging an individual's psychological preparedness to resume sporting activities post injury. This scale comprises six items designed to measure a participant's confidence level regarding their return to full sports engagement. Each item on the scale is rated on a scale from 0 to 100, representing varying levels of confidence: 0 denoting no confidence, 50 indicating moderate confidence, and 100 signifying complete confidence. The total score, obtained by summing the scores of all six items and dividing by 10, provides the overall confidence level. For instance, a total score of 60 denotes complete confidence, 40 indicates moderate confidence, and 20 implies poor confidence in returning to full sports participation.

Participants were interviewed on the structure of their rehabilitation programme. Previous work concerning knee, shoulder and Achilles tendon injuries in our lab has highlighted a lack of good retention in participant's memory concerning details of rehabilitation. Thus, the aim was to gain an informal evaluation of the quality of rehabilitation without any intention of notable statistical analyses. Hence, questions were answered 'yes' or 'no' based on the participants' inclusion of a certain form of exercise as part of their rehabilitation programme. Participants were asked about the inclusion of range of motion exercises, body weight and resistance strength exercises, balance exercises, plyometric exercises, and sports-specific exercises. Participants were also asked about their overall satisfaction with their rehabilitation programme.

3.4.2 Achilles tendon length assessment

Patients' Achilles tendon length or Achilles resting angle was measured using a digital inclinometer. The subjects were placed prone, and the knee flexed to 90 degrees. The participants were instructed to remain relaxed. A digital inclinometer was then placed on the sole of the participant's foot, in line with the 5th metatarsal bone and a reading of ankle plantarflexion was taken. The measurement of the inside angle off the horizontal level was taken. The validity and reliability of the test have been established previously (Carmont et al., 2013).

3.4.3 Total heel raise work test

The participants completed a heel raise work test as described by Silbernagel et al. (2010), who established its reliability and validity. After a 5-minute warm-up on a stationary bike, participants stood on a 10-degree decline step. A linear transducer was then attached to the shoe heel area with tape (see Figure 3.1) and measurements of linear movement as the participant undertook repeated heel raises were recorded on a computer-based data collection system. Specifically, analogue data from the transducer, was transmitted to an analogue to digital board (InstruNet, GW Instruments, Boston, USA) at 1000 Hz**.** A custom-built software routine was created in DasyLab software (Data Acquisition System Laboratory, Company: National Instruments, Ireland Resources Limited). This programme allowed assessment of the data collected, saved data, and provided measures of heel raise height, repetitions and total heel raise work, presented in graphical and table formats. The participants were asked to complete as many heel raises as possible to the beat of a metronome set at 60 beats per minute with each limb, with each beat indicating movement up or down.

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Figure 3.1 The participants set up during the total heel raise work test

3.4.4 Maximum voluntary contraction of plantar flexors

The MVC of the plantar flexion muscles of both limbs was measured using a handheld dynamometer, model Dynamo (VALD Performance equipment, 75 Sandgate Rd Albion, 4010 Australia). This method of assessing muscle strength has been validated previously (Thorborg et al., 2013). In long sitting, the knee was locked in 0 degrees extension using a knee brace and the participant was seated with their back against a wall. A strap was anchored to a fixed point behind the participant and extended to a foot strap which was attached to the foot. The reference point for the position of the strap was the 1st metatarsal head. The handheld dynamometer was placed inline in this system (see Figure 3.2). The participant was then asked to complete five sub-maximal warm-up trials to familiarise themselves with the test and then asked to perform three maximum effort trials, with one minute rest in between trials. The highest reading was used for data analysis. The test was performed at a neutral ankle joint position.

Figure 3.2 Participants set up for the MVC test of the plantar flexors

3.4.5 Hop Performance

Participants were also asked to complete a counter-movement single leg hop for height and distance test and a repeated lateral hop test. Such hop tests have been extensively used in the literature to assess single leg power (Gustavsson et al., 2006; Kyritsis et al., 2016; Thomeé et al., 2011). Gustavsson et al. (2006) showed that 75% to 100% of healthy subjects had normal asymmetry of less than 10% in the above-mentioned hop tests**.** The participant was asked to perform five sub-maximal hops as a warm-up and then completed three maximal effort hops, with 30-second rest periods between trials for the vertical and horizontal hop tests.

Single leg hop for distance: The single hop for distance is a valid and reliable test for measuring function and is widely used as a criterion for return to sport in an ACL-reconstructed population (Gustavsson et al., 2006). It has an ICC of 0.92 (lower 95% confidence interval (CI) of 0.87). It has also shown reliability in a healthy population with an ICC of 0.98 (Augustsson et al., 2006). Participants were instructed to position themselves behind a marked starting line, standing on their non-injured leg with the great toe just positioned behind this line. They were instructed to keep their hands on their hips during the movement. The task involved a single leg hop, whereby participants were instructed to hop forward as far as possible while landing solely on the same leg used for take-off. For a hop to be considered successful, several criteria were followed: no secondary hop following the initial landing; avoidance of any contact with the floor using the opposite leg or upper limbs; and maintaining balance for a minimum of two seconds upon landing. Measurement of the distance hopped was conducted from the starting point to the point where the heel landed upon completion of the hop. Upon finishing all hops on the uninjured limb, the same protocol was repeated on the injured limb.

Single leg hop for height: The vertical hop is reliable in a healthy population with an ICC of 0.89 (95% CI: 0.79–0.95) (Gustavsson et al., 2006). The vertical hop performance was recorded using the VALD ForceDeck dual force plate system (VALD Performance equipment, 75 Sandgate Rd Albion, 4010 Australia). Signals from the plate were recorded at 1000 Hz, and Vald software was used to determine jump height. Participants were asked to stand on the force plate initially to allow for the system to record to their weight. They were then instructed to stand on one leg, with their hands on their hips, jump as high as possible off the plate and land again on the same leg. The following criteria were implemented to record a successful jump; no secondary jumps after the initial jump, no contact with the floor of either the opposite leg or upper limb; balance was maintained for two seconds after landing, and the participant's entire foot landed within the boundaries of the plate. Once completed on the uninjured limb, the same protocol was repeated on the injured limb.

Lateral continuous hop test: The lateral hopping test is reliable in a healthy population with an ICC of 0.87 (95% CI: 0.75–0.94) (Gustavsson et al., 2006). Participants were asked to stand on their uninjured limb. Participants were instructed to hop back and forth sideways repetitively for 30 seconds without touching lines 40 cm apart on the floor. When participants landed short of the line that repetition was not counted. The number of successful repetitions completed was recorded. Before the recorded test, participants were permitted to perform a practice trial of 10 repetitions, until they were satisfied that they had mastered the technique. A break of 60 seconds was given between the practice test and the recorded test. Once completed on the uninjured limb, the side hop test was repeated on the injured limb.

3.5 Data analysis and statistical procedures

The IBM Statistical Package for Social Sciences (SPSS) software program version 29.0 was used for data analysis. Data was checked for errors and outliers using descriptive analyses, box plots and Grubb’s test. Normality of data distributions was checked using combination of Shapiro-Wilks test, kurtosis and skewness values, histogram plots and normal Q-Q plot.

For comparisons across groups for demographic variables and the perceived function questionnaires, an independent sample T-test was utilised. For performance variables in which involved and uninvolved legs were analysed, linear mixed-effect models using maximum likelihood calculations were generated with the fixed factors being group (Standard care & VACOped), legs (involved & uninvolved) and the interaction effect between these factors. Utilising the Pearson Product Moment procedure, coefficients between demographic variables (months since injury, age, height, weight) and the dependant variables (hanging angle, work test, MVC, hop for distance, hop for height and lateral hops) were calculated to establish whether covariates would be included in the Linear mixed-effect models. A random intercept was utilised in all final models with observations clustered within each participant. In the linear mixed-effects analyses, the "goodness of fit" was established by the Conditional Pseudo-R Square (Nakagawa et al., 2013). This value was complemented by the adjusted intraclass correlation coefficient (ICC) which measures variance associated with individuals or sites as a proportion of the total variance (Nakagawa et al., 2010, Johnson et al., 2014). Model improvement was also assessed from differences in 2 Log likelihood and Schwarz's Bayesian Criterion (BIC) obtained from the base model and the subsequent model with a covariate present (Twisk et al., 2013). Additionally, when covariates were included, their significance ($p<0.05$) was also noted in Type III tests of fixed effects and in Estimates of Fixed Effects tables. In all final models, graphs were used to assess the linearity, normality, and homogeneity of the residuals (Cheng et al., 2009).

In respect of multiple statistical tests and the chance of a Type I error, as indicated in Chapter 1, our a priori hypotheses required the assessment across the factors: legs, groups and the interaction across legs and groups. Cramer et al. (2016) highlight that a 2x2 factor ANOVA includes three tests. In total, six linear models were conducted and hence 18 statistical tests (factors: group, legs and the interaction effect in each model) were undertaken. Ottenbacher (1991) provides an equation allowing the calculation of the actual percent Type I error rate after statistical analyses have been undertaken. It requires the number of statistically significant results together with the total number of tests undertaken. Specifically, the equation is: (100* alpha level * number of tests)/(number of significant results (ie: $p<0.05$)). In the current study the number of significant results was six, therefore the percent error rate was 15%, indicating that 15% of the significant results were likely by chance alone.

Chapter 4 - Results

4.1 Introduction

This chapter is divided into four main sections. Section 4.2 details the demographic of the participants. Section 4.3 relates to the first research question and provides the results of the performance based tests between groups and across uninvolved and involved limbs. Section 4.4 addresses the second research question regarding tendon elongation between groups and across limbs. Finally, section 4.5 relates to the third research question showing the results in self-perceived functional outcomes between groups.

4.2 Participant Details

Potential participants (N=127) were contacted on two occasions by phone and the current study was presented to them. From this contact, the total number of participants recruited was 34. Of these, 20 participants were recruited in the VACOped group, and 14 participants were recruited in the standard care group. The reasons for participants not participating were: not interested (64), could not come into the testing venue (8), could not be contacted (21). All participants had sustained an Achilles tendon rupture between 12-18 months before testing and had received their acute treatment and subsequent rehabilitation within a larger randomised controlled trial undertaken by the Orthopaedic Dept at Wellington Hospital.

Details concerning the participant demographics are shown in Table 4.1. In summary, the VACOped group had 12 males and eight females. The standard care group had 10 males and four females. The VACOped group had a mean age of 38 years with a mean weight and height of 92 kg and 174 cm, respectively. The group's mean time since rupture was 15 months. The standard care group had a mean age of 37 years. In this group mean weight and height were 90 kg and 174 cm, respectively. The group's mean time since rupture was 15 months. There were no significant differences ($p > 0.05$) between the VACOped group and the standard care group in age, height, weight, and time since rupture. All participants were involved in recreational or low-level competitive sport, the latter involving formal practices and a game each week in the local area/competition.

All participants' rehabilitation was led by a physiotherapist, who interacted with them on a weekly to monthly schedule. In between these sessions, patients were assigned exercises that were undertaken in a gym type environment often by themselves. A varied number of physiotherapists were responsible for the participants, so specific exercises were not the same across the groups. Range of motion exercises were performed by 73 percent of the participants as part of their rehabilitation. Proprioceptive training was carried out by 63 percent of the participants. Regarding strength training, 80 percent of participants had performed bodyweight exercises as part of their rehabilitation but only 50 percent had performed resisted exercises during rehabilitation. In the later stages of rehabilitation, 60 percent of participants had performed plyometric training. Regarding return to sport-specific training, this was performed by 30 percent of participants. Regarding their overall physiotherapy rehabilitation programme, 36 percent of the participants were very satisfied, and 26 percent were quite satisfied with their rehabilitation. The remaining 38 percent were neutral (i.e. neither satisfied nor not satisfied). The main activities that the participants returned to post injury were football, netball, basketball, squash, tennis and running. When asked about the level of sport they were currently playing, 37 percent reported they were playing at a reduced level. The remaining 63 percent were playing at the same level as before the injury. Across VACOped and standard care groups, qualitative examination indicated that there were no distinct differences in the rehabilitation program duration and its content.

Table 4.1 Demographic of the participants as mean (SD)

	Sex (female/male ratio)	Age (years)	Weight (Kg)	Height (cm)	Months post injury (months)
VACOped Group (n=20)	8/12	38 (12)	92 (16)	174 (8)	15 (1)
Standard Care Group (n=14)	4/10	37 (14)	90 (14)	174 (7)	15 (1)

4.3 Endurance, strength, and hop performance outcomes

Correlations between demographic variables (age, height, and mass) were assessed for potential relationships with these variables. Findings showed height as a significant covariant with the MVC and the three hop tests (r= 0.44-0.67), and thus were adjusted for within the mixed method analysis as a fixed effect. Data entry for one participant for the hop for distance, lateral continuous hop and resting angle was lost due to assessor error.

4.3.1 Total heel raise work

Concerning the total heel raise work test, there was a significant difference ($p < 0.05$) across limbs, but no significant group or interaction effect ($p > 0.05$). The mean (SD) for the involved limb was 2385 (251) J and for the uninvolved limb was 3598 (300) J**.** Regarding limbs, the overall deficit across both groups was 33 percent. See Figure 4.1.

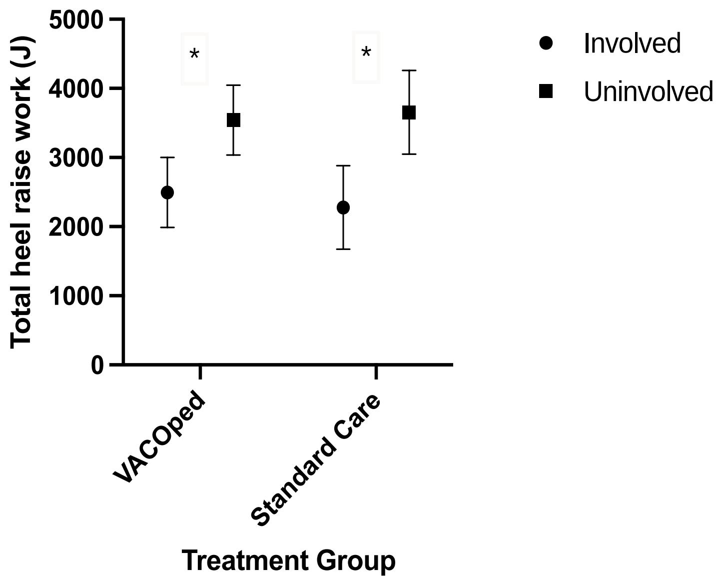

Figure 4.1 Total heel raise work (J) of the involved and uninvolved limbs between groups. Data are means and 95% confidence intervals. * = significant limb effect only ($p < 0.05$)

4.3.2 Maximum Voluntary Contraction

For the MVC of the plantar flexors, there was a significant difference ($p < 0.05$) across limbs, but no significant group or interaction effect ($p > 0.05$). The mean (SD) for the involved limb was 39 (3) kg and for the uninvolved limb was 48 (4) kg**.** The overall deficit between limbs in both groups was 18 percent. See Figure 4.2.

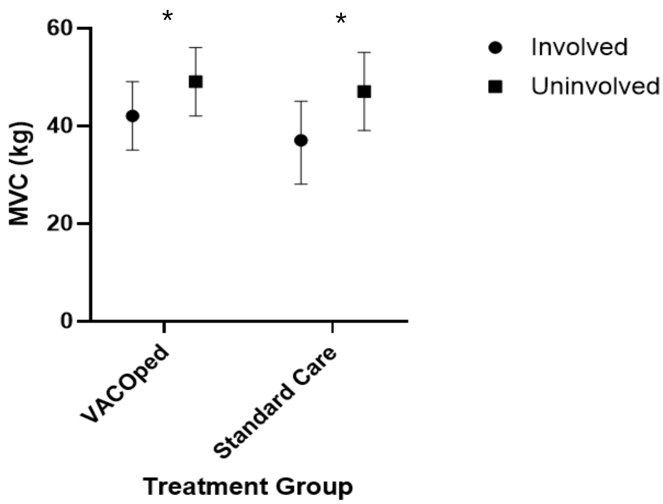

Figure 4.2 MVC (kg) of the involved and uninvolved limbs between groups. Data are means and 95% confidence intervals. * = significant limb effect only (p <0.05)

4.3.3 Single Leg Hop for Distance

There was a significant difference (p <0.05) across limbs, but no significant group or interaction effect (p >0.05) for the single leg hop for distance test. The mean (SD) for the involved limb was 108 (6) cm and for the uninvolved limb was 123 (7) cm. The overall deficit between limbs in both groups was 12 percent. See Figure 4.3.

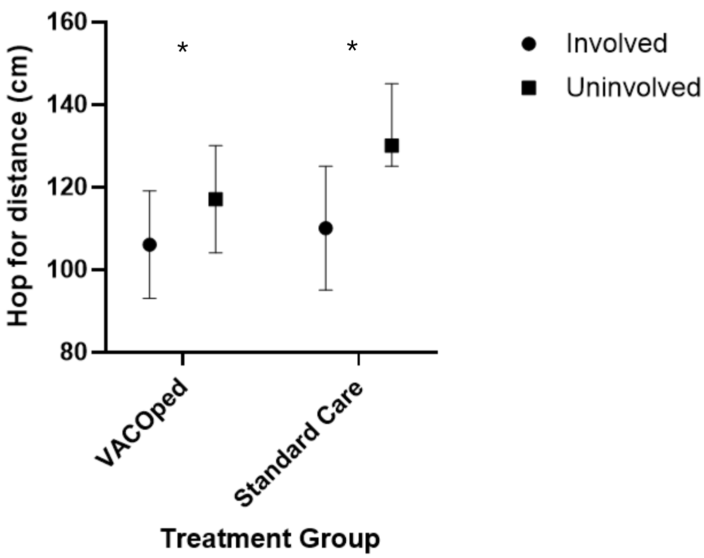

Figure 4.3 Single leg hop for distance (cm) of the involved and uninvolved limbs between groups. Data are means and 95% confidence intervals. * = significant limb effect only (p <0.05)

4.3.4 Single Leg Hop for Height

For the single leg hop for height test, there was a significant difference ($p < 0.05$) across limbs, but no significant group or interaction effect ($p > 0.05$). The mean (SD) for the involved limb was 11.5 (1) cm and for the uninvolved limb was 14.5 (1) cm**.** The overall deficit between limbs was 19 percent. See Figure 4.4.

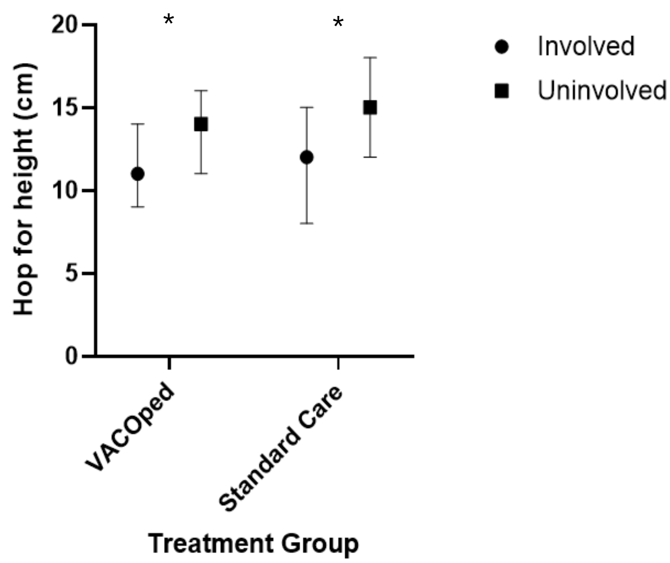

Figure 4.4 Single leg hop for height (cm) of the involved and uninvolved limbs between groups. Data are means and 95% confidence intervals. * = significant limb effect only ($p < 0.05$)

4.3.5 Continuous Lateral Hop

No significant difference across limbs ($p > 0.05$) and no significant group or interaction effect ($p > 0.05$) was observed for the continuous lateral hop test. The mean (SD) for the involved limb was 26 (3) reps and for the uninvolved limb was 28 (3) reps**.** The overall deficit between limbs in both groups was eight percent. See Figure 4.5.

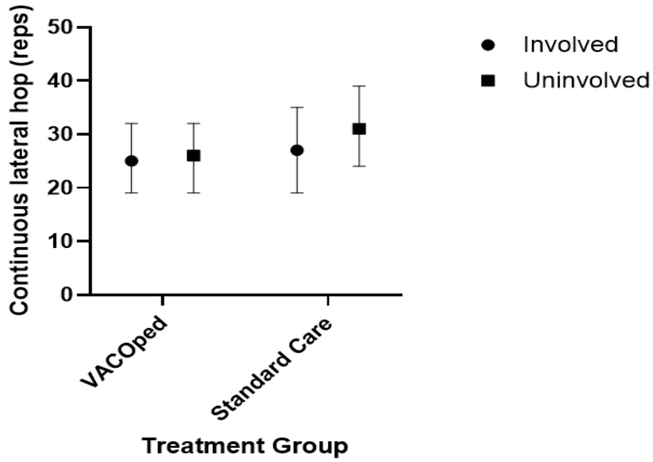

Figure 4.5 Continuous Lateral hop (reps) of the involved and uninvolved limbs between groups. Data are means and 95% confidence intervals.

4.3.6 Limb Symmetry Index

The limb symmetry index (LSI) of performance based tests is widely used in return to sport criteria, hence the mean LSI of all the main performance outcomes are shown in Figure 4.6. In accordance with the EBSR recommendations (Thomeé et al., 2011), individually none of the participants passed the return to sport criteria set by this organisation. The mean LSI across limbs for the total heel raise work test was 68 percent. The mean LSI across limbs for the MVC test was 82 percent. The mean LSI across limbs for the hop for distance test was 87 percent. The mean LSI across limbs for the hop for height test was 81 percent. The mean LSI across limbs for the lateral continuous hop test was 91 percent.

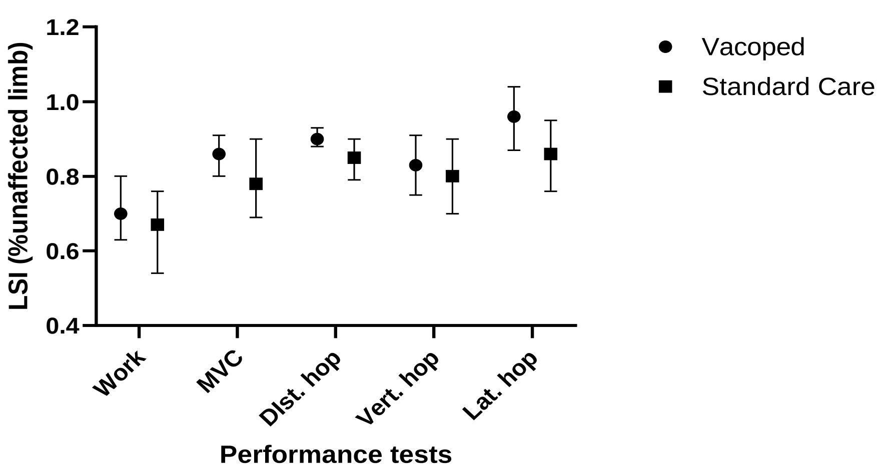

Figure 4.6 Limb symmetry index (LSI) as a percentage of the unaffected limb, between groups. Data are means and 95% confidence intervals.

4.4 Achilles Tendon Length Test

In relation to the Achilles tendon length test, there was a significant difference ($p < 0.05$) across limbs, but no significant group or interaction effect ($p > 0.05$). An increase of 32 percent in the resting ankle joint angle was observed between limbs in both groups. See Figure 4.7.

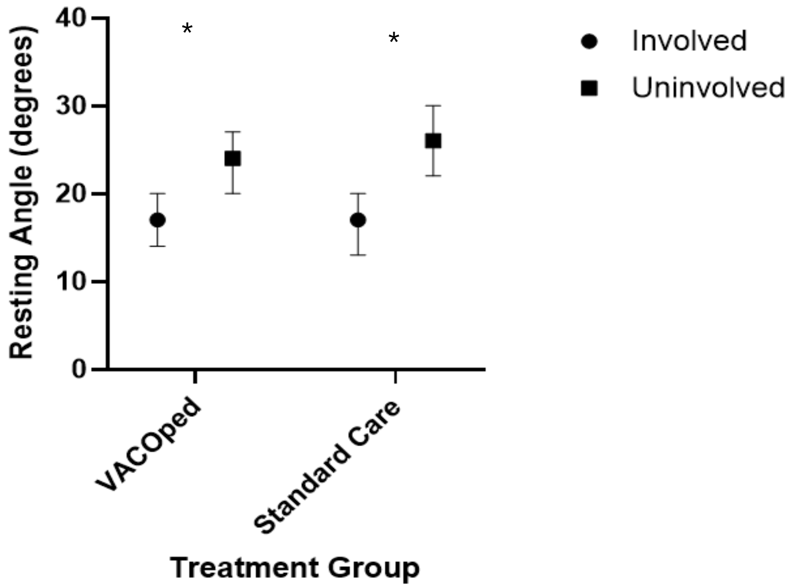

Figure 4.7 Achilles resting angle (degrees) of the involved and uninvolved limbs between groups. Data are means and 95% confidence intervals. * = significant limb effect only ($p < 0.05$)

4.5 Self-perceived functional outcomes

4.5.1 Achilles tendon rupture score

The ATRS has a maximum score of 100, with that figure indicative of high-level function. The mean score in the VACOped group was 80 while in the standard care group it was 72. However, there were no significant difference ($p > 0.05$) across groups. See Table 4.2.

4.5.2 Injury-psychological readiness to return to sport

The I-PRRS has a maximum score of 60, with that figure indicative of high confidence levels. The mean score in the VACOped group was 46 compared to 38 in the standard care group. A notable trend was observed with the p-value equal to 0.08. See Table 4.2.

Table 4.2 Raw data for perceived function outcomes

	VACOped Group		Standard Care Group		p-value
	n	Mean (SD)	n	Mean (SD)	
ATRS	20	80 (18)	14	72 (25)	p =0.273
I-PRRS	20	46 (15)	14	38 (15)	p = 0.08

ATRS: Achilles Tendon Rupture Score; I-PRRS: Injury Psychological Readiness to Return to Sport

Chapter 5: Discussion

5.1 Introduction

Research relating to immediate weight bearing post conservatively managed Achilles tendon rupture has shown that there is no difference in self-perceived outcomes of participants at 12 months post injury (Barfod et al., 2014; Kastoft et al., 2019; Korkmaz et al., 2015). However, it is apparent that there is notably less research concerning performance variables related to endurance, strength, and hop performance between affected and unaffected limbs at this time point. A key finding was that immediate weight bearing compared to standard care non-weight bearing in the early stages of rehabilitation did not lead to differences in performance based outcomes at 12-18 months post injury. However, our findings demonstrated that there is still a significant deficit in performance based outcomes across limbs, and that perceived function was also not as high as one would hope for at this time point. These findings are discussed in more detail below.

5.2 Analysis of the Participants

The mean age in the VACOped group was 38 years and in the standard care group was 37 years. This matches the same age range (37-42 years) for all previous studies conducted on immediate weight bearing post Achilles tendon rupture (Barfod et al., 2014; Costa et al., 2006, 2020; Kastoft et al., 2019; Saleh et al., 1992). Wider research regarding Achilles tendon rupture suggests that the mean age of injury is 35-45 years (Lantto et al., 2015). The mean height and weight of the VACOped group and the standard care group were similar to previous research in this area (Barfod et al., 2014). The mean time since rupture for both the VACOped and standard care group was 15 months. Previous research in the area had a mean time since injury of 12 months (Barfod et al., 2014; Costa et al., 2006; Kastoft et al., 2019).

At present, there is uncertainty concerning the most effective treatment in the early stages of rehabilitation post Achilles tendon rupture (Zellers et al., 2019). Hence it is not surprising that there is an absence of Achilles tendon rupture rehabilitation guidelines within the literature. Across randomised control trials examining Achilles tendon rupture rehabilitation, there is often insufficient detail regarding the rehabilitation programmes there were implemented. Therefore, physiotherapists confidence in rehabilitating this injury will be affected due to this lack of information. Concerning our participants, while all were initially treated within a hospital environment, there was no standardised rehabilitation programme provided. Multiple physiotherapists from difference private practices were involved in their rehabilitation, and hence rehabilitation programmes varied widely. Unfortunately, it was apparent that fundamental components typical of rehabilitation programmes for other injuries were often not undertaken. For instance, less than 60 percent of participants had resistance-based strength training as part of their rehabilitation, and less than 50 percent of the participants had plyometrics included in their rehabilitation. Researchers (Olsson et al., 2011) have also highlighted the importance of remedying strength deficits and thereafter progressing to plyometrics to further enhance the likelihood of a return to full function. Relatedly, some authors (Chimenti et al., 2021; Kvist and Silbernagel., 2022) have suggested that the fear of re-injury can be a barrier for patients during their rehabilitation. It may limit patients' ability to work muscles at higher intensities to get strength changes. It may also be that this fear of re-injury also affected physiotherapists and they were more cautious in prescribing high intensity exercises that create notable stress in the Achiiles tendon. Thus, the observed lack of strength and plyometric training may well have contributed to deficits across limbs observed in the performance based tests. Therefore, it seems likely that there is a need for improved education of physiotherapists treating this injury.

5.3 Analysis of endurance, strength, and hop performance

5.3.1 Total heel raise work test

In this test the overall deficit across legs was 33 percent (VACOped group 30 percent and standard care group 37 percent). Previous research assessing immediate weight bearing has shown deficits in total heel raise work as high as 55-60 percent at 12 months (Barfod et al., 2014; Kastoft et al., 2019). Although the mean time since injury in the current study was 15 months, it seems unlikely that this time difference is responsible, particularly as the length of formal rehabilitation undertaken by physiotherapists for this injury is generally between six and nine months following injury (Saxena et al., 2022). It seems more likely these large deficits reflect a lack of rehabilitation exercises that are focused on endurance as well as the lack of functional testing throughout the phases of rehabilitation which would help identify these deficits (Silbernagel et al., 2010). This is surprising given the fact that so many activities demand repeated moderate to high levels of ankle joint plantar flexor muscle endurance and that researchers (Silbernagel et al., 2010) have highlighted ongoing deficits post injury 15 years ago. Concerning other lower limb injuries (e.g. ACL injuries), compared to strengthening exercises, there are very few papers that have highlighted the importance of muscle endurance exercises as an important component of a rehabilitation programme. Interestingly, large deficits in total heel raise work can be observed post non-surgically managed Achilles tendon rupture up to seven years after injury with Brorsson et al. (2018) reporting a mean deficit of 26 percent at this time point.

5.3.2 Maximum Voluntary Contraction

Regarding the MVC test, the overall deficits across limbs was 18 percent (VACOped group 14 percent and the standard care group 22 percent). Other research (Saleh et al., 1992; Willits et al., 2010) looking at immediate weight bearing have noted deficits in plantar flexor strength between 15 and 30 percent at the 12-month time point. Such deficits were surprising given that strength training should be a standard part of any rehabilitation regime where there has been notable immobilisation and subsequent muscle atrophy (Peng et al., 2017; de Boer et al., 2008). As mentioned above, fear of re-rupture may have led to patients not being willing to work at levels needed for strength deficits to be remedied. Given the significant amount of atrophy that occurs early post injury, together with the state of healing at the tendon rupture site, the inability to work the plantar flexors affectively in the early phases of the rehabilitation may adversely affect strength gains. Details of strength-based exercises following an Achilles tendon rupture in the research are lacking (Christensen et al., 2020) and of those that are described, the resistance used are often body weight or Thera band (Christensen et al., 2020). Given that the plantar flexor muscles exert loads of up to 10 times our body weight while running (Baxter et al., 2021), using body weight or Thera band as the external load may not be sufficient to generate the needed strength gains. Of note, only 50 percent of participants in our study had performed resisted exercises during rehabilitation. This further highlights the need for clear rehabilitation guidelines for physiotherapists. Such deficits in plantar flexor strength can persist, with Brorsson et al. (2018) showing deficits of 20 percent at 7 years post injury.

5.3.3 Hop performance

Concerning the hop for distance test, overall deficit across legs was 12 percent (VACOped group 10 percent and standard care group 15 percent). No previous study has assessed hop for distance measures at 12 months post immediate weight bearing following an Achilles tendon rupture. In a surgically managed group, Kiedrowski et al. (2022) reported on a 21 percent deficit in hop for distance at 12 months post injury. From a biomechanical perspective, Kotsifaki et al. (2021) have shown that during a hop for distance, 43 percent of the work occurs at the ankle joint during the propulsion phase. In the landing phase, this work was reduced to 11 percent. Work at the ankle is calculated in part from torque generated by the plantar flexors. The MVC deficits mentioned above are likely to contribute to the reduced hop for distance seen in the affected limb. In the long term, Brorsson et al. (2018) assessed hop for distance in a non-surgically managed population at seven years post rupture and showed a mean difference of four percent. This finding suggests that given time this measurement may continue to improve.

Concerning the single leg hop for height test, the overall deficit across legs was 19 percent (VACOped group 17 percent and standard care group 20 percent). The hop for height test has not been used previously in an immediate weight bearing cohort following an Achilles tendon rupture. Nilsson-Helander et al. (2010) assessed power using a single leg drop counter movement jump when comparing surgical versus non-surgical management. The non-surgical group were non-weight bearing for six weeks. These authors reported a 17 percent deficit between limbs on jump height at 12 months. It is interesting to note that long-term biomechanical changes occur during landing from a vertical height following an Achilles tendon rupture. Powell et al. (2018) reported a 40 percent increased loading rate through the knee joint and 20 percent lower eccentric power at the ankle joint during the landing of a single leg drop hop six years following an Achilles tendon rupture. They also showed a 12 percent deficit in height jumped at this time point. In an uninjured group, Kotsifaki et al. (2021) compared work contributions across ankle, knee, and hip joints during a hop for height test. These researchers highlighted that, during the propulsive phase and landing phase of a hop for height, 35 percent of the work occurred across the ankle joint. At a muscle and tendon level, researchers (Lidstone et al., 2018; Fukashiro et al., 2005) have reported that during landing from a jump, muscle fascicles remain in a near isometric length resulting in lengthening of the tendon. Given the elastic properties of the tendon, this lengthening and subsequent recoil allows for increased energy storage and leads to increase kinetic energy in the concentric stage and increased hopping height. Given the deficits in MVC as well as increase in tendon length seen in the current study, this may well have contributed to the deficits seen in hop height.

In respect to the lateral hop test overall deficit across legs was eight percent (VACOped group four percent and standard care group 13 percent). The lateral continuous hop test has not been used previously in an Achilles tendon rupture cohort. The lack of significant difference between limbs may be due to the sub-maximal nature of the test. Nilsson-Helander et al. (2010) assessed a continuous on-the-spot hopping test in a non-surgical Achilles rupture group and showed no between limb difference at 12 months. In uninjured individuals, Figures from Ono et al. (2023) show that ankle plantar flexion power was approximately twice that of the power observed at the knee and hip joints. Ono et al. (2023) suggested that in the lateral phase of the side hopping test, subjects with chronic ankle instability have notable potential for compensation using hip extensors resulting in similar performance score to an uninjured population. This compensatory movement pattern could also be occurring following Achilles tendon rupture and may explain the lack of asymmetry seen in the lateral hop test in the current study.

In summary, concerning the three hop tests the observed deficits demonstrate significant impairment in functional performance at a mean of 15 months post Achilles tendon rupture. There are some factors that are likely to be influencing all these tests. Firstly, the deficits seen in MVC are likely to contribute to the reduced ability to generate torque during the hop tests. There are potential for compensatory movement to occur, with increased work being performed at the knee and hip joints. Physiologically, the increased lengthening of the Achilles tendon seen may have affected plantar flexor's ability to perform work. Psychologically, a fear of reinjury may hinder the participants ability to perform at maximal efforts. Finally, less than 50 percent of the participants in our cohort performed plyometric training as part of their rehabilitation and this may also have contributed to the poor performance on these tests.

5.3.4 Limb Symmetry Index

Regarding LSI, except for the lateral continuous hop test, the mean LSI scores for the total heel raise work, vertical hop, and horizontal hop tests were outside the recommendation of 90 percent (Thomeé et al., 2011). Individually, none of the participants would have passed the return to play criteria set out by the EBSR (Thomeé et al., 2011) which states that athletes returning to non-pivoting, non-contact, and recreational sports should have an LSI of >90 percent in muscle strength and hop performance. This is surprising considering that most of participants of this study had returned to some form of recreational sports.

5.4 Analysis of tendon length test

Concerning the second research question, a secondary measure of interest was the Achilles tendon resting angle. This angle was significantly increased in both groups, and this provided indirect evidence that elongation had occurred in the healed Achilles tendon (Carmont et al., 2013). The mean hanging angle measurements were lower than previous studies (Carmont et al., 2013) due to the different measuring position of the digital inclinometer used. The overall increase across limbs, irrespective of groups, was 32 percent. Barfod et al. (2014) measured heel raise height, an alternative measure of tendon length, at 12 months post rupture in an immediate weight bearing group and showed a deficit of 33 percent. Saleh et al. (1992) found no tendon lengthening effect post immediate weight bearing, however, they measured passive ankle dorsiflexion range. This method has not been seen in Achilles tendon rupture research as a measure of Achilles tendon length and may not be accurate. Increases in tendon length are thought to affect heel height when raising from standing into a plantarflexed position (Silbernagel et al., 2012). Such a deficit might lead to a reduced ability to perform work, which involved force and distance primarily. From a biomechanical perspective, this deficit may negatively affect the length-tension relationship in the muscle. The plantar flexor muscle fibres would be unable to create as many cross bridges compared to the unaffected limb and hence generate less force over a similar range. This loss of heel height has been shown to correlate with increased tendon length (Silbernagel et al., 2012). Increased tendon length of 17 percent has been seen up to two years post rupture (Olsson et al., 2011). Interestingly, Brorsson et al. (2018) showed that between the one and seven-year time point post Achilles rupture, a significant reduction in tendon length was apparent, however there was still a deficit of 15 percent between limbs. This would suggest that the tendon may go through gradual stiffening over time. Increased Achilles tendon length is associated with smaller calf muscle volumes and reduced plantar flexor strength after surgical repair of Achilles tendon rupture (Aufwerber et al., 2020). These potential morphological changes together with the increased tendon length seen in this study may explain the deficits seen in the total heel raise work, MVC, and hop tests.

5.5 Analysis of self-perceived outcomes

Regarding research question three, the mean ATRS scores were 80 and 72 in the VACOped group and the standard care group, respectively. These results were in keeping with the range of scores seen in the literature. In a large multicentred study, Costa et al. (2020) reported ATRS scores of 73 at 9 months following an immediate weight bearing protocol, while at 12 months

ATRS scores have ranged from 73-80 (Barfod et al., 2014; Kastoft et al., 2019; Korkmaz et al., 2015). Such scores highlight notable ongoing levels of perceived dysfunction for both activities of daily living and sports/recreational activities months after patients have finished formal rehabilitation. These scores may explain the poor return to sport levels seen following an Achilles tendon rupture. In an earlier study by Costa et al. (2006), these researchers showed that irrespective of immediate and delayed weight bearing post Achilles tendon rupture, only 50 percent of patients in both groups had returned to sport by 12 months. Relatedly, in research concerning Achilles tendon rupture, return to sport rates at 12 months range from 61-79 percent in professional sports like NFL, NBA, and soccer (Grassi et al., 2020; Parekh & Shah, 2017; Trofa et al., 2017). Concerning general health and wellbeing, Lantto et al. (2016) utilised the RAND-36 questionnaire and showed that following immediate weight bearing, both surgical and non-surgical groups scored poorly in the domains of physical functioning and bodily pain, general health, mental health, and vitality. Such findings demonstrate that wider health issues, including psychological well-being, are apparent post Achilles tendon rupture. Psychological status is an important component in the return to sport and several psychological factors have been shown to correlate with a return to sport (D'Astous et al., 2020; Ardern et al., 2014). The current study was the first to assess psychological readiness to return to sport in an Achilles tendon rupture cohort. Mean I-PRRS scores were 48 in the VACOped group and 41 in the standard care group, highlighting the ongoing lack of confidence regarding a return to sport, confidence in performance capability, and confidence in recovery. Personal communication with the Douglas Glazer who developed the I-PRRS indicated that scores under 50 were indicative of not being sufficiently confident to return to competitive sports. Given that at 15 months post injury, most patients will likely be expected to have attempted to return to sport, these scores are surprising. Fear of re-injury may be a factor in the lack of confidence in returning to sport. Olsson et al. (2014) reported that kinesiophobia had a significant negative correlation with patient-reported outcomes and physical activity level in a surgically managed population following Achilles tendon rupture. Kvist and Silbernagel (2022) reported that at the return-to-sport phase following an Achilles tendon rupture, a limiting factor is participants choosing not to return due to the risk of re-injury. Relatedly, high levels of kinesiophobia in patients suffering from Achilles tendinopathy, which is a chronic condition affecting the Achilles tendon, have also been shown to affect their ability to perform physical exercise and rehabilitation and were associated with pain catastrophizing (Chimenti et al., 2021). Speculatively, our participant's I-PRRS scores may also explain the lack of resistance training and plyometric training as part of participants' rehabilitation. It could be that our participants' lack of confidence resulted in a fear of these exercises. This highlights a possible need for more inclusion of psychological intervention within rehabilitation.

5.6 Limitations of the Study

There are several limitations in this study that should be considered. Firstly, the total number of participants per group did not meet the minimum number of 26 participants per group to provide sufficient power to detect the change at the alpha level of 0.05. This target was based on the total heel raise work test, the primary outcome measure and hence power to defect changes was reduced. We were unable to recruit additional participants as this thesis study was part of a larger randomised control trial that had been started prior to the current work. Potential participants were contacted twice to encourage them, yet many were reticent to participate.

The total heel raise work test used a linear transducer, a piece of equipment which is not readily available in a physiotherapy clinic environment, particularly as it needs to be linked to a data collection system and a computerised analysis software. This creates a barrier to establishing this test in clinical practice. However, calculating total work has been shown to be more reliable way of measuring calf endurance compared to counting repetitions alone (Silbernagel et al., 2010). Further research in investigating how the total heel raise work test could be established in clinical practices is warranted. Interestingly, since the start of this thesis research, the development of an app-based measurement system (Calf Raise, Kim Hebert-Losier) has been observed and its clinical utility is apparent. It also has some evidence supporting it being valid and reliable (Fernandez et al., 2022).

The MVC test was conducted at 90 degrees plantar flexion, whereas notable deficits in strength are often seen in the end range of plantar flexion. The MVC test conducted was also unable to measure eccentric torque. Eccentric movements is when the Achilles tendon will experience peak loads.

Given the monetary resources available for the study, it was not possible to have a blinded assessor undertake the assessments. On receiving the participant list, unexpectedly the assessor was made aware of the groups to which the participants had been randomised.

The participants' rehabilitation during the months after rupture varied significantly. The cost of human and financial resources required to run a standardised rehabilitation was beyond the scope of the current work. Additionally, such a program would not be typical of how physiotherapy rehabilitation is undertaken in New Zealand. Private physiotherapy practitioners in local clinics receive referrals usually based upon locality where a patient lives, so recruitment would be difficult due to the standardised program being undertaken at a single location that might require the patient to travel long distances.

5.7 Summary and Conclusions

Firstly, the results showed that there was no notable advantage being able to immediately weight bear compared to delayed weight bearing when measured by physical performance tests. However, ongoing significant differences between affected and unaffected limbs in both groups remained. These deficits were as much as 35 percent at 15 months post injury. These novel findings are likely to contribute to reduced physical performance in many sports, and perhaps even a greater likelihood of further injury.

Secondly, the assessment of tendon lengthening between groups showed that there was no difference, but again a significant difference between affected and unaffected limbs was seen in both groups with the mean resting angle deficit of 32 percent. As such, it was thought likely to contribute to the across limb deficits seen in the above mentioned physical performance tests.

Finally, in line with previous research our findings showed that participants did not have high perceptions concerning their ability to engage in sporting and recreational activities. Furthermore, their self confidence in performance capability and confidence in recovery of their injured tendon was low and highlighted the need for psychological strategies to be considered. Certainly, physiotherapists who see patients regularly should be capable of identifying such issues with a view that those notably affected be referred to a psychologist for specific treatment.

Overall, it seems likely that the lack of self-confidence and hence low perception of function together with physical impairments (plantar flexors strength and Achilles tendon length) contribute to reduced physical performance in physical activities, such as hops, that are often required in many sports. Unfortunately, the limited sample size of the current study prevented the utilisation of a modelling statistical procedure that included a combination of variables associated with the above mentioned factors. Nevertheless, it would likely be beneficial if physiotherapists and other rehabilitation professionals implemented earlier testing of patients and repeated testing as they progressed through their rehabilitation.

5.8 Clinical Implications

Early loading is often thought to have a positive effect on tissue healing. Our results show that immediate weight bearing post Achilles tendon rupture had no detrimental effects on performance tests and self-perceived function at 15 months post rupture. These findings should provide patients and clinicians with confidence around loading the Achilles tendon early post rupture.

This study demonstrated significant deficits in performance testing 15 months post Achilles tendon rupture. This raises questions regarding the magnitude and type of treatment provided for Achilles tendon rupture as well as the expectations regarding recovery.

5.9 Future Research

Several potential research projects were identified:

1. To assess the benefits of early weight bearing within the first three-six months post Achilles tendon rupture using performance tests, patient satisfaction, and self-perceived function questionnaires. This may further encourage the use of immediate weight bearing as a standard treatment approach as the ability to weight bear early in the recovery would be expected to be more satisfactory.

2. The inclusion of early supervised rehabilitation together with early weight bearing as a progression of the current study. This would encourage definite loading and limit any fear avoidance or kinesiophobia which may occur during patient-lead early weight bearing. This would also provide clinicians with some guidance around loading in the early phase of rehabilitation.

3. The development of a return to sport battery of tests to help identify areas of focus for rehabilitation which result in the most successful outcome of return to sport. Currently, no return to sport guidelines exists for Achilles tendon rupture. The development of a test battery would provide clinicians with milestones and benchmarks for rehabilitation.

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Appendices

Appendix A – CCDHB Ethics Approval

Capital & Coast District Health Board
ŪPOKO KI TE URU HAUORA

HUTT VALLEY DHB

Locality sign off for Hospital/Ethical Approval

Full project title:	Effect of weight bearing on functional outcomes post non-surgically managed Achilles tendon rupture
Short project title:	

1. Declaration by principal investigator

The information supplied in this application is, to the best of my knowledge and belief, accurate. I have considered the ethical issues involved in this research and believe that I have adequately addressed them in this application. I understand that if the protocol for this research changes in any way, I must inform the ethics committee. I have read and understood 2DHB research policy

Name of Principal Investigator (please print):	Shane Finn
Signature of Principal Investigator:	Shane Finn
Date:	17-05-22

2. Declaration by Clinical Leader or CNM in which the Principal Investigator is located

I have read the application, and it is appropriate for this research to be conducted in this department. I give my consent for the application to be forwarded to the ethics committee.

Name (please print):	Gareth Coulter		
Signature:	[signature]	Institution:	Wellington Tegional Hospital
Date:	9/8/2022	Designation:	Clinical HOD Orthopaedics

- Where the Clinical Leader is also one of the investigators, the Clinical Leader declaration must be signed by the Clinical Executive Director.

Page **1** of **2**

Version 3.0 dated 22Feb2022

Capital & Coast
District Health Board
ŌPOKO KI TE URU HAUORA

HUTT VALLEY DHB

3. If the application is for a student project, the supervisor should sign the declaration.

If study conducted across several clinical areas, please have CL/CNM of appropriate clinical area to sign in this space.

I have read the application, and it is appropriate for this research to be conducted under my supervision. I give my consent for the application to be forwarded to the ethics committee.

Name (please print):	Peter McNair		
Signature:	PJMcNair	Institution:	Auckland University of Technology
Date:	18/05/22	Designation:	Professor

4. Declaration by Executive Director or Professional Lead in which the Principal Investigator is located

I have read the application, and it is appropriate for this research to be conducted in this department. I give my consent for the application to be forwarded to the ethics committee.

Name (please print):	Dr Graham Sharpe Executive Clinical Director Surgery, Women and Children's Directorate Capital & Coast District Health Board		
Signature:	[signature]	Institution:	
Date:	11 August 2022	Designation:	

Please include the flowing items with your application to the 2DHB Research Office:

1. Study Protocol with the outline of what will be required from the 2DHB (with specific details such as Medical records will be requested, access to eMR system [Concerto] will be required and so on)
2. Participant Information Sheet and Informed Consent Form [All HDEC PIS/IC for the study]
3. Evidence of local iwi consultation [e.g. RAG-M]
4. Health & Disability Ethics Committee [HDEC] approval letter; if approved by the HDEC- Lead site to request authorisation from 2DHB by using the following email address-

Hutt Valley District Health Board: Research@huttvalleydhb.org.nz
Capital & Coast District Health Board: Res-Research@ccdhb.org.nz

5. Any other relevant paperwork;

- Insurance certificate,
- Medsafe Approval,
- Financial arrangements,
- Study contract,
- Indemnity Agreement and other relevant document etc.

Appendix B – Local Māori Research Group ethics Approval

Māori Partnership Board, Capital & Coast DHB

RESEARCH ADVISORY GROUP – MĀORI (RAG-M)

20-06-22

Shane Finn and Peter McNair

Faculty of Health and Environmental Sciences
AG 129, North Campus
90 Akoranga Drive
Northcote, Auckland

RE: RAG-M #954 – Effect of weight bearing on functional outcomes post non-surgically managed Achilles tendon rupture

Tēnā kōrua Shane and Peter,

Thank you for your consideration of ethical issues for whānau Māori.

☑ Your application has been endorsed.

All the best for this research.

Ngā mihi nui,

Raulle Sol Cruz

2DHB Research Office Manager

Appendix C – AUT Ethics Approval

Auckland University of Technology Ethics Committee (AUTEC)

TE WĀNANGA ARONUI O TĀMAKI MAKAU RAU

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

13 May 2022

Peter McNair
Faculty of Health and Environmental Sciences

Dear Peter

Re Ethics Application: **22/71 Effect of weight bearing on functional outcomes post non-surgical managed Achilles tendon rupture**

Thank you for providing evidence as requested, which satisfies the points raised by the Auckland University of Technology Ethics Committee (AUTEC).

Your ethics application has been approved for three years until 13 May 2025.

Non-Standard Conditions of Approval

1. Please send through the updated public documents for file.

Non-standard conditions must be completed before commencing your study. Non-standard conditions do not need to be reviewed by AUTEC before commencing your study.

Standard Conditions of Approval

1. The research is to be undertaken in accordance with the Auckland University of Technology Code of Conduct for Research and as approved by AUTEC in this application.
2. A progress report is due annually on the anniversary of the approval date, using the EA2 form.
3. A final report is due at the expiration of the approval period, or, upon completion of project, using the EA3 form.
4. Any amendments to the project must be approved by AUTEC prior to being implemented. Amendments can be requested using the EA2 form.
5. Any serious or unexpected adverse events must be reported to AUTEC Secretariat as a matter of priority.
6. Any unforeseen events that might affect continued ethical acceptability of the project should also be reported to the AUTEC Secretariat as a matter of priority.
7. It is your responsibility to ensure that the spelling and grammar of documents being provided to participants or external organisations is of a high standard and that all the dates on the documents are updated.
8. AUTEC grants ethical approval only. You are responsible for obtaining management approval for access for your research from any institution or organisation at which your research is being conducted and you need to meet all ethical, legal, public health, and locality obligations or requirements for the jurisdictions in which the research is being undertaken.

Please quote the application number and title on all future correspondence related to this project.

For any enquiries please contact ethics@aut.ac.nz. The forms mentioned above are available online through http://www.aut.ac.nz/research/researchethics

(This is a computer-generated letter for which no signature is required)

The AUTEC Secretariat
Auckland University of Technology Ethics Committee

Cc: shane@willisstreetphysiotherapy.co.nz

Appendix D – Information Sheet

Participant Information Sheet

Date Information Sheet Produced:

05/02/2022

Project Title

Effect of weight bearing on functional outcomes post conservatively managed Achilles tendon rupture

An Invitation

Many thanks for taking this time to consider participating in this research project. My name is Shane Finn and I am a physiotherapist undertaking my Masters in Musculoskeletal Physiotherapy at Auckland University of Technology. I am working alongside the orthopaedic team at Wellington Hospital who have been running a study investigating the effects of immediate weight bearing following an Achilles tendon rupture. I hope to investigate the functional effects of immediate weight bearing at 12-18 months post Achilles tendon rupture. I am looking for 60 participants to take part in this study. I invite you to come to Willis Street Physiotherapy to participate in a number of physical performance tests. The results of these tests will be collated and used to obtain a Masters of Physiotherapy qualification. They will also be used within journal articles to be published in the physiotherapy literature. Should you choose to participate, you will not be identifiable in any research outcomes.

What is the purpose of this research?

The aim of this study is to assess calf muscle length, strength, endurance, and power at 12 - 18 months following an Achilles tendon rupture that has been managed conservatively. You will have taken part in phase one of this research and will have been managed either in an immediate weight bearing moon boot or standard practice of a hard cast followed by a moon boot and partial weight bearing over 8 weeks. These different treatments are being compared. The findings of this research may improve rehabilitation from an Achilles tendon rupture.

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

As a participant of the initial phase of this research trial currently being run by the Wellington Orthopaedic team at Wellington Hospital, you have matched the inclusion criteria and been identified as a possible participant for phase 2 of the study. You have verbally consented to receiving this information sheet as well as having your details passed onto the lead investigator.

You will be excluded from participation in this study if you have 1) re-ruptured your Achilles tendon 2) have sustained other injuries since the initial tendon rupture or 3) are a patient of the main researcher (myself).

How do I agree to participate in this research?

If you decide you would like to participate in the study, your details will be passed onto the lead investigator. They will then contact you to discuss your participation further, and to arrange a suitable time for you to carry out the testing. You will be asked to complete a consent form on the day of testing. Your participation in this research is voluntary (it is your choice) and whether you choose to participate will neither advantage nor disadvantage you. You can withdraw from the study at any time. If you choose to withdraw from the study, then you will be offered the choice between having any data that is identifiable as belonging to you removed or allowing it to continue to be used. However, once the findings have been produced, removal of your data may not be possible.

What will happen in this research?

You will attend a session at Willis St Physiotherapy where you will undergo the physical testing. You are more than welcome to bring a support person with you. You will be asked to complete a written consent prior to testing. The testing will last approximately 45-60 minutes. All participants will complete a 5-minute warm up on a stationary bike. This will be followed by 3 sets of 10 repetitions of double legged heel raises. They will then complete the Achilles tendon length test. This is a simple measurement of the length of the Achilles tendon at rest while lying on a plinth. Followed by this you will complete the maximum effort strength test of the calf muscles (MVC). This requires the participant to perform a maximum contraction of the calf muscle at a fixed ankle joint position. You will then perform a single leg calf raise endurance test. This requires the participants to do a single leg calf raise for as many repetitions as possible. Following this the participants will perform a single hop for height and for distance.

Finally you will perform a sideways repetitive hopping test over a 30 second period. Between all the tests you will have a 5-minute rest. All testing will be carried out on the unaffected side as well as the affected side.

What are the discomforts and risks?

There are no significant risks associated with the tests. You may experience some discomfort with some of the tests if you do not participate in physical activities or play sports on a regular basis. Sufficient time will be provided for a warm-up and familiarization of the test. The tests are designed to replicate movements during sporting activities, and you should not experience anything greater than what you would experience when you play sports.

How will these discomforts and risks be alleviated?

You will be adequately warmed up prior to testing, appropriate rest times will be given between testing and testing will cease if you wish to stop or feel you are at risk of injury. You will be made aware of your right to stop the testing at any time and your right to not continue in the study if you wish.

What are the benefits?

Participating in this study will provide you with information regarding your calf performance. Any deficits in performance, calf strength or ankle range of movement will be identified, and you could use this information to improve your lower limb function further. This information may also help to guide management and rehabilitation protocols in future. This study is a part of Master's thesis and your participation will help me to achieve a qualification of a Masters in Health Science.

What compensation is available for injury or negligence?

In the unlikely event of a physical injury as a result of your participation in this study, rehabilitation and compensation for injury by accident may be available from the Accident Compensation Corporation, providing the incident details satisfy the requirements of the law and the Corporation's regulations. Provision of Māori Health services will also be provided.

How will my privacy be protected?

When you enter the study, you will be given an identification code and your name will not be used on data/records collected. The consent form will contain both your name and identification code, and this will be stored securely on AUT premises. Only the primary researcher and his supervisor will have access to this form. Your identification will be concealed in any research outputs. If you consent, your data (non identified) will be added to a database allowing comparisons of data from this project with other projects that might be undertaken in the future and will be stored indefinitely.

What are the costs of participating in this research?

There is no financial cost to participating in this study. The only cost associated with participation is that of 60 minutes of your time. You will receive a small token of appreciation for your time and participation.

What opportunity do I have to consider this invitation?

You will be given 4 weeks to consider this invitation to participate. We will contact you 7 days after you receive this information sheet. If you require more time, please let us know.

Will I receive feedback on the results of this research?

Yes. You will be provided with a short detailed summary of the results of this study. You will also be provided with a copy of the full research article once published. You will also be offered a copy of your own results.

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

Any concerns regarding the nature of this project should be notified in the first instance to the Project Supervisor, ***Peter McNair, peter.mcnair@aut.ac.nz, +64 9 9219999 Ext.7143.***

Concerns regarding the conduct of the research should be notified to the Executive Secretary of AUTEC, *ethics@aut.ac.nz* , (+649) 921 9999 ext 6038.

Whom do I contact for further information about this research?

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

Researcher Contact Details:

Shane Finn - Lead investigator

shane@willisstreetphysiotherapy.co.nz

Willis Street Physiotherapy, Floor 9, 57 Willis Street, Wellington, NZ.

Project Supervisor Contact Details:

Peter McNair - Project supervisor

peter.mcnair@aut.ac.nz

Approved by the Auckland University of Technology Ethics Committee on *type the date final ethics approval was granted*, AUTEC Reference number *type the reference number*.

Appendix E – Consent Form

Consent Form

Project title: ***Effect of weight bearing on functional outcomes post non-surgically managed Achilles tendon rupture***

Project Supervisor: ***Peter McNair***

Researcher: ***Shane Finn***

- I have read and understood the information provided about this research project in the Information Sheet dated 05/02/2022.
- I have had an opportunity to ask questions and to have them answered.
- I understand that taking part in this study is voluntary (my choice) and that I may withdraw from the study at any time without being disadvantaged in any way.
- I understand that if I withdraw from the study then I will be offered the choice between having any data that is identifiable as belonging to me removed or allowing it to continue to be used. However, once the findings have been produced, removal of my data may not be possible.
- I do not suffer from previous notable lower limb injuries other than an Achilles tendon rupture, nor have neurological or cardiovascular conditions, or other injuries/conditions which may impair my physical performance in the activities indicated in the information sheet.
- I agree to take part in this research.
  - I wish to receive a copy of my own results Yes ○ No ○
- I wish to receive a summary of the research findings (please tick one): Yes ○ No ○
- I wish to allow my data to be stored indefinitely in a database in which I am not able to be identified and be utilised in other studies (please tick one): Yes ○ No ○
- I wish to be contacted concerning later studies that are investigating Achilles tendon rupture. (please tick one): Yes ○ No ○

Participant's signature: ....

Participant's name: ....

Participant's Contact Details (if appropriate):

....

....

....

....

Date:

Approved by the Auckland University of Technology Ethics Committee on type the date on which the final approval was granted AUTEC Reference number type the AUTEC reference number

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

Appendix F – Achilles Tendon Rupture Score

ATRS

(Achilles Tendon Total Rupture Score)

Today's Date: ____/____/_______ Date of Birth____/____/_______

Name:____

All questions refer to your limitations/difficulties related to your injured Achilles tendon.
Answer every question by grading your limitations/symptoms from 0-10.
Remember (0= Major limitations and 10= No limitations).

Please circle the number that matches your level of limitation

1. Are you limited due to decreased strength in the calf/Achilles tendon/foot?

0 1 2 3 4 5 6 7 8 9 10 (No limitations)

2. Are you limited due to fatigue in the calf/Achilles tendon/foot?

0 1 2 3 4 5 6 7 8 9 10 (No limitations)

3. Are you limited due to stiffness in the calf/Achilles tendon/foot?

0 1 2 3 4 5 6 7 8 9 10 (No limitations)

4. Are you limited due to pain in the calf/Achilles tendon/foot?

0 1 2 3 4 5 6 7 8 9 10 (No limitations)

5. Are you limited during activities of daily living?

0 1 2 3 4 5 6 7 8 9 10 (No limitations)

6. Are you limited when walking on uneven surfaces?

0 1 2 3 4 5 6 7 8 9 10 (No limitations)

7. Are you limited when walking quickly up the stairs or up a hill?

0 1 2 3 4 5 6 7 8 9 10 (No limitations)

8. Are you limited during activities that include running?

0 1 2 3 4 5 6 7 8 9 10 (No limitations)

9. Are you limited during activities that include jumping?

0 1 2 3 4 5 6 7 8 9 10 (No limitations)

10. Are you limited in performing hard physical labour?

0 1 2 3 4 5 6 7 8 9 10 (No limitations

Thank you very much for completing all the questions in this questionnaire.

Appendix G – Injury Psychological Readiness to Return to Sport Scale

INJURY-PSYCHOLOGICAL READINESS TO RETURN TO SPORT SCALE

Please rate your confidence to return to your sport on a scale from 0 – 100.
0 = no confidence at all
50 = moderate confidence
100 = complete confidence

1. My overall confidence to play is _____________

2. My confidence to play without pain is ____________

3. My confidence to give 100% effort is ____________

4. My confidence to not concentrate on the injury is ______

5. My confidence in the injured body part to handle the demands of the situation is _________

6. My confidence in my skill level/ability is __________

Add total and divide by 10 = _____